Climate risk report for the Central & South Asia region

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Met Office Hadley Centre ODI UKaid from the British people

Image location: Kabul, Afghanistan

Foreign, Commonwealth & Development Office

FOREWORD

Central Asia

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International climate finance is integral to the UK's global climate and development objectives. We are committed to supporting the most vulnerable who are experiencing the worst impacts of the climate crisis and working together with partners to meet the objectives of the Paris Agreement.

Central Asia: climate change in context

There is an urgent need to address climate impacts in Central Asia and deliver climate resilient and inclusive growth. Central Asia is already experiencing the impacts of climate change, which is leading to higher temperatures, increased rainfall volatility, and increased natural disasters including floods, landslides and dust storms. Climate change will have particularly severe implications for water availability in Central Asia, which is already a contested and critical resource.

These impacts will threaten economic growth, livelihoods, and development goals in Central Asia, with impacts falling hardest on those already facing inequalities and higher levels of poverty, including women and girls, indigenous and local communities, people with disabilities and other marginalised groups. Increasing temperatures and water stress will have particularly severe impacts for the region's agriculture sector, which is a major employer in rural areas that are dependent on small scale farming. This could threaten food insecurity, leading to migration and instability. Engagement on climate in Central Asia will be important for regional prosperity and resilience, as well as supporting UK national security interests.

Delivering low carbon growth and decarbonisation in Central Asia also supports climate action globally. The Central Asia region has globally significant greenhouse gas emissions and includes some of the most energy intensive economies globally. The region could play a key role in the global low carbon transition through its abundant and diverse renewable energy potential and critical minerals deposits.

Regional development and programming priorities

Central Asia matters to the UK in our efforts to foster an open and stable international order, and to support UK security, trade, climate, development, and prosperity interests. UK engagement aims to promote the regions' sovereignty, integration, prosperity and resilience. UK interventions align with existing host country strategies. In Central Asia, the UK aims to support a more resilient, independent, stable, prosperous and connected region, a more open, inclusive society and a greener economy. The UK works through a regional lens recognising the interconnectivity of issues like infrastructure, water, energy, and trade.

Our priority areas of focus on development include: working with partner governments to enable evidence-based reforms to support inclusive and sustainable economic development; championing Small Medium Enterprise (SME) development across the region as part of diversifying and strengthening the private sector; working with multi-lateral partners to enable integrated responses to regional drivers of instability and increase resilience.

Recognising climate change as a driver of instability, we will work to promote regional cooperation across Central Asia in relation to energy security, connectivity and water security, including with the Multilateral Development Banks (MDBs) and International Finance Institutions (IFIs). This will include strengthening the enabling environment and greening infrastructure investments.

The UK works to support alignment with the Paris Agreement and COP26 outcomes and implementation of regional and national climate and nature plans towards a credible pathway to net zero. We work with the private sector, civil society and communities to advocate on climate issues and support climate vulnerable communities to become more resilient. This risk report was commissioned to better understand the climate risks to development in Central Asia across these themes.

Image location: Kabul, Afghanistan

Foreign, Commonwealth & Development Office

FOREWORD

South Asia

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Tackling climate change is at the core of UK's international development strategy – now reaffirmed by the Foreign Secretary's priority around 'restoring UK global leadership on climate and nature'. The impacts of climate change are faced disproportionately by the most vulnerable groups, and it is therefore important to direct effort towards those who face the highest climate risks.

The South Asia context

South Asia has experienced an intensification of extreme weather and climate events in the last two decades, including flooding, cyclones, heat waves and droughts, affecting over half of the region's population. With over 600 million people in absolute poverty and dependent on natural resources for their livelihoods, the region is among the most vulnerable to climate change. This makes action against climate change all the more critical in this region. For example, flooding and cyclones pose severe risks to low-lying and densely populated Bangladesh, whereas heavy rainfall-driven landslides and glacial outbursts threaten mountainous Nepal. Pakistan has experienced severe water scarcity due to variable rainfall and more frequent droughts and suffered massive floods in recent years. The intensity and frequency of heat waves are increasing in the region – with parts of India and Pakistan witnessing alarmingly high temperatures.

It may be noted that climate change leads to a range of multiplier impacts; for example, climate-induced water scarcity results in adverse impacts on agriculture and food security which then increases the risk of nutrition-related diseases and undernourishment. Similarly, climate events lead to loss in productivity which then affect economic growth. Several countries in the region (notably Pakistan and Sri Lanka) have experienced major economic crises in the recent past – with moderately weak regional growth forecasts reflecting the aftermath of economic and social shocks; this has limited the availability of resources for climate action. Climate change compounds existing issues around lack of mobility and access to resources faced by women, elderly and disabled people which in turn erodes their capacity to anticipate, adapt, and recover from climate change events.

Regional development and programming priorities

South Asian countries have reinforced their national climate commitments to varying degrees. India, for example, has committed to achieving net zero emissions by 2070. To support these commitments and to reduce the region's vulnerability to climate change, UK's development programming in this region seeks to enhance adaptation action through building of climate resilience at multiple levels, for example, through the building of sustainable assets and promoting sustainable livelihoods, often with capacity building support at the community level - to promote more effective responses to both fast and slow onset climate events. Working closely with governments, regional institutions, cities, communities, and the private sector, the UK also helps South Asian countries access climate finance, improve weather information and forecasting, and develop urban infrastructure that is resilient to future climate shocks. Our programmes align strongly with the Paris Agreement, and support delivery of the goals of the Kunming-Montreal Global Biodiversity Framework and International Climate Finance (ICF) commitments. Examples include the regional programmes like Climate Action for a Resilient Asia and several bilateral programmes like Infrastructure for Climate resilient Growth (India), Climate smart Development for Nepal, Water Resources Accounting in Pakistan, and Building Resilience and Addressing Vulnerability in Emergencies (Pakistan). UK has also provided significant support around research and evidence on climate impacts in the region, for example through studies on the implications of climate-induced migration and the effectiveness of Nature-based Solutions.

This risk report was commissioned to better understand the climate risks to development in the South Asia region across these themes. Within this context, a deep and nuanced assessment of climate risks is of critical importance at this time. Not only does this report provide a rigorous synthesis of current scientific knowledge in this area but also presents an analysis of the full range of impacts – in a manner accessible to the policymaking community. We strongly hope and believe that climate action in the region will be informed by the findings of the report – which, in turn, will result in stronger and more sustainable outcomes

Image location: Dhaka, Bangladesh

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Central Asia Executive Summary

Central Asia is already exposed to a changing climate and its impacts, and these must be considered to ensure climate-resilient development planning. This report analyses key risks across the Central Asia region, alongside South Asia, under a changing climate up to the 2050s. The risks are analysed under seven themes that have been identified as priorities within a development context for FCDO: (1) **agriculture and food security**; (2) **water resources and water-dependent services**; (3) **health**; (4) **infrastructure and settlements**; (5) **energy**; (6) **environment**; and (7) **the blue economy and the marine environment**. These themes cover many of the key risks facing Central and South Asian countries but cannot analyse all possible climate risks. Themes and risks intersect; therefore, links are signposted in the thematic sections that follow.

In this report, the Central Asia region includes northern **Afghanistan**, **Kazakhstan**, **Kyrgyzstan**, **Tajikistan**, **Turkmenistan**, and **Uzbekistan**. For the purposes of this report, southern **Afghanistan** has been classified under the South Asia region (based on its climate classification). Climate change is one of several risks to resources, livelihoods, economies, and ecosystems. Central Asia is a large and economically dynamic region, working to improve living standards, develop infrastructure, and transition towards renewable energy, therefore an assessment of climate risk provides only a partial picture of the many drivers of change shaping development outcomes.

Key climate-related risks for Central Asia have been identified by considering how the current climate interacts with underlying socio-economic conditions, and then assessing how risks may develop to the 2050s as both climate and socio-economic conditions change. Seeing the 'bigger picture' where multiple risks compound, interact with one another and drive change, will remain important for those charged with designing, monitoring, and evaluating development programmes. Section 2.1 and the context parts of Section 3 provide background information on socio-economic conditions and vulnerability context in which climate risks will compound. Importantly, most risks identified in this report are not new for the Central Asia region. However, the frequency, severity, and distribution of those risks are evolving as climate conditions change and economies develop.

The region experiences very diverse climates: northern / western Central Asia is arid, whereas southern / eastern Central Asia experiences cold, temperate, or tundra climates. Most of Central Asia experienced around 0.3 to 0.4°C of warming per decade between 1980 and 2015 with the number of heatwaves having increased by 30% since the 1960s.

Central Asia experiences very diverse climates: northern / western Central Asia is arid, whereas southern / eastern Central Asia experience cold, temperate or tundra climates. Most of Central Asia experienced around 0.3 to 0.4°C of warming per decade between 1980 and 2015 with the number of heatwaves having increased by 30% since the 1960s.

By the 2050s, annual average temperatures in Central Asia will be between 2°C- 6°C warmer relative to a 1981-2010 baseline under the highest emission scenario. By the 2050s, the intensity, number and duration of heat extremes, heatwaves and droughts will increase across Central Asia, particularly in northern and southwestern areas.

No significant changes in precipitation have been seen across much of Central Asia, except for western Central Asia and mountainous regions in SE Central Asia which has seen a wetting trend in recent decades. Future changes in precipitation (rainfall and/or snowfall) are uncertain. Northern Central Asia is unlikely to become significantly wetter on average, but there may be wetter winter-spring months in the mountainous regions, but drier conditions in western Central Asia. In the high mountain regions of Asia, rainfall will continue to replace snowfall causing earlier snowmelt and thus a shift in seasonality of downstream river flow. Extreme rainfall will become more intense and frequent in Central Asia, particularly in the SE mountainous region of Central Asia (Kazakhstan, Kyrgyzstan, Uzbekistan).

The Caspian and Aral Seas will continue to shrink with water levels falling significantly, exacerbating drought conditions in Central Asia. By the 2050s, the Caspian Sea could warm by 1.7-1.9°C under a high emission scenario.

Climate change will likely have mixed impacts on Agriculture and Food Security (Section 3.1) in Central Asia, with production outcomes to the 2050s dependent on local agroecological conditions and crop choices. However, more frequent, and intense climate extremes could make production and prices more variable, affecting food affordability and potentially undermining progress on SDG2: *Ending hunger and achieving food security and improved nutrition.*

Ongoing land degradation in hot spot areas of Central Asia is already costing the region around 3% of GDP and could be exacerbated by rising temperatures and greater aridity (see Sections 3.1.2, 3.6.2). Symptoms include the salinisation of irrigated lowlands, soil erosion, fertility depletion in rainfed and mountainous areas, deforestation, and the loss of rangeland vegetation. Salinisation affects roughly 50% of irrigated lands. It is acute in almost all lowland irrigated areas in Turkmenistan, and the provinces of Uzbekistan and Kazakhstan bordering the Aralkum desert, reducing crop yields or leading to the abandonment of land altogether. The underlying causes are varied, and the contribution of climate change is unclear. For lowland irrigation, however, the combination of declining meltwater flows after a 2050 peak, plus higher rates of evapotranspiration, will likely increase crop water demands and the risk of further soil-water salinisation.

Climate change could also have positive impacts on crop yields and pasture/rangeland productivity in some rainfed and irrigated areas less affected by soil-water degradation, at least until the 2050s (3.1.2). Specifically, areas that either have moderate summers or grow several crops in a relatively cold winter could benefit from climate change, whereas those that grow many of the same crops in summer will more likely experience losses as heat and water stress increase. In Kyrgyzstan, potentially positive impacts are projected to 2050, as warming trends could increase the area and yield of important crops such as wheat, maize, vegetables and potatoes, and reduce import needs for maize and wheat. In Kazakhstan, the region's biggest wheat producer and exporter, range expansions and yield increases could be expected for winter wheat. In contrast, hotter lowland areas of Tajikistan and Uzbekistan are expected to see yield declines for most key crops.

Livestock production is an important source of food, income, and employment across the region, and warming trends will likely have mixed impacts on livestock and pasture productivity (3.1.4). Livestock numbers, mainly cattle, are growing in all Central Asian countries, and livestock contributes between 26% (Tajikistan) and 54% (Turkmenistan) of total agricultural production value. However, cattle are vulnerable to heat stress, and greater aridity could reduce the productivity of cropped pasture or rangelands in those areas already experiencing hot summer temperatures and land degradation in the southwest (e.g. lowland parts of Tajikistan and Uzbekistan).

Agricultural production is likely to become less stable as the frequency and intensity of climate extremes increase, leading to food price spikes that could increase food insecurity (3.1.6). Food security outcomes to the 2050s will depend on the interplay between production, prices, and affordability for different groups of people. Production stability will be undermined by more frequent and intense climate extremes, leading to more volatile food prices and price spikes. Some rural households could benefit as net sellers of food, but net consumers – subsistence-orientated farmers and urban consumers – could face greater food insecurity, at least periodically. Levels of food insecurity and undernutrition in the region are much lower than in South Asia but remain high in rural Tajikistan, especially. Over the longer term (2050s onwards) the viability of intensive irrigation, at least in its current form/scale, will likely be threatened by declining meltwater flows and water scarcity. This will raise difficult questions about how to support food production, rural livelihoods, and export earnings, and how to resolve the claims of competing water uses, increasingly urban.

A growing challenge for Central Asia is sustainable land management, including the **development of agroecosystems that can deliver a range of ecosystem services including food production, water and soil conservation, soil protection, carbon storage, and nutrient recycling in a changing climate**. The redesign of agricultural systems (away from narrow production goals) to maintain or increase production and enhance environmental outcomes will be a long-term process requiring research and capacity-building support.

Central Asia's Water Resources and Water-dependent Services (Section 3.2) are threatened by climate-driven changes in the mountain ranges where the region's major rivers originate. Rising temperatures are melting glaciers, snowpack, and permafrost, accelerating the transformation of ice and snow into liquid water. As a result, the modulating effect provided by slow-release meltwater will diminish, the seasonality of flows will change, and overall volumes will likely reduce from the 2050s onwards. These trends, and their ripple effects on downstream users and uses, could hinder progress on SDG6: *Availability and sustainable management of water and sanitation for all.*

Risks to irrigation, power generation, and urban water supply will increase as river flows become more variable and ultimately decline from the 2050s (3.1.2; 3.2.2; 3.5.2). The region's two largest river basins, the Amu Darya (Uzbekistan, Turkmenistan, Afghanistan, Tajikistan) and the Syr Darya (Kyrgyzstan), account for roughly 90% of the region's water needs. Both rivers support hydropower generation in upstream countries (Tajikistan, Kyrgyzstan), provide water to major downstream irrigation economies (Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan, Tajikistan), and provide most of the region's drinking water. However, meltwater flows in both river basins will decrease after their 2050s peak, and rainfall is unlikely to make up for the meltwater deficit from mid-century onwards. Higher rates of warming-induced evapotranspiration are also likely to reduce runoff to rivers after the 2030s. Water insecurity for different sectors could therefore increase, with reduced river flows to the Aral Sea from the 2050s (3.7.1, 3.7.3).

Water contamination is likely to increase, posing risks to drinking water quality and irrigation-dependent cropping in lowland areas (3.2.2; 3.3.4). Deteriorating water quality is a problem across the region because of agricultural and industrial pollution, widespread salinisation in irrigated areas, and poor human waste management along the sanitation chain. Although access to safe water and sanitation is high overall, urban water and sewerage systems are generally old (Soviet era) and poorly maintained, and access to safe services in rural areas is more limited. In Tajikistan, almost 50% of the population (mainly rural) lack access to safely managed drinking water, contributing to high rates of water-borne disease and childhood undernutrition. More intense rainfall events and floods could spread contaminants and overwhelm treatment plants (where present), polluting drinking water. More intense droughts will also reduce the capacity of rivers to dilute, attenuate, and remove pollution. Higher temperatures will also increase evapotranspiration, exacerbating problems of water and soil salinsation.

Transboundary risk management will grow in importance as countries have to share more variable and increasingly limited water supplies across boundaries. Central Asian rivers cross numerous international and internal borders, and greater cooperation between upstream and downstream countries will be needed to address conflicts over allocation priorities, volumes, and the timing of dam releases, particularly for energy generation and irrigation. Diversions to Afghanistan from the Amu Darya river via the Qosh Tepa canal could complicate the allocation picture further. Tensions could potentially increase as meltwater flows decline, though dialogue and data sharing around the impacts of climate change could provide an entry point for more difficult discussions around water allocations.

A key source of future water resource uncertainty is the lack of **observational data at high altitudes** on hazards linked to **landscape instability** and **changing cycles of melting and thawing in the mountain ranges where the region's major rivers originate (Tien Shan, Hindu Kush, Karakoram) and their impact on downstream river flows and water users**. More robust projections of future river flow depend on comprehensive monitoring in high-altitude areas, linked to more advanced atmosphere-cryosphere-hydrology models.

The Health (Section 3.3) outcomes sensitive to climate change in Central Asia include heat stress and heat-related mortality, diarrhoeal and water-borne diseases, undernutrition, and health conditions linked to air pollution. Many of the pathways linking climate variables with human health are indirect and hard to quantify, but the most significant for the region are likely to be heat stress/heat-related mortality and undernutrition, with the latter linked closely to diarrhoeal and water-borne diseases. Combined, these risks could hamper progress on SDG3: *Ensuring healthy lives and promoting well-being for all at all ages,* although health outcomes for the region have improved markedly over the last two decades.

Heat-related morbidity and mortality are projected to increase as heatwaves become more frequent and intense (3.3.6). Available data are limited but indicate over 1000 additional heat-related deaths by 2050 across the region, with hotter southern-central areas (Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan) most affected. The most vulnerable to heat-related mortality are the elderly, infants, pregnant women, people living in informal settlements, and those engaged in outdoor manual labour, both rural and urban. Rural populations in all four south-central countries, working mainly in exposed agricultural occupations, exceed 40% (over 70% in Tajikistan).

Air pollution linked to rising temperatures and heatwaves is also likely to increase (3.3.7). Air pollution is now one of the leading causes of death and illness in Central Asia. Drylands cover roughly two-thirds of Central Asia's land area (mainly Kazakhstan, Turkmenistan, and Uzbekistan), and duststorms exacerbated by heat waves, higher aridity, and land degradation are linked with a range of respiratory and cardiovascular problems. In 2021, a summer heatwave in Kazakhstan (>45ºC) dried up vegetation and soils to a depth of 50cm leading to a winter duststom extending into Uzbekistan and the Fergana Valley, with particulate levels far exceeding safe standards. Longer-term analysis confirms a link between summer heatwaves and duststorm intensity. Sand and dust from the former Aral seabed in Uzbekistan – the 60,000km^2 Aralkum Desert – have also affected the health of surrounding populations, and contain salt and toxic chemicals accumulated over many years from upstream irrigation returns.

The prevalence of water-borne diseases and undernutrition could also increase because higher temperatures, more intense rainfall events, and floods, can accelerate the growth and spread of dangerous pathogens (3.3.4, 3.3.5). Although the regional evidence base linking climate change with disease and undernutrition is limited, evidence from other regions highlights the impacts of floods, droughts, and warmer air (and water) temperatures on water-borne diseases and nutritional outcomes. Risks increase for those populations with limited access to safe water and sanitation, for example in Kyrgyzstan and Tajikistan where childhood stunting levels reach 10% and 13%, respectively (see also 3.2.3).

Risks to Infrastructure and Settlements (Section 3.4) in Central Asia arise mainly from heavy rainfall and flood events and in mountain areas landscape instability linked to rising temperatures and thawing. Impacts can cascade across economic sectors, areas, and population groups because of the increasingly interconnected nature of power, transport, and communications systems, highlighting the need to *Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation* (SDG9) while also *Making cities and human settlements inclusive, safe, resilient and sustainable* (SDG11). Risks to energy infrastructure are discussed in Section 3.5.

Climate risk and poverty will increasingly coincide in the region's fast-growing towns and cities, especially informal settlements exposed to flooding and land-mud slides in Afghanistan and Tajikistan (3.4.1, 3.4.2). Roughly 41% of the region's 120 million population (78 million excluding Afghanistan) live in urban areas, but the urban share will likely increase to over 50% by 2050. Kazakhstan and Turkmenistan are already largely urban. Roughly 73% of the urban population in Afghanistan and 17% in Tajikistan (around nine million people combined) live in informal settlements lacking one or more basic services, including adequate housing, drainage, flood protection, and sanitation. More intense rainfall events will increase the risks of flash flooding, property damage, environmental contamination, and disease spread in low-lying areas, and also increase the risks of land and mud slides – hazards that have persistently affected hills and valleys across the region and are reckoned to cost Central Asian countries 1-2% of GDP annually.

Population mobility is influenced by many different factors, but there is no clear evidence that it is *driven* by climate change (3.4.2). The wider Asian and global evidence base indicates that climate-related shocks and slower changes in climate-related environmental conditions can contribute to both increases and decreases in migration, but there is no clear evidence that population mobility is *driven* by climate change. Nonetheless, recent modelling suggests that Central Asia could *potentially* see between 1.7 million and 2.4 million additional 'climate migrants' by 2050, with out-migration hotspots along the southern border of Kazakhstan, pockets surrounding the Ferghana Valley in Uzbekistan and Tajikistan, and the area around Bishkek (Kyrgyzstan), due to projected decreases in water availability and crop productivity.

The region's transport and communication networks are also vulnerable to intense rainfall events, floods, and mud and landslides (3.4.3, 3.4.4). Current weather-related damages to road and rail are highest in Uzbekistan and Kazakhstan at around USD45 million annually. Roughly 10% of Kazakhstan's transport infrastructure is exposed to natural hazards, particularly from flooding. In 2019, the additional cost to firms in Kazakhstan from lower utilisation of transport infrastructure due to natural hazards was USD1.1 billion, or 0.5% of GDP. Costs can be expected to increase as floods and land/mud slide risks increase, especially in areas of existing land degradation concentrated in the region's border areas (3.1.2; 3.6.2). Although evidence for Central Asia is limited, floods and landscape instability could also impact exposed communications infrastructure (cables, pylons, mobile towers) with cascading impacts across sectors and services – from financial transactions to transport, education, and health.

Central Asian countries have achieved near universal access to access to Energy (Section 3.5), but climate change is likely to make power generation and transmission less reliable and increase average and peak energy demand. Increasing the share of renewables in electricity generation, and mitigating risks to both power generation and distribution posed by climate change, will be needed to achieve SDG7: *Ensure access to affordable, reliable, sustainable and modern energy for all*.

Central Asia's energy supply is dominated by thermoelectric generation, mainly from fossil fuels, and by hydropower, with both involving major, long-lived investments in fixed infrastructure that are sensitive to changes in water availability and temperature (3.5.2). Electricity production from thermal power plants (coal, gas) dominates the electricity supply in Turkmenistan (100%), Uzbekistan (93%), and Kazakhstan (87%), and will remain important to the 2050s. Country-level data are scarce, but reductions in the usable capacity of thermoelectric plants are likely because of water constraints and higher temperatures. Hydropower dominates electricity generation in Tajikistan (89%) and Kyrgyzstan (86%), with further dams planned or underway in the Pamir and Tian Shan mountains. Risks to hydropower arise from greater river flow variability to the 2050s (and reductions thereafter), warming-induced landscape-infrastructure instability, and the need to balance upstream power generation with downstream (transboundary) priorities, including irrigation and the maintenance of flows to the Aral Sea (see also 3.1, 3.2, 3.7).

Solar and wind projects can be developed incrementally and at different scales to meet demand, so the risks of locking-in climate vulnerabilities are potentially less significant, though still evident (3.5.2). Solar and wind resources remain under-developed, but Uzbekistan is investing heavily in wind and solar as a potential power hub for renewables and power trading in Central Asia. Power outputs from solar projects are sensitive to changes in the frequency of very warm, cloudy and/or hazy conditions, and modest reductions in PV outputs for more northern parts of the region are possible. More intense dust storms linked to rising aridity and soil loss from Central Asia's drylands (see also 3.1, 3.6) could also lower solar outputs and damage panels. Power generation from wind farms can be disrupted by temperature extremes, with standard operating limits of -30ºC to 50ºC for turbines. Rising winter temperatures could reduce the risks of turbine blade icing (northern areas) but increase longer-term risks from overheating in summer (southwest). Case study evidence, albeit limited, suggests that major new investments in both solar and wind do not adequately address climate risks.

Electricity transmission and distribution will be negatively affected by rising temperatures and heat extremes, adding to pressure on fragile systems (3.5.3). Transmission and delivery losses are already high in Central Asia (~20% in Uzbekistan) because of ageing infrastructure and poor maintenance, and power outages incur costs on businesses and households. The contribution of climate hazards to network disruption is unclear, but projections for 2050 for the US and Europe suggest that rising temperatures and heat extremes could lower the capacity of generators, substations, and transmission lines by 2-27%, depending on the component. While energy companies in Central Asia factor in winter extremes into network design, they may have less experience in dealing with extreme heat. A general conclusion is that more resilient electricity systems will increasingly need to combine multiple energy sources spread across multiple grids - smart, mini, and hybrid – with fewer 'network critical' points of failure.

Higher cooling needs linked to rising temperatures and heatwaves will increase overall and peak energy demands, requiring grid flexibility, higher storage capacity, and more peak generation capacity (3.5.4). Higher electricity demand for cooling due to hotter summer temperatures is likely to outweigh any energy savings from warmer winters. Regional data are scarce, but increased electricity demand for current cooling during heatwaves has been estimated at 25% for Uzbekistan and Tajikistan. Higher electricity demand to power irrigation and drainage pumps could also be expected in hotter conditions as crop water requirements increase (see also 3.1). In Uzbekistan, irrigation and drainage pumping already accounts for 16% of national electricity generation, costing close to USD$350 million annually, and future costs could expected to increase further with rising temperatures.

Investments in large-scale, land-based solar projects are accelerating in Central Asia, in part because solar PV in this region does not face the same land availability constraints as South Asia. However, **solar power outputs are sensitive to changes in climate, and solar projects make demands on local, high-quality water resources. These issues have been highlighted by IPCC, but regional impacts remain uncertain – an evidence gap**.

Central Asia's Environment (Section 3.6) is characterised by sensitive ecosystems under pressure from agricultural expansion, deforestation, pollution, wildlife trade, and over-grazing. Climate change is now acting as an additional stressor on more pristine mountain habitats in the Tian Shan and Pamir mountains (a global biodiversity hotspot), and on more degraded, arid lowlands. Combined, these pressures will hinder progress towards SDG15: *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably* *manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss*.

The boundaries of major biomes are projected to shift northward in response to rising temperatures, contributing to an upward shift in mountain treelines and a squeeze on alpine zones and species (3.6.2, 3.6.3). Upward shifts in key treeline species could increase human-wildlife conflict as shrinking alpine grasslands support both livestock grazing and endangered species. Tajikistan, Kyrgyzstan, and Kazakhstan are home to different pastoralist groups making a living by raising livestock in alpine zones, but endangered species such as the snow leopard require large, protected areas within and above the treeline. Alpine zones support many endemic plant species that could also be threatened by higher grazing pressures in more confined areas.

Permafrost thawing in the high mountains could also release large quantities of greenhouse gasses and impact vegetation growth and composition (3.6.4) However, relationships between rising temperatures, thawing, vegetation change, and the timing/ magnitude of gas release are poorly understood, and regional data are limited. Global evidence suggests that increased ecosystem carbon losses could potentially cause large temperature increases in the future.

Drier hills and remaining lowland trees are at risk from drought-related dieback as temperatures rise and aridity increases (3.6.2). Drought-induced tree mortality is well documented in other regions and could be expected to increase in Central Asia's increasingly arid lowlands and on drier hill slopes, although data are limited. Forest/tree dieback could be exacerbated by the increasing risk of fires. Risks of species loss are highest in fragmented ecosystems, including more fragmented lowland woods where species are unable to disperse or migrate along elevational (temperature) gradients in response to rising temperatures.

Ongoing problems of land degradation and desertification in Central Asia may be exacerbated by more intense droughts and higher levels of warming-induced evapotranspiration (3.6.2; 3.1.2) Roughly two-thirds of Central Asia's land area consists of drylands (mainly Kazakhstan, Turkmenistan, and Uzbekistan) with extreme biophysical constraints associated with dry climates, making them vulnerable to both rising temperatures and direct anthropogenic pressures from land conversion, logging, and overgrazing. The annual cost of land degradation, concentrated in lowland irrigated areas and along more densely populated borders, is estimated at 3% of regional GDP. Dust storms could also become more frequent and intense, including those from the former Aral Sea bed – the Aralkum Desert (see also Sections 3.2, 3.3 and 3.7).

Central Asia will likely achieve protected area conservation targets by 2030, but areas may need to shift to accommodate changes in climate-driven biome boundaries and allow species migration/dispersal along elevational gradients (3.6.3). This, in turn, may require greater transboundary cooperation in the biodiversity hotspots of the Tian Shan and Pamir mountains. Weak monitoring and enforcement of existing control measures in protected areas will also need to be addressed to ensure habitat protection.

Landscape restoration projects are underway in a number of Central Asian countries focussing on joint forest management, afforestation/reafforestation, and rangeland rehabilitation and management. **Long-term monitoring of impacts on ecosystem health and rural livelihoods will be needed to assess performance, as programmes focussing on nature-based interventions typically assume rather than assess impacts beyond programme end dates.**

Central Asia's Blue Economy and Marine Environment (Section 3.7) is linked to the health of the Aral and Caspian inland seas where warmer air and water temperatures will amplify pressures from pollution and over-exploitation. Combined, these risks will undermine progress on SDG14: C*onserve and sustainably use the seas and marine resources for sustainable development.*

Water levels in the Caspian Sea have been falling over the last 20 years because of reduced inflows (upstream river diversions), direct water withdrawals, and higher rates of sea and catchment evaporation (3.7.1; 3.7.3). Sea levels are projected to fall 8-14m by the end of the century, driven largely by higher rates of warming-induced evaporation from the sea surface and wider catchment.

Falling water levels in the Caspian Sea will expose many shallower areas that currently provide important aquatic habitats for fish, migrating birds, and endemic seal, and potentially disrupt local economies (3.7.1, 3.7.3). The loss of shallow shelf habitats and coastal wetlands will also mean that river pollutants and nutrients will directly impact the central basin with no prior filtration. These impacts, together with rising sea temperatures, will likely cause major ecosystem disruption, threatening the unique Caspian biota that has evolved over millions of years. Economic and geopolitical ramifications could also be significant, with shipping potentially disrupted, ports made obsolete, and fisheries (for Kazakhstan) reduced. The five littoral states, including Turkmenistan and Kazakhstan relevant to this report, could also be faced with the challenge of having to re-negotiate maritime zones of jurisdiction linked to water withdrawals, planned desalination, fishing zones, and oil and gas claims.

Continued shrinkage of the Aral Sea caused by upstream river diversions and reduced inflows to catchment rivers is likely, especially after the 2050s when meltwater contributions decline (3.1.7; 3.7.3). The Aral Sea was once the fourth largest inland lake in the world, but upstream irrigation diversions on the Amu Darya and Syr Darya rivers since the early 1960s have led to shrinkage and salinisation. The exposed seabed has created the 60,000km^2 Aralkum Desert, contributing to damaging dust storms exacerbated by rising temperatures (see also 3.3; 3.6). Since 2005, increased meltwater inflows due to higher mountain temperatures and glacier-snowpack melt have slowed the sea's decline, but its partial recovery may only be temporary: meltwater contributions to catchment rivers will likely decline from the 2050s, and rainfall is unlikely to make up the difference. Aquaculture production from reservoirs within the Aral Sea basin has some potential for growth, and aquaculture already provides the main source of fish in Uzbekistan, but rising temperatures and growing water scarcity within the Aral Sea basin may limit potential over the longer term.

While the long-term shrinkage of the Aral Sea has captured most academic and media attention, **falling water levels and warming waters in the Caspian Sea** are a more pressing concern. Given the ***potential*** **economic, environmental, and geo-political implications, further action-oriented research is needed on potential impacts for the five littoral states and opportunities for addressing them.**

South Asia Executive Summary

South Asia is already exposed to a changing climate and its impacts, and these must be considered to ensure climate-resilient development planning. This report analyses key risks across the South Asia region, alongside Central Asia, under seven themes: (1) **agriculture and food security**; (2) **water resources and water-dependent services**; (3) **health**; (4) **infrastructure and settlements**; (5) **energy**; (6) **environment**; and (7) **the blue economy and the marine environment**. Themes and risks intersect; therefore, links are signposted in the thematic summaries below.

In this report the South Asia region includes southern **Afghanistan**, **Bangladesh**, **Bhutan**, **India**, **Maldives**, **Nepal**, **Pakistan**, **Sri Lanka**. Climate change is one of several risks to resources, livelihoods, economies, and ecosystems. South Asia is a dynamic region, experiencing rapid population growth, urbanisation, and economic transformation, and assessments of climate risks can only ever provide a partial picture of the role climate change plays in shaping development outcomes. Further research, evidence gaps and recommendations on how to better expand the risk landscape are also highlighted in the green boxes at the beginning of each section, alongside key messages.

Key climate-related risks for South Asia have been identified by considering how the current climate interacts with underlying socio-economic conditions, and then assessing how risks may develop to the 2050s as both climate and socio-economic conditions change. Seeing the ‘bigger picture’ where multiple risks compound, interact with one another, and drive change, will remain important for those charged with designing, monitoring, and evaluating development programmes. Section 2.1 and the contextual parts of Section 3 provide background information on socio-economic conditions and key vulnerabilities in context as climate risks compound. Importantly, most risks identified in this report are not new for the South Asia region. However, the frequency, severity and distribution of those risks are evolving as climate conditions change and economies develop.

South Asia experiences very diverse climates: northern South Asia is temperate and tundra, western South Asia is arid, and central and southern South Asia are tropical. Most of South Asia has warmed by 0.1 to 0.2°C per decade between 1980 and 2015, with Pakistan and Afghanistan warming by 0.4°C–0.5°C per decade.

By the 2050s, northern regions of South Asia will warm more (2-6°C) than southern regions (1.5-3.5°C) under a high emission scenario, relative to a 1981-2010 baseline. The intensity, number, and duration of heat extremes, heatwaves and droughts will increase across South Asia, particularly in NW India, NE Pakistan, southern India, and Sri Lanka.

Changes in the South Asian monsoon have caused contrasting precipitation trends across the South Asia region with some areas experiencing a wetting trend and others a drying trend. **By the 2050s, all of South Asia will become significantly wetter in the monsoon season (June-September), particularly in southern Pakistan and western India. Eastern Himalayas, northern India, southern Nepal and Bhutan will become drier (rainfall and/or snowfall) in winter**. In the high mountain areas of South Asia, rainfall will continue to replace snowfall causing earlier snowmelt and a shift in seasonality of downstream river flow. Extreme rainfall will become more intense and frequent, especially in the eastern Himalayas of South Asia during the monsoon period.

Coastal regions are already exposed to rising sea levels, increasing sea surface temperatures, acidification, and marine heatwaves, trends that will continue. South Asia is also exposed to tropical cyclones with the intensity of the most intense tropical cyclones expected to increase.

Climate change will have broadly negative impacts on Agriculture and Food Security (Section 3.1) in South Asia, with yields for key food staples and other crops projected to fall in most areas by the 2050s. More frequent and intense climate extremes will also make agricultural production and prices more variable, affecting food affordability and potentially undermining progress on SDG2: *Ending hunger achieving food security and improved nutrition.*

South Asia is an important global production centre for wheat and rice serving both domestic and international markets, but combinations of heat and water stress are projected to reduce crop yields by 5-15% by the 2050s with no adaptation (3.1.2). Heat stress is a particular risk, with temperatures across the Indo-Gangetic Plain (northern and eastern India, most of eastern Pakistan, most of Bangladesh, and the southern plains of Nepal), responsible for much of the region's rice and wheat, approaching critical levels for wheat and maize grown over the winter season (October to May) and rice crops grown during the summer monsoon (June to September). South Asia's deltas, including the Ganges-Brahmaputra-Meghna (Bangladesh, Bhutan, China, India, Nepal) are additionally exposed to rising sea levels, storm surges, and soil-water salinisation, reducing rice (and potentially aquaculture) productivity.

The importance of irrigation in sustaining crop production will grow, but the availability of water for irrigation will be affected by climate-driven changes in river flows and groundwater recharge, and increasing competition for water from urban and industrial users(3.1.2; 3.2.4). Over 125 million farmers in the Indus and Ganges lowlands, and 48 million farmers in the mountains, substantially depend on snow and glacier melt for irrigation, either directly from canal networks or indirectly from groundwater resources replenished by canal leakage. As meltwater contributions decrease and river flows become more rainfall-dependent (and less predictable), sustaining crop production will depend increasingly on groundwater resources replenished by monsoon rains – a poorly understood dynamic (3.2.3). Water demands are also increasing: across the Indo-Gangetic Plain, populations could potentially double (Ganges, Brahmaputra) or triple (Indus) during the twenty-first century, and urban and industrial demands are increasing (3.2.4). Irrigation extension into rainfed areas, and the adoption of climate-smart agricultural practices, could help stabilise or boost production, for example in rainfed (and drought-vulnerable) eastern India and eastern Bangladesh, where droughts cause regular crop failures and food insecurity.

Inland aquaculture and livestock play an increasingly important role in meeting food and income needs but are threatened by rising temperatures and climate extremes (3.1.3). Aquaculture development has played a key role in supporting rural livelihoods, particularly for women, and in improving diets. In Bangladesh, fish provides roughly 60% of animal protein consumption, mostly from aquaculture. India and Bangladesh are by far the biggest aquaculture producers in the region and stand to lose the most in terms of production and income as rising water temperatures affect fish productivity, and climate extremes disrupt production. Impacts on livestock and pasture could also be significant because animals provide draft power, manure, and food, and an additional source of income, with the livestock sector contributing over 50% of agricultural GDP in Pakistan, around 26% in India, and significant shares in other countries. Larger animals are vulnerable to heat stress, and rising temperatures and more intense droughts could amplify existing pressures from over-stocking and the fragmentation of rangelands.

Agricultural productivity will be negatively affected by heat stress in the labour force, with impacts falling increasingly on women and the elderly (3.1.5; 3.3.6). Working hours lost to heat will likely be highest in Bangladesh, India, and Pakistan - areas of high heat and humidity with large shares of agricultural labour. In India, working hours lost to heat stress are projected to rise 15% by 2030 (compared with a 1998-2017 average baseline), with economic costs estimated at USD150-250 billion (2.5-4.5% of GDP).

Agricultural production is likely to become less stable as the frequency and intensity of climate extremes increases, leading to food price spikes and potentially longer-term price rises that could increase food insecurity (3.1.6). Food security outcomes to 2050 will depend on the interplay between production, prices, and affordability for different groups of people. Production stability will be undermined by more frequent and intense climate extremes, leading to more volatile food prices and potentially longer-term price increases. Some rural households could benefit as net sellers of food. However, net consumers including subsistence-orientated farmers and growing numbers of urban poor could face greater food insecurity.

Many of the impacts of climate change will be felt through the region's Water Resources and Water-dependent Services (Section 3.2). The region's three major river basins, the Indus, Ganges, and Brahmaputra, originate in the mountains of the Hindu Kush-Karakorum Himalayas and provide water to over 1.5 billion people. Water, food, and broader livelihood security in all three basins will be strongly influenced by climate-driven changes in meltwater and rainfall-runoff, and the ability of groundwater resources to buffer low flow and drought-related deficits, particularly after the 2050s meltwater peak. These dynamics will have a major bearing on the ability to achieve SDG6: *Availability and sustainable management of water and sanitation for all.*

The most vulnerable basin to declining meltwater flows *after* their 2050s peak is the Indus basin, crossing Pakistan and India (3.2.2). The Indus basin receives significant amounts of meltwater from its high mountain catchment, and meltwater also makes a major contribution to downstream flows in Pakistan. Declines in predictable meltwater flows from the 2050s will leave the basin increasingly dependent on more episodic and intense monsoon rains and groundwater storage. With roughly 60% of pre-monsoon river-canal irrigation originating from snow and glacier melt, longer-term impacts on meltwater-dependent rice, wheat, cotton, and sugarcane cropping could be significant, with changes in cropping decisions and/or increasing groundwater use required to sustain production. River flows in the wetter Ganges and Brahmaputra basins are less meltwater-dependent, and the eventual loss of the meltwater buffer may have less of an impact on agricultural, urban, and industrial users as monsoon rainfall increases. However, dry season (pre-monsoon) cotton and sugarcane cropping on the Ganges floodplain, currently dependent on meltwater, is threatened.

The role of groundwater storage in buffering more variable rainfall and river flow will grow in importance, especially on South Asia's Indo-Gangetic Plain, spanning large parts of Pakistan, India, Nepal and Bangladesh (3.2.3). The groundwater resources beneath the Indo-Gangetic Plain extend over a vast area and to great depth, with volumes held in storage equivalent to three times the combined annual flows of the Indus, Ganges, and Brahmaputra. As hydrological variability increases, particularly once meltwater flows recede, the buffering role of groundwater will grow in importance - to bolster or potentially replace more erratic, monsoon-dominated river flows – especially in the Indus basin. However, groundwater is intensively used already, and existing problems of over-exploitation and water quality deterioration could potentially worsen in heavily exploited areas. Declining water quality is a wider concern: roughly 60% of the shallow aquifer fails to meet drinking water standards because of salinisation, arsenic contamination, and pollution. Climate impacts on groundwater storage and supply are complex, though more intense monsoons could potentially increase groundwater recharge and replenish storage, both beneath the Indo-Gangetic Plain and in other areas of high groundwater stress, such as arid and semi-arid areas of western and peninsular India. A tentative conclusion is that changes in groundwater levels and water quality will continue to be driven more by abstraction and contamination than climate change.

Risks to drinking water, hygiene, and sanitation will be amplified by more intense rainfall events and flash floods, more frequent and intense droughts, and higher water temperatures, particularly in areas where access to safely managed services is low (3.2.2; 3.3.4). Declining water quality is a problem across much of South Asia because of agricultural and industrial pollution, widespread salinisation in coastal deltas and intensively irrigated areas, and unsafe management of human waste along the sanitation chain. Contamination of drinking water is a key risk given the limited progress made in meeting 'safely managed' targets for water, sanitation, and hygiene (WASH) in most countries. Risks arise because more intense rainfall events and floods can damage or destroy basic latrines and spread faecal matter and other pollutants into poorly protected water sources. Higher water temperatures and more intense droughts also present risks, stimulating the growth of toxic algae, or reducing the capacity of water sources to dilute, attenuate, and remove pollution. Preventable deaths (mainly children) attributable to inadequate WASH exceeded one million in India, Pakistan, and Bangladesh alone in 2019 because unsafe services leave people exposed to diseases strongly linked to droughts and floods (3.3.4).

Transboundary risk management will grow in importance as countries have to share more variable water supplies or the benefits that flow from them, within and across national boundaries (3.2.4). South Asian rivers cross numerous international borders and many (internal) provincial/state boundaries, and greater cooperation between upstream and downstream jurisdictions will be needed to address conflicts over allocation priorities, volumes, and the timing of dam releases. Dialogue around the impacts of climate change on transboundary flows can potentially serve as an entry point for more contentious discussions around water allocations. The changing seasonality of downstream flow due to earlier snowmelt and sediment flow to the Ganges-Brahmaputra-Meghna delta is one area. However, higher rates of sediment transmission to the delta (and accretion within it) associated with more intense monsoon rainfall in upper river catchments may be sufficient to negate the effects of climate-driven sea level rise this century, provided sediment delivery is not interrupted by further dam building and river diversion upstream.

Health (Section 3.3) outcomes sensitive to climate change in South Asia include heat stress and heat-related mortality, diarrhoeal and water-borne diseases, undernutrition, vector-borne diseases, and health conditions linked to air pollution. Risks will be unevenly spread, exacerbating health inequalities linked to economic status, location, gender, and age. Many of the pathways linking climate variables with human health are indirect and hard to quantify, but the most significant for the region are likely to be heat stress/heat-related mortality and undernutrition, with the latter linked closely to diarrhoeal and water-borne diseases. Combined, these risks could hamper progress on SDG3: *Ensuring healthy lives and promoting well-being for all at all ages,* although health outcomes for the region have improved markedly over the last two decades.

South Asia will experience the largest cumulative exposure to heatwave events (measured in person days) and heat-related mortality of any global region (3.3.6). Combinations of heat and humidity pose the biggest risks to health, with southern Afghanistan, eastern Pakistan, northern, central, and eastern India, Sri Lanka, and Bangladesh likely to be worst affected. In India, 160-200 million people annually could face a 5% chance of being exposed to a lethal heat wave as early as 2030. The most vulnerable to heat-related illness and death are the elderly, infants, pregnant women, people living in informal settlements, and those engaged in outdoor manual labour, both urban and rural. In Afghanistan, Pakistan, and Bangladesh, over 50% of the urban population lives in informal settlements already exposed to elevated heat and other risks, especially flooding (3.4.2, 3.4.5).

Air pollution from fires, dust storms, and surface ozone will be exacerbated by higher temperatures and heatwaves (3.3.7). With the exception of Sri Lanka and Maldives, indoor and outdoor air pollution is now the leading risk factor for all-cause mortality across South Asia, with roughly 60% of the population living in areas where concentrations of fine particulate matter in the air exceed safe limits by a factor of seven or more. South Asia is home to 37 of the world's 40 most polluted cities, but much of the air pollution in cities such as Dhaka (India), Kathmandu (Nepal), and Colombo (Sri Lanka) originates from non-urban sources, including the burning of waste and crop stubble, forest fires, and dust storms. Both fire risks and dust storms could be expected to increase during more intense heatwaves and droughts.

The prevalence of diarrhoeal and water-borne diseases, key contributors to undernutrition, will likely increase to the 2050s (3.3.4, 3.3.5). This is because higher temperatures and floods can accelerate the growth and spread of dangerous pathogens linked to disease and undernutrition and because nutritional outcomes could be additionally impacted by declines in food availability and access (3.1.6). The highest rates of diarrhoeal disease and undernutrition are found in India and Pakistan, where spikes in diseases (and longer-term undernutrition) are strongly linked with droughts and floods, particularly where access to safe water and sanitation is lacking as floods spread faecal matter into water sources and the wider environment. South Asia already has one of the highest undernutrition levels in the world (31%), and combined risks from warming and more frequent/intense floods, will likely undermine progress on SDG2: *Ending hunger and improving nutrition.*

The seasonality and spatial distribution of vector-borne diseases such as malaria and dengue will change, highlighting the need for improved public health surveillance and vector control (3.3.3). Rising temperatures and changing rainfall patterns will create new areas of transmission for vector-borne diseases (e.g. malaria and dengue) and contract others. Whether elevated risks translate into higher morbidity and mortality will depend on efforts to tackle vector breeding and transmission pathways, and many other factors unrelated to climate such as land use change. Interventions in most countries have thus far limited risks despite broadly more favourable climate conditions for disease spread. In the World Health Organisation (WHO) defined South Asia region, including Bangladesh, India, Nepal, and Sri

Lanka, malaria case incidence has declined by 82% over the last two decades. India accounts for around 80% of the remaining cases.

Risks to Infrastructure and Settlements (Section 3.4) in South Asia arise mainly from floods, cyclones, and rising sea levels. Impacts can cascade across economic sectors, areas, and population groups because of the increasingly interconnected nature of power, transport, and communications systems, highlighting the need to *Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation* (SDG9) while also *Making cities and human settlements inclusive, safe, resilient and sustainable* (SDG11). Risks to energy infrastructure are covered in Section 3.5.

Climate risk and poverty will increasingly coincide in the region's fast-growing towns and cities, especially informal settlements exposed to flooding and extreme heat (3.4.1, 3.4.2). Roughly 36% of the region's 1973 million population now live in urban areas, but that share will likely increase to over 50% by 2045. Rapid urbanisation has been associated with the growth of informal settlements. Roughly 56% of the urban population in Pakistan, 52% in Bangladesh, and 49% in India – some 278 million people in total - live in informal settlements lacking one or more basic services, including adequate housing, drainage, and flood protection. More intense rainfall events will increase the risks of flash flooding and environmental contamination in low-lying areas, especially for those lacking adequate drainage and faecal waste management, leading to regular outbreaks of water-related disease (3.3.4). Roughly 110 million urban residents in South Asia – some 15% of the urban population - are already highly exposed to flash floods, mostly in Pakistan (44 million), India (41 million) and Bangladesh (23 million).

Population mobility is influenced by many different factors, with no clear evidence it can be *driven* by climate change (3.4.2). The potential for additional, climate-induced migration from high-risk areas, rural or urban, is unclear. Evidence to date indicates climate-related shocks and slower onset changes in environmental conditions can contribute to both increases and decreases in migration, with no simple causal chain or robust estimates of climate-driven migration or 'climate migrants'. Coastal cities such as Mumbai and Chennai (India) continue to attract large numbers of migrants because of job opportunities, even though the cities may be more exposed to climate hazards than rural areas, and migrants may have no choice but to settle in risky, flood-prone places.

In densely populated coastal areas, risks to infrastructure and settlements are amplified by cyclones, storm surges, and sea level rise (3.4.2, 3.4.5, 3.7.1). Many of South Asia's 110 million urban residents exposed to floods live in low-lying coastal areas where flood risks are exacerbated by cyclones, storm surges, and sea level rise. By the end of the century, and without effective adaptation, coastal flooding will likely affect 5-18 million people in India, depending on the emission scenario. The eastern coast is particularly exposed as major river deltas allow storm surge water to flow further inland. In Bangladesh, around 46% of the population live in areas that are within 10m of current sea levels. Damage to coastal infrastructure in Bangladesh, currently estimated at USD300 million/year, could double by 2050. South Asian cities confronting the fastest changes in sea levels are those where land is rapidly subsiding because of groundwater pumping, heavy buildings, and reduced sediment flows to coastal deltas, including Chittagong (Bangladesh) and Ahmedabad (India). Maintaining sediment flows to deltas could mitigate at least some of the impacts of climate-driven sea level rise.

The region's transport networks, communications systems, and ports are also vulnerable to climate extremes, especially intense rainfall events, floods, and cyclones (3.4.3, 3.4.4). Current annual damages to road and rail systems, caused mainly by floods and cyclones, are highest in India (USD340 million), Pakistan (USD99 million), and Bangladesh (USD90 million). As a share of national GDP, damages are highest in Bhutan and Nepal where landscape instability in mountain areas linked to rising temperatures poses major risks (see also 3.2.2; 3.5.2). Communication infrastructure, including cables, pylons, and mobile towers is also exposed, with the potential for cascading impacts across sectors and services – from financial transactions to transport, education, and health. In India, telecommunication services in the coastal districts of Odisha were severely impacted after the landfall of tropical cyclone Fani in 2019, causing damage to power and telecom infrastructure and disruption to mobile and internet services in 11 of the most affected districts, extending over several months. Port-specific and wider maritime trade risks are highest for the Indian ports of Mumbai and Marmagoa (west coast) and Vishakhapatnam, Paradip and Haldia (east coast), with current annual risks estimated at between USD5 million and USD25 million. Of these, risks were highest for Vishakhapatnam – among the global top 50 'at risk' ports – with cyclones and floods the main hazards.

While the severity of climate-related impacts is often measured in terms of direct, short-term damage to assets, longer-term impacts on the services, businesses, and people they support receive less attention. **Plugging this evidence gap in South Asia would help identify 'network critical' points of failure in the transport and communications sectors, and priority investments for resilience-building.**

Access to Energy (Section 3.5) has improved across South Asia, but climate change is likely to make power generation and transmission less reliable and increase average and peak demand. Closing remaining gaps in clean cooking fuel provision, increasing the share of renewables in electricity generation, and mitigating risks to power generation and distribution posed by climate change, will be needed to achieve SDG7: *Ensure access to affordable, reliable, sustainable and modern energy for all.*

Regional electricity production is dominated by thermoelectric generation from fossil fuels, and by hydropower, with both types of generation based on major, long-lived investments in fixed infrastructure that are sensitive to changes in water supply and temperature (3.5.2). Electricity production from thermal power plants (coal, gas, oil) dominates the energy mix in Pakistan, Bangladesh, India, Sri Lanka and Maldives, and will remain important to the 2050s. Country-level data are scarce, but reductions in the the usable capacity of thermoelectric plants are likely because of water constraints and higher temperatures (see also 3.2.2). In India, shutdowns forced by water shortages between 2013 and 2016 cost Indian power utilities roughly USD1.4 billion in lost revenue, and new power plants are planned for water-scarce areas. Hydropower accounts for almost all electricity production in Bhutan and Nepal, and significant shares in Afghanistan, Sri Lanka, and Pakistan, with further investments underway or planned in high-mountain Asia. Risks to hydropower arise from greater river flow variability to the 2050s, warming-induced landscape-infrastructure instability, and the need to balance power generation with other (transboundary) priorities, including downstream irrigation, sediment flow to the Ganges-Brahmaputra-Meghna delta shared by India and Bangladesh, and drought-flood management (see also 3.1, 3.2).

Solar and wind projects can be developed incrementally and at different scales to meet demand, so the risks of locking-in climate vulnerabilities are potentially less significant, though still evident (3.5.2). Solar and wind resources remain under-developed, but Bangladesh, India, and Pakistan are investing heavily in both mini and utility-scale projects to diversify their energy portfolios and reduce carbon emissions. Power outputs from solar projects are sensitive to changes in the frequency of very warm, cloudy and/or hazy conditions, but regional impacts to the 2050s are likely to be minor, though potentially more negative in very hot and dusty desert locations. Higher wind speeds associated with more intense cyclones and extreme heat can disrupt power generation from wind turbines, although adaptations are available at higher cost. Case study evidence from the China-Pakistan Energy Corridor (CPEC), albeit limited, suggests that major investments in both renewable and thermoelectric power do not adequately address climate risks.

Electricity transmission and distribution will be negatively affected by rising temperatures, heat extremes, floods, and strong winds, adding to pressure on fragile systems (3.5.3). Transmission and delivery losses remain high in many countries, with cascading risks for businesses and households. In 2022, almost 60% of companies of all sizes operating in South Asia experienced power outages, forcing many to invest in back-up generation. In Bangladesh, India, and Pakistan, long power outages are associated with a decrease in both per capita income and women's labour force productivity. The contribution of climate change to network disruption is unclear, but more intense cyclones and higher wind speeds pose widespread risks to exposed networks, and analysis from the US and Europe indicates that rising temperatures and heat extremes could lower the capacity of generators, substations, and transmission lines by 2-27%, depending on the component. More resilient systems will increasingly need to combine multiple energy sources spread across multiple grids - smart, mini and hybrid – with fewer 'network critical' points of failure.

Higher cooling needs linked to rising temperatures and heatwaves will increase overall and peak electricity demands, requiring grid flexibility, higher storage capacity, and more peak generation capacity (3.5.4). By the 2050s, regional demand for cooling will account for growing shares of peak summer electricity loads, driven largely by the uptake of residential air conditioning. In India, overall energy demand is projected to rise by 15% to 2050 because of warming-related air conditioning alone, with daily summer demand peaks increasing by 20-30% as a result. It is unclear whether government energy projections in the region account for the impacts of higher temperatures on overall and peak loads, although India and Bangladesh (along with some major cities) have recently adopted cooling action plans to manage demand and address health impacts associated with extreme heat (see also 3.3.6).

South Asia's <u>Environment (Section 3.6)</u> and biodiversity hotspots are under pressure from agricultural expansion, urban encroachment, pollution, and illegal wildlife trade, with climate change acting as an additional stressor on remaining habitats. South Asia's environment includes three of the world's biodiversity hotspots (the eastern Himalayas, the tropical Indo-Burma area, and the Western Ghats Mountain range in western peninsular India), but habitats are becoming increasingly degraded and/or fragmented, increasing their vulnerability to rising temperatures and changing rainfall patterns. Combined, these pressures will hinder progress towards SDG15: *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*.

The boundaries of major biomes are projected to shift northward in response to rising temperatures, contributing to an upward shift in mountain treelines and a squeeze on alpine zones and species (3.6.2, 3.6.3). Upward shifts in key treeline species could increase human-wildlife conflict as shrinking alpine grasslands support livestock grazing, medicinal plant collection, and endangered species. India, Pakistan, Nepal, and Bhutan are home to different pastoralist groups making a living by raising livestock in alpine zones, but endangered species such as the snow leopard require large, protected areas around and above the treeline. Between 10-30% of snow leopard habitats in the Himalayas could be lost because of shrinking alpine habitats by the 2050s. Alpine zones also support many endemic plant species that could also be threatened by higher grazing pressures in more confined areas, including medicinal and aromatic plants.

Permafrost thawing in the high mountains could also release large quantities of greenhouse gasses and impact vegetation growth and composition (3.6.4) However, relationships between rising temperatures, thawing, vegetation change, and the timing/ magnitude of gas release are poorly understood, and regional data are limited. Global evidence suggests that increased ecosystem carbon losses could potentially cause large temperature increases in the future.

At lower elevations habitats are more fragmented, increasing the risk of species loss as temperatures rise, and the intensity of droughts and heatwaves increases (3.6.2). Across the Asia Pacific region, biodiversity continues to decline with 25% of the region's endemic species under threat. The main drivers of change in more densely populated areas will continue to be agricultural and urban expansion. In India, many of the country's 1394 threatened species, including rhinoceros, tigers, and elephants, are in decline because of habitat loss and poaching. Climate change is likely to cause or exacerbate biodiversity and habitat loss, as remaining forest areas are likely to experience more drought-related forest dieback episodes with longer-term changes in species composition, exacerbated by higher risks of forest fires. Risks of species loss are highest in fragmented ecosystems, where species are unable to disperse or migrate along elevational (temperature) gradients in response to rising temperatures. Climate change is already thought to have caused habitat loss for amphibians and the extinction of some endemic species.

Remaining wetlands are sensitive to changes in rainfall and temperature affecting inflows, direct evaporation, and outflows, with evidence suggesting the wetlands of the Upper Meghna River Basin (Bangladesh and India) could be damaged by more intense monsoon rainfall and floods, and lower dry season inflows (3.6.1, 3.6.2, 3.6.4). Wetlands play a key role in storing carbon and reducing greenhouse gas emissions in addition to flood control, nutrient cycling, biodiversity, and food/fuel provision, but many have been drained or degraded. India alone accounted for 6.5% of global wetland loss in 2020.

South Asian countries will struggle to achieve protected area (Aichi) conservation targets by 2030, and some existing zones may need to shift to accommodate changes in climate-driven biome boundaries and allow species migration/dispersal along elevational corridors (3.6.3). This, in turn, may require greater transboundary cooperation in South Asia's biodiversity hotspots. Weak monitoring and enforcement of existing control measures in protected areas will also need to be addressed to ensure habitat and species protection.

South Asia's Blue Economy and Marine Environment (Section 3.7) is threatened by rising sea levels, warming seas and marine heatwaves, cyclones and storm surges, and ocean acidification. These hazards will amplify existing pressures from dredging, mining, pollution, mangrove deforestation, and inappropriate coastal development, collectively undermining efforts to achieve SDG14: C*onserve and sustainably use the oceans, seas and marine resources for sustainable development.*

Coral reefs provide vital ecosystem services but are threatened by higher sea surface temperatures, marine heatwaves, and ocean acidification (3.7.2). Coral reefs, found mainly in the coastal waters of Pakistan, India, Sri Lanka, Bangladesh, and Maldives, provide fish nurseries, support tourism, and protect coastlines. In Maldives, coral reefs are estimated to prevent around USD3.6 billion of flood-related damage per decade and support tourism industries that contribute over 25% of GDP. Rising sea surface temperatures and marine heatwaves will lead to an increase in coral bleaching events across the region, with waters around southern India, Sri Lanka, and Maldives already approaching the upper tolerance limits for most coral species.

South Asia's mangrove forests and seagrass meadows, some of the most extensive and biodiverse in the world, are vulnerable to rising sea levels, cyclones, and storm surges, although deforestation and pollution remain the major threats (3.7.2). The world's largest mangrove forest (the Sundarbans), located in the Ganges-Brahmaputra delta, benefits around 3.5 million coastal residents. In Bangladesh alone, the forest's value has been estimated at USD10 billion, including providing cyclone shelter, flood protection, and carbon storage. Although mangrove clearance for (mainly) aquaculture remains the biggest regional threat, more intense cyclones and storm surges pose growing risks to forest integrity. Sea grass meadows and salt marshes act in synchrony with mangroves to support resilient coasts but are also threatened by rising sea levels and storm surges, as well as pollution and dredging.

Marine fisheries, including marine aquaculture, provide a key source of employment, income, and food security, but fish catch potential is projected to decline in India and Bangladesh by roughly 20% and 10% by the 2050s, respectively (3.7.3). In Bangladesh, marine and freshwater fisheries account for 7-8% of employment and over 11% of annual export revenue. Fish also contribute 60% of all animal protein consumed in Bangladesh and Maldives, and over 50% in Sri Lanka. However, South Asia's marine and freshwater habitats are projected to warm significantly, resulting in species experiencing average and maximum temperatures above, and pH and oxygen below, the levels to which they are adapted. In eastern Indian and western Pacific oceans, these changes will amplify existing pressures on fish stocks from overfishing and habitat destruction. Poorer artisanal fishers face the biggest risks from these changes, as well as from coastal habitat destruction, the loss of fish nurseries, and the intensifying 'squeeze' on coastal space.

Met Office Hadley Centre | UKaid | ODI | Foreign, Commonwealth & Development Office

Central and South Asia Climate Risk Report – Central Asia

HEADLINE CLIMATE STATEMENTS

Central Asia has warmed by around 0.3 to 0.4°C per decade from 1980 to 2015.

By the 2050s*, annual average temperatures in Central Asia will be between 2 to 6°C warmer, under the highest emission scenario, or 1 to 4°C warmer under a medium emissions scenario, relative to a 1981-2010 baseline. Average summertime temperatures in northern areas of Kazakhstan will experience the highest rates of warming, resulting in a significant increase in wildfire weather.

By the 2050s, the intensity, number, and duration of heat extremes, heatwaves, and droughts will increase across Central Asia, particularly in northern and southwestern areas, irrespective of the warming level.

Future changes in precipitation (rainfall and/or snowfall) over Central Asia are more uncertain than temperature changes, and vary geographically.

Kazakhstan, Turkmenistan, and Uzbekistan are unlikely to become significantly wetter on average, but there is medium confidence for wetter winter and spring months in higher elevation Central Asia (eastern Uzbekistan, Tajikistan, Kyrgyzstan, northern Afghanistan).

In the high mountain regions of Asia, including those in Central Asia, rainfall will continue to replace snowfall causing earlier snowmelt and a shift in seasonality of downstream river flow.

Extreme rainfall will become more intense and frequent in Central Asia, particularly in the mountainous regions of eastern Central Asia.

By the 2050s, the sea surface temperatures for the Caspian Sea could increase by 2 to 3°C under a high emission scenario, relative to a 1980-2010 baseline.

The Caspian and Aral Seas will continue to shrink by several metres, exacerbating drought conditions in Central Asia.

Peak flow of rivers in Central Asia will be reached before or by the 2050s, after which glacial meltwater will decline, exacerbating the shrinkage of the Aral Sea.

*The 2050s refer to the 2041-2060 time period

Central and South Asia Climate Risk Report – South Asia

HEADLINE CLIMATE STATEMENTS

Most of South Asia has warmed by around 0.1 to 0.2°C per decade during 1980 to 2015, with Pakistan and Afghanistan warming 0.4 to 0.5°C per decade.

By the 2050s*, northern regions of South Asia (Pakistan, northern Nepal, northwest India, southern Afghanistan) will warm more (2 to 6°C under high emissions; 1 to 4°C under medium emissions) than southern regions (southern Nepal, Bhutan, southern India, Bangladesh, Sri Lanka, Maldives) (1.5 to 3.5°C under high emissions; 1 to 2.5°C under medium emissions) relative to a 1981-2010 baseline.

By the 2050s, the intensity, number, and duration of heat extremes, heatwaves, and droughts will increase across South Asia, particularly in northwest India, northeast Pakistan, southern India and Sri Lanka.

By the 2050s, all South Asia will become significantly wetter in the monsoon season (June to September), particularly in southern Pakistan and western India.

By the 2050s, the eastern Himalayas, northern India, southern Nepal, and Bhutan will become drier in winter.

In the high mountain areas of South Asia, rainfall will continue to replace snowfall causing earlier snowmelt and a shift in seasonality of downstream river flow.

Extreme rainfall will become more intense and frequent, especially in the eastern Himalayas of South Asia during the monsoon period (June to September).

On average, the number of tropical cyclones per year are not likely to increase, but they will become more intense, particularly in the Bay of Bengal, amplified by higher sea surface temperatures.

South Asian river flow will increase due to greater monsoon rainfall (June to September) after the 2050s.

By the 2050s, average annual sea surface temperatures in the oceans surrounding South Asia will increase by 1.2 to 1.4°C under a high emission scenario, relative to a 1971-2014 baseline.

More frequent and intense marine heatwaves are expected in the oceans surrounding South Asia, especially during the pre-monsoon and monsoon seasons.

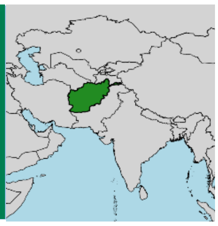
*The 2050s refer to the 2041-2060 time period.
**pH refers to the acidity or alkalinity of a solution with lower values indicating higher acidity.

Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Country Reference Tables

Analysis is conducted at the regional level using five zones. These country summaries are intended to help direct readers towards the relevant sections within the report by country; they are not a complete assessment of the full range of risks at a country level. These summaries do not provide a national level analysis and there will be additional climate risks pertinent at a national scale that should also be considered in a national or subnational development plan. Where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis would be required.

Afghanistan country profile[1]

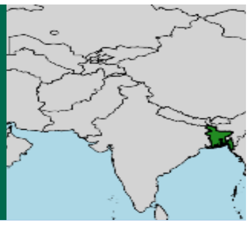


Summary of climate analysis relevant to Afghanistan	Report section
Northern Afghanistan experiences a mix of temperate, cold and tundra climates due to its higher elevation, whilst southern Afghanistan experiences an arid climate. Northern Afghanistan has already experienced warming of around 0.3 to 0.4 °C per decade (along with the rest of Central Asia) from 1980 to 2015 while southern Afghanistan has warmed by at least 0.4 to 0.5 °C per decade during the same time period. Maximum winter temperatures (December to February) have particularly increased in recent decades for northern Afghanistan. Temperatures will continue to rise in the future across all seasons. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Precipitation trends for recent decades show increased precipitation during winter, including both rainfall and snowfall. Extreme precipitation (rainfall and snowfall) has also increased. Southern Afghanistan has already experienced warming in recent decades. Afghanistan is likely to become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) throughout the year in the north and especially during the monsoon season June to September in the south. Northern Afghanistan will receive more rainfall instead of snowfall over mountains. Earlier spring melt is expected leading to increased downstream flow until 2050.	2

Regional risks relevant to Afghanistan	Report section
The Kunduz Province in Afghanistan may see an increase in invasive golden apple snail habitat, negatively impacting rice production, due to increasing minimum winter temperatures.	3.1
Southern Afghanistan is expected to experience more heat-related mortality and less cold-related mortality. In Afghanistan, impacts will be overwhelmingly heat-related due to the large number of people already experiencing high summer temperatures.	3.3
Southern Afghanistan will experience significant risks to human and livestock health, especially for outdoor labourers. This is as a result of projections indicating even hotter summer temperatures of more than 40 °C more regularly in the future.	3.3
Significant risks to health due to projected increases in high overnight minimum temperatures during summer.	3.3
Heatwave events and heat-related mortality is expected to increase in southern parts of Afghanistan.	3.3

[1]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Bangladesh country profile[2]

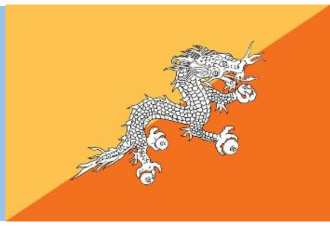


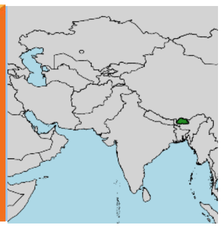
Summary of climate analysis relevant to Bangladesh	Report section
Bangladesh experiences a tropical climate. Bangladesh hosts three large river deltas: Ganges, Brahmaputra, and Meghna. Bangladesh has already experienced warming of around 0.2 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future across all seasons, particularly during the pre-monsoon season March to May. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. There has been a significant increase in average precipitation over recent decades. Bangladesh will become significantly wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in the monsoon season June to September, by the 2050s. Sea surface temperatures have risen more quickly in the Indian and western Pacific oceans than other regions globally. Marine heatwaves have increased in frequency in the Indian Ocean. Sea levels will rise, sea surface temperatures and ocean acidification will increase, and marine heatwaves will become more frequent and intense. The strongest tropical cyclones will become more intense, although overall will decrease in frequency.	2

Regional risks relevant to Bangladesh	Report section
A key risk hotspot is the rice-wheat cropping system of the Indo-Gangetic Plain where production yields are projected to decline by the 2050s due to increasing temperatures and heat stress to crops.	3.1
Increased risk of damage to crops and agriculture in the Ganges-Brahmaputra (one of Asia's mega deltas which accounts for over one third of rice production for Bangladesh). This is due to increased flooding events increasingly damaging crops and agricultural infrastructure.	3.1
Risk of decreasing water availability due to ingress of salty water into coastal aquifers due to sea-level rise which is further exacerbated by groundwater pumping.	3.2
Increased risk of dengue incidence and/or transmission due to increased temperature and rainfall. Outbreaks have been linked to floods, high temperatures and the potential impacts of the El Niño weather creating more favourable conditions.	3.3
There is potential for increased barriers to resilience building and poverty eradication due to the compounded impacts of climate-related natural hazards. This is especially relevant for Bangladesh where over half of the population is considered to be low-income.	3.4
Bangladesh is highly vulnerable to climate-induced internal migration with millions of people likely to be displaced due to climate impacts by the 2050s.	3.4
Increased risk of inundation of almost one fifth of the country's land area by the 2050s due to sea-level rise, putting millions of people at risk. Almost half of Bangladesh's population live in low-lying areas vulnerable to sea-level rise.	3.4
Increased risk to large-scale human and economics in coastal settlements due to their high population concentrations. Economic assets and activities are exposed to increased risks of more intense tropical cyclones, storm surges and increased floodings.	3.4
Marine species will be impacted by rising summer sea surface temperatures which is further exacerbated by the increased frequency and intensity of marine heatwaves.	3.7

[2]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Bhutan country profile[3]



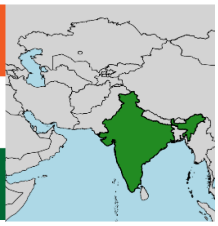


Summary of climate analysis relevant to Bhutan	Report section
Bhutan experiences a temperate climate. Bhutan has already experienced warming of at least 0.4 to 0.5 °C per decade between 1980 and 2015. Temperatures will continue to rise in the future across all seasons. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Bhutan is likely to become significantly wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in the future during the monsoon season June to September and drier in winter December to February. The intensity and frequency of heat extremes will increase in Bhutan. Earlier spring melt is expected leading to increased downstream flow until 2050.	2

Regional risks relevant to Bhutan	Report section
Health will be impacted negatively by increasingly high overnight minimum temperatures during summer which are projected to occur more frequently in Bhutan.	3.3
Bhutan will experience increasing cumulative exposure to heat-wave events and heat-related mortality where summer temperatures will regularly reach over 40°C in the future.	3.3
Run-of-river hydropower generation could be impacted by changes to seasonal rainfall, such as greater rainfall variability and more frequent/prolonged droughts. Hydropower already has limited storage capacity and dominates the electricity mix in Bhutan, enhancing the impacts.	3.5
All modes of transport in Bhutan could be at risk of damage and disruption from extreme weather events, mainly floods and tropical cyclones. This could be expected to increase substantially as hazards intensify.	3.4

[3]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

India country profile[4]



Summary of climate analysis relevant to India	Report section
India experiences a range of climates. The Hindu Kush Himalaya which cover Himalayan areas of NW India experience a tundra climate. Parts of western India experience an arid climate. Northern India experiences a temperate climate. Southern India experiences a predominantly tropical climate. Selected larger rivers include the Brahmaputra and Ganges Rivers which run through eastern and western India's mountainous areas respectively. India has already experience warming in the Hindu Kush Himalaya to the north of 0.1 to 0.2 °C, western India of 0.4 to 0.5 °C, and southern India of around 0.2 °C per decade from 1980 to 2015. Northern India has also experienced warming during the winter and pre-monsoon seasons. Temperatures will continue to increase across all of India in the future across all seasons. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Winter precipitation has increased in the Hindu Kush Himalaya of northwestern India. There has been a drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) over eastern and central north regions of India with lower monsoon rainfall totals in central and north India. Southern India has experienced significant increases in observed precipitation. There have been multiple cases though of extreme heat and humidity recorded in the last few decades throughout India. India is likely to become wetter overall, especially during monsoon season June to September, with significant wetting indicated over northern and southern India. The eastern Himalayas are projected to have more extreme rainfall but drier winters whilst the western Himalayas are projected to become wetter overall. Northern India is projected to see a decrease in winter precipitation (December to February) however. Earlier spring melt is expected leading to increased downstream flow until 2050. Sea surface temperatures have risen more quickly in the Indian and western Pacific oceans than other regions globally. Marine heatwaves have increased in frequency in the Indian Ocean. Sea levels will rise, sea surface temperatures and ocean acidification will increase, and marine heatwaves will become more frequent and intense. The strongest tropical cyclones will become more intense, although overall will decrease in frequency.	2

Regional risks relevant to India	Report section
Production yields for rice-wheat cropping systems of the Indo-Gangetic Plain (extending large areas of India) are projected to decline by the 2050s as a result of increasing temperatures and heat extremes.	3.1
In Himalayan areas of NW India, people living near flood-prone glacial lakes are increasingly at risk from hazards linked to glacier, snowpack, and permafrost thawing as temperatures rise.	3.2
Freshwater supply is at risk in coastal areas of India, where the ingress of salty water into coastal aquifers (saline intrusion) is a growing problem due to rising sea levels, exacerbated by groundwater pumping.	3.2
Increase in heat-related mortality from increasingly high overnight minimum temperatures during summer.	3.3
Housing infrastructure at risk from more intense flooding, heavy rainfall, landslides, and tropical cyclones.	3.4
Wetlands of the Upper Meghna river basin and south, central and eastern India are at risk of increasing evapotranspiration driven by higher temperatures. More intense/frequent droughts will compound impacts.	3.6
Marine species are at risk from more intense/frequent marine heatwaves driven by rising summer sea surface temperatures.	3.7

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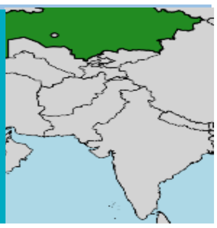
Kazakhstan country profile[5]



Summary of climate analysis relevant to Kazakhstan	Report section
Kazakhstan experiences an arid climate. The Caspian and Aral Seas are situated to the southwest of the country. Kazakhstan has already experienced warming of around 0.3 to 0.4 °C per decade (along with the rest of Central Asia) from 1980 to 2015. Temperatures will continue to rise in the future across all seasons, particularly in winter (December to February). The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Precipitation trends in recent decades show a wetting trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) however future projections indicate that it is unlikely to become significantly wetter. However, droughts are projected to be more frequent and intense during drier periods as temperatures rise. Earlier spring melt is expected leading to increased downstream flow until 2050. The Caspian and Aral Seas have shrunk over recent decades mainly due to irrigation and/or damming. The Aral Sea shrinkage has caused (very high confidence) an increase in surface air temperature in the surrounding region. Increasing temperatures and drought conditions in the future will lead to further shrinkages.	2

Regional risks relevant to Kazakhstan	Report section
In Kazakhstan, Central Asia's largest wheat producer and a major global exporter, areas suitable for currently cultivated cereal crops and livestock are shifting northward as summers grow longer and hotter and winters grow shorter and warmer.	3.1
Negative impacts are expected on irrigation with reduced flows to the Aral Sea. This is due to downstream areas in Kazakhstan not being projected to become wetter. Therefore, evapotranspiration from rising summer temperatures is expected to outweigh rainfall contributions to river flow by the 2030s.	3.2
Road and rail networks are at risk from expected annual damages from increasing heat extremes/droughts and heavy rainfall events/flooding.	3.4
Kazakhstan's drylands are among those globally most climate vulnerable due to desertification, driven by human activities and increased droughts.	3.6
The Caspian Sea is expected to shrink by 9-18m by 2100 with negative implications for Kazakhstan's fishing industry mostly due to warming waters causing evaporation. The Caspian Sea is projected to warm substantially by the 2050s with the Caspian Sea showing greater levels of warming than the Bay of Bengal, Arabian Sea, and Gulf of Persia.	3.7

[5] Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

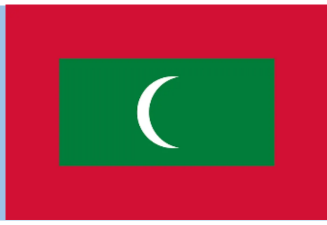
Kyrgyzstan country profile[6]

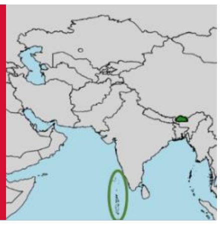
Summary of climate analysis relevant to Kyrgyzstan	Report section
Kyrgyzstan experiences a mix of temperate, cold and tundra climates. Kyrgyzstan has already experienced warming of around 0.3 to 0.4 °C per decade from 1980 to 2015. Warming has especially occurred during winter (December to February). Temperatures will continue to rise in the future across all seasons. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Precipitation trends show an increased precipitation trend during winter, including rainfall and snowfall. Extreme precipitation has increased particularly in Kyrgyzstan. Kyrgyzstan will become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in the future throughout the year, particularly in October to November and March to May. More rainfall is expected instead of snowfall during winter however there is lower confidence over mountains. Earlier spring melt is expected leading to increased downstream flow until 2050 after which, flow rate will decline especially during the summer months.	2

Regional risks relevant to Kyrgyzstan	Report section
There are projected positive impacts, by the 2050s, on important crops in Kyrgyzstan. This is due to warming trends increasing the area and yield of wheat, maize, vegetables, and potatoes and reducing the need for imported maize and wheat.	3.1
Water supply is at risk in upstream countries such as Kyrgyzstan which rely on glacial-snowmelt dominated headwaters which are most vulnerable to reduced and/or variable river flow due to rising temperatures.	3.2
Hydropower insecurity will become a critical risk for Kyrgyzstan and a source of economic and social risk. This is due to reduced and/or variable river flows from glacial snowmelt due to rising temperatures.	3.5
Health is at series risk from combinations of heat and humidity which are projected to increase. This is particularly prevalent for people working outdoors and those living in informal settlements. The intensity and frequency of heat extremes, including heatwaves, will continue to increase across Kyrgyzstan with days over 40°C expected to increase.	3.3

[6]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

The Maldives country profile[7]





Summary of climate analysis relevant to The Maldives	Report section
The Maldives experience a tropical climate. Observed changes in annual average temperature vary across the atolls of the Maldives, but have increased in the central region (IFRC, 2021). Throughout the Maldives archipelago, sea surface temperatures have risen at a rate of 0.11 to 0.15 °C per decade (Ministry of Environment and Energy, 2016; UNDP, 2013). Cool days are getting warmer in both the north and south regions. Overall, there has been a drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) with number of days >1mm rain has declined 1967-2012, particularly in the north (IFRC, 2021). Temperatures will continue to rise but less than the global average. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. The Maldives will experience a general wetting trend. Sea-level rise in the Maldives was 3.6 mm per year between 2006 and 2015, which is greater the global average (3.25 mm per year). Sea surface temperatures have also risen at a rate of 0.11-0.15 °C per decade. Sea levels will rise, sea surface temperatures and ocean acidification will increase, and marine heatwaves will become more frequent and intense. The strongest tropical cyclones will become more intense, although overall will decrease in frequency.	2

Regional risks relevant to The Maldives	Report section
Populations in very low-lying areas of the Maldives are at risk of losing houses and livelihoods from sea-level rise and subsequent flooding. This is particularly alarming because nearly half of the total Maldives population live in very low-lying areas. Climate projections indicate that, at the current rate of warming, most of the Maldives' islands could become inhabitable.	3.4
Marine species and fishing livelihoods will be at risk due to rising summer sea surface temperatures exacerbating the frequency and the intensity of marine heatwaves around the North Indian Ocean Coastline.	3.7
Coral reefs are at risk of mass coral bleaching from the projected increasing frequency and intensity of marine heatwaves. This also impacts potential tourism success.	3.7
Fisheries and aquaculture could see a decline in the amount of fish caught due to rising sea surface temperatures, and the increasing frequency and intensity of marine heatwaves.	3.7
Tourism in the Maldives is at risk of large adaptation costs and significant losses due to sea-level rise and marine heatwaves induced by climate change.	3.7

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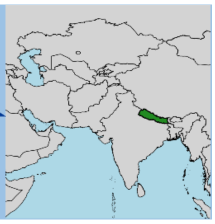
Nepal country profile[8]

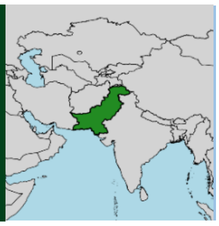


Summary of climate analysis relevant to Nepal	Report section
Nepal experiences a tundra climate in the north and a temperate climate in the south. Nepal has already experienced warming in recent decades over the Hindu Kush Himalaya of northern Nepal of 0.1 to 0.2 °C per decade from 1980 to 2015. Warming has especially occurred during winter (December to February) and pre-monsoon seasons over southern Nepal. Temperatures will continue to rise in the future over northern and southern Nepal across all seasons. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Winter temperatures will increase more in northern Nepal. Winter precipitation has increased over northern Nepal. Northern Nepal containing the Himalayas will be significantly wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in the monsoon season June to September, compared to Southern Nepal. Eastern Himalayas will experience more extreme rainfall but drier winters whilst the western Himalayas will be wetter overall. Southern Nepal will see drier winters (December to February). Spring melt is expected to be earlier leading to increased downstream flow until 2050, after which potentially more rainfall in the monsoon dominated basins will replace glacial meltwater flow.	2

Regional risks relevant to Nepal	Report section
Production yields for rice-wheat cropping systems of the Indo-Gangetic Plain (extending large areas of Nepal) are projected to decline by the 2050s as a result of increasing temperatures and heat extremes.	3.1
In Nepal, vector-borne diseases such as malaria, dengue, chikungunya, Japanese encephalitis, visceral leishmaniasis, and lymphatic filariasis are mostly endemic in the lowland Terai and hills, with very large proportions of the population at risk. Projected temperature rises will likely increase exposure as transmission extends further into the country’s highlands.	3.3
Health risks will become more prevalent in Nepal as high overnight minimum temperatures are projected to occur more frequently during summer and during more months of the year.	3.3
Low-income households in growing urban (informal) settlements will be increasingly exposed to health risks (such as disease) associated with flooding, poor drainage and inadequate WASH (Water, Sanitation, and Hygiene).	3.3

[8] Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Pakistan country profile[9]



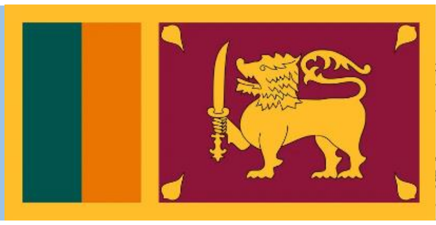
Summary of climate analysis relevant to Pakistan	Report section
Pakistan experiences a tundra climate in the north over the Hindu Kush Himalaya and an arid climate in the south. Pakistan has already experienced warming in the northern regions (Hindu Kush Himalay) of 0.1 to 0.2 °C and in the south of at least 0.4 to 0.5 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future for both northern and southern Pakistan. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. The Hindu Kush Himalaya areas in northern Pakistan has seem an increase in precipitation (with more rain replacing snowfall) during winter months over recent decades. The central monsoon belt of Pakistan has also experienced an increase in monsoonal precipitation during June-September. It is likely that Pakistan will become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in the south and significantly wetter in the north, especially during the monsoon season June to September. The eastern Himalayas will have more extreme rainfall but drier winters while western Himalayas will be wetter overall. Spring melt is expected to be earlier leading to increased downstream flow until 2050, after which, flow rate may decline in glacial dominated rivers (e.g. upper Indus basin), but increase in monsoon rainfall-dominated rivers (e.g. lower Indus basin). Sea surface temperatures have risen more quickly in the Indian and western Pacific oceans than other regions globally. Marine heatwaves have increased in frequency in the Indian Ocean. Sea levels will rise, sea surface temperatures and ocean acidification will increase, and marine heatwaves will become more frequent and intense. The strongest tropical cyclones will become more intense, although overall will decrease in frequency.	2

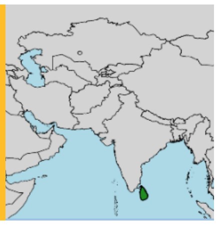
Regional risks relevant to Pakistan	Report section
Production yields for rice-wheat cropping systems of the Indo-Gangetic Plain (extending large areas of Nepal) are projected to decline by the 2050s as a result of increasing temperatures and heat extremes.	3.1
Rice production could be negatively impacted in cooler parts of Pakistan due to a potential increase in invasive golden apple snail habitat due to increasing minimum winter temperatures.	3.1
The productivity of Pakistan's livestock sector is at risk from widespread deterioration of pastures and rangelands and increased risk of disease from successive droughts and floods in the future. This is especially relevant for Pakistan because the livestock sector accounts for over half of the agricultural GDP and has traditionally buffered the impacts of economic and weather shocks on low-income and land-poor households.	3.1
In mountainous areas of Pakistan, people living near flood-prone glacial lakes are increasingly at risk from hazards linked to glacier, snowpack, and permafrost thawing as temperatures rise.	3.2
Pakistan, and southern Pakistan in particular, is at risk from heat-related risks and impacts such as heat stress impacting health and livestock, cooling energy demands, droughts, and water demand/supply. This is because there are already a large number of people living in areas experiencing high summer temperatures and projections indicate temperatures will continue to rise, especially in southern Pakistan which is projected to experience summer temperatures exceeding 40°C.	3.3

[9]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Met Office Hadley Centre ODI UKaid from the British people

Sri Lanka country profile[10]



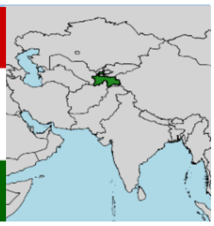


Summary of climate analysis relevant to Sri Lanka	Report section
Sri Lanka experiences a tropical climate. Sri Lanka has already experienced warming of around 0.2 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future across all seasons, especially during pre-monsoon March to May. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. There have been significant increases in annual mean precipitation. It is likely that Sri Lanka will become significantly wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) during the monsoon season June to September in the future. Sea surface temperatures have risen more quickly in the Indian and western Pacific oceans than other regions globally. Marine heatwaves have increased in frequency in the Indian Ocean. Sea levels will rise, sea surface temperatures and ocean acidification will increase, and marine heatwaves will become more frequent and intense. The strongest tropical cyclones will become more intense, although overall will decrease in frequency.	2

Regional risks relevant to Sri Lanka	Report section
Human and livestock health will be impacted, especially for outdoor labourers, due to projected hotter summer temperatures exceeding 40°C more regularly in the future.	3.3
Health will be impacted in Sri Lanka, such as heat stress and dehydration, due to high overnight minimum temperatures occurring more frequently in the future and during more months of the year.	3.3
Coastal cities of Sri Lanka are exposed to the risks of large-scale human and economic losses due to tropical cyclone, storm surge and flooding damages as the intensity of the most intense tropical cyclones is projected to increase. This is especially relevant due to the cities' high population concentrations and economic assets.	3.4
Coastal infrastructure and settlements, important for tourism, are at risk from shoreline retreat along most of the sandy coasts in Sri Lanka.	3.4
Marine species and fishing livelihoods will be at risk from the increasing intensity and frequency of marine heatwaves around the North Indian Ocean coastline due to rising summer sea surface temperatures.	3.7
Coral reefs, which support artisanal fisheries for food and the ornamental fish trade, are at risk of mass coral bleaching and overall decline as sea temperatures rise and ocean acidification increases.	3.7
Tourism in Sri Lanka is at risk of large adaptation costs and significant losses due to sea-level rise and marine heatwaves induced by climate change.	3.7

[10] Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Tajikistan country profile[11]



Summary of climate analysis relevant to Tajikistan	Report section
Tajikistan experiences a mix of temperate, cold and tundra climates. Tajikistan has already experienced warming of around 0.3 to 0.4 °C per decade (along with the rest of Central Asia) from 1980 to 2015. Temperatures will continue to rise in the future across all seasons. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Precipitation trends of recent decades show increased precipitation during winter, including both rainfall and snowfall. Extreme precipitation has also increased. Tajikistan will become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in the future throughout the year but particularly in October to November and March to May. However, there is lower confidence in precipitation trends over mountains. Spring melt is expected to be earlier leading to increased downstream flow until 2050, after which flow rate will decline especially during the summer months.	2

Regional risks relevant to Tajikistan	Report section
Water supply is at risk in upstream countries such as Tajikistan which rely on glacial-snowmelt dominated headwaters which are most vulnerable to reduced and/or variable river flow due to rising temperatures.	3.2
Hydropower insecurity will become a critical risk for Tajikistan and a source of economic and social risk. This is due to reduced and/or variable river flows from glacial snowmelt due to rising temperatures.	3.5
In the Pamiri region of eastern Tajikistan, suitable habitats of the Marco Polo sheep, already classified as a 'near-threatened' species, will expand at higher elevations due to warmer temperatures, but shrink at lower elevations due to less rainfall.	3.6
Health is at risk from combinations of heat and humidity, especially for people working outdoors and those living in informal settlements.	3.3

[11] Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

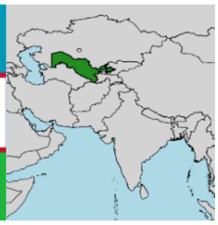
Turkmenistan country profile[12]

Summary of climate analysis relevant to Turkmenistan	Report section
Turkmenistan experiences an arid climate. Turkmenistan has already experienced warming of around 0.3 to 0.4 °C per decade (along with the rest of Central Asia) from 1980 to 2015. Temperatures will continue to rise in the future, particularly in winter (December to February). The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Turkmenistan has experienced a wetting trend in recent decades (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)). It is unlikely that Turkmenistan will become significantly wetter in the future and droughts will likely be more frequent and intense. Spring melt is expected to be earlier resulting in increased downstream flow until 2050. The Caspian has shrunk over recent decades mainly due to irrigation and/or damming. Increasing temperatures and drought conditions in the future will lead to further shrinkages.	2

Regional risks relevant to Turkmenistan	Report section
Turkmenistan's drylands are at risk from desertification, driven by human activities and increase droughts.	3.6
Human and livestock health will be impacted, especially for outdoor labourers, as the intensity and frequency of heat extremes, including heatwaves, will continue to increase across Turkmenistan with days exceeding 40°C expected to increase.	3.3
The Caspian Sea is expected to shrink by 9-18m by 2100 with negative implications for Turkmenistan's port infrastructure and oil and gas industry, especially the port city of Turkmenbashi due to warming waters causing evaporation and restricting transportation. The Caspian Sea is projected to warm by the 2050s with the Caspian Sea showing greater levels of warming than the Bay of Bengal, Arabian Sea and Gulf of Persia.	3.7

[12]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Uzbekistan country profile[13]



Summary of climate analysis relevant to Uzbekistan	Report section
Uzbekistan experiences a predominantly arid climate except the higher elevation eastern Uzbekistan which experiences a mix of temperate, cold and tundra climates. Uzbekistan has already experienced warming of around 0.3 to 0.4 per decade (along with the rest of Central Asia) from 1980 to 2015. Temperatures will continue to rise in the future, particularly during winter. The intensity and frequency of heat extremes (e.g., heatwaves) will continue to increase. Uzbekistan has experienced a wetting trend in recent decades (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)), especially during winter for eastern Uzbekistan (both rainfall and snowfall). Uzbekistan is unlikely to become significantly wetter in the future and droughts are likely to be more frequent and intense, however, eastern Uzbekistan (mountainous areas) will be wetter throughout the year (particularly October to November and March to May) with more rainfall replacing snowfall. Spring melt will be earlier which will increase downstream flow until 2050.	2

Regional risks relevant to Uzbekistan	Report section
Uzbekistan's drylands are at risk from desertification driven by human activities and increased droughts.	3.6
Human and livestock health, especially for outdoor labourers, is at risk from the increasing intensity and frequency of heat extremes, including heatwaves, and as days over 40°C are expected to increase.	3.3
Yields of important irrigated crops for Uzbekistan (cotton, wheat, apples, tomatoes, potatoes) could decline by the 2050s due to heat and water stress, also increasing food insecurity.	3.1

[13]Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Image location: Malé, Maldives

Source: © Crown Copyright 2024, Met Office

1 Introduction

Lead author: Kate Salmon, Met Office

1.1 Purpose of this report

The current climate has already undergone significant changes which human and ecological systems are often not well adapted to. This report provides an evidence base on the Central and South Asia regions' changing climate and highlights some key climate risks they will or may face up to the 2050s[14] in the context of pre-existing and future socio-economic risks and stressors.

It forms part of a series of climate risk reports assessing the implications of climate variability and change in the context of the socio-economic exposure and vulnerability in ODA-eligible regions of Africa and Asia, produced through a collaboration between the Met Office and ODI, and funded by FCDO. The reports provide accessible and authoritative evidence to UK Government on climate risk in support of adaptation and resilience planning and investments. They present a top-level regional overview of potential risks to development associated with climate and climate change out to the 2050s, signposting key issues and complexities.

The reports look at climate risk as a combination of hazard, exposure, and vulnerability. Each report details information about the weather and climate relevant to the context of the lives and livelihoods of the populations affected. This risk-based approach helps to frame the challenges of climate change in a way that can best inform action and the evidence generated in the reports is focused on informing UK development programming and actions that support climate resilience in current and future complex human-environment systems.

These reports are aimed to inform UK Government's long-term planning and design of development programmes, including supporting the compliance of these programmes with mandatory climate risk assurance.

In this report, Central and South Asia includes Afghanistan, Bangladesh, Bhutan, India, Kazakhstan, Kyrgyzstan, Maldives, Nepal, Pakistan, Sri Lanka, Tajikistan, Turkmenistan, and Uzbekistan (Figure 1). Key aspects of the region, such as the elevation of the region and population densities, are also shown in Figure 2 (topography and population maps).

[14] In climate modelling, 2050s refers to the period 2041-2060.

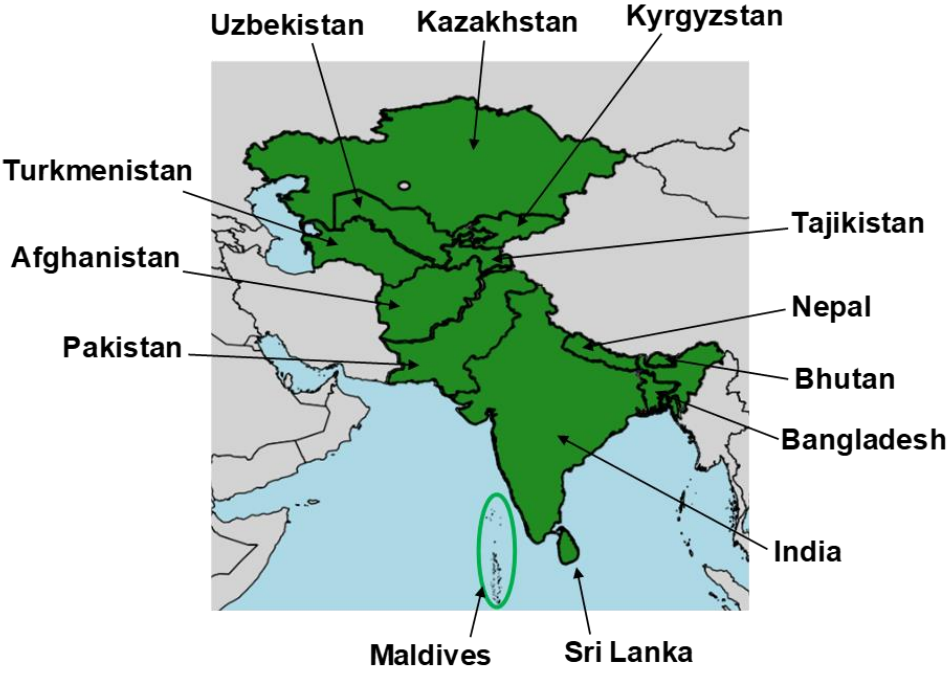


Figure 1: Countries included in the Central and South Asia region for this report.

Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

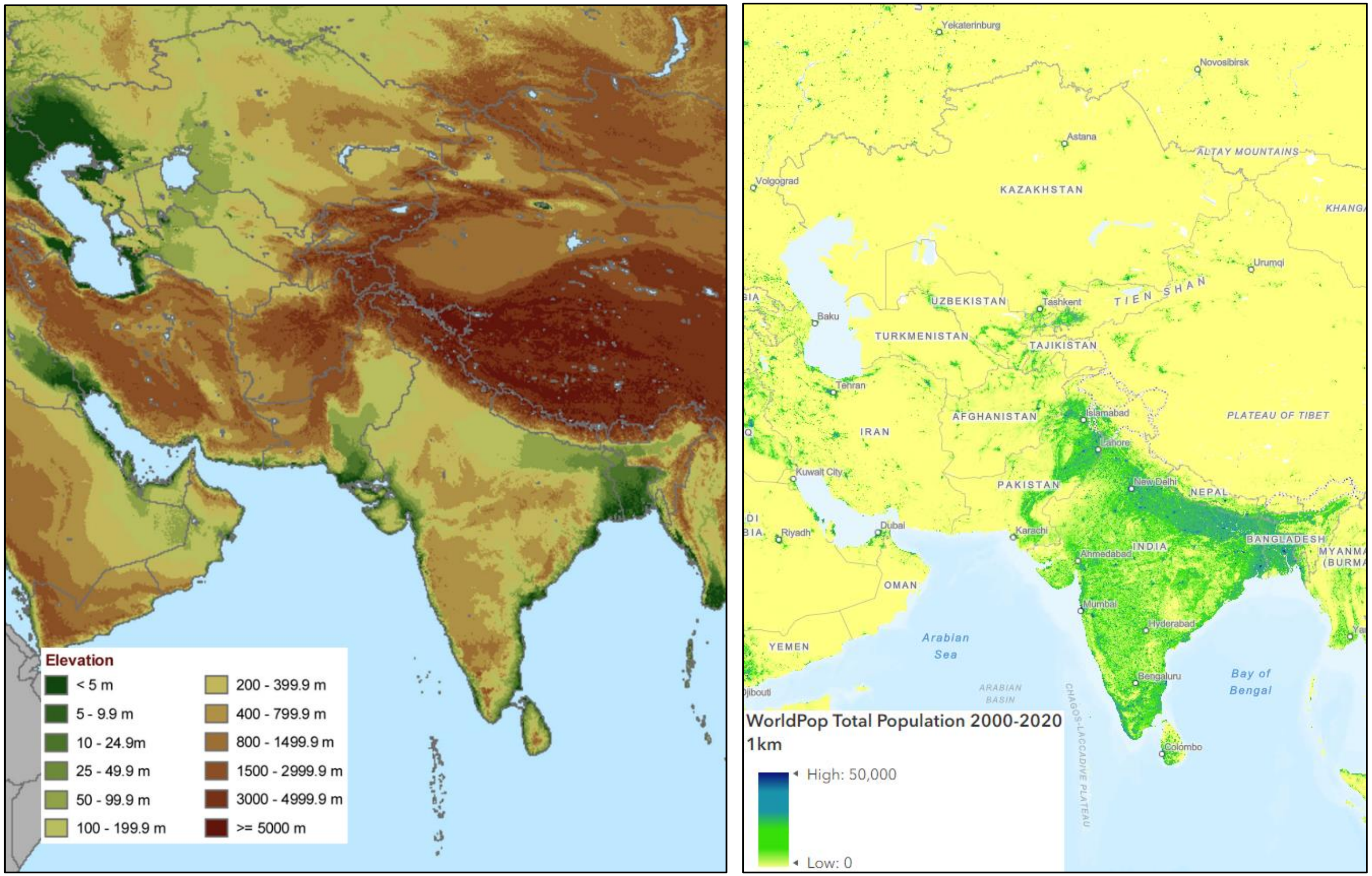
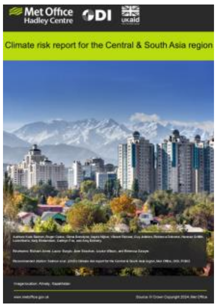


Figure 2: Topographic map (left, data from SEDACMaps) and total population map (right; data from WorldPop, 2018) of Southeast Asia and the Maritime Continent. Population data shows number of inhabitants per 1km grid square.

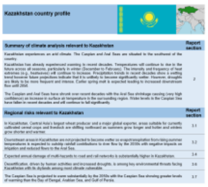
Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

1.2 Report structure and risk-informed development

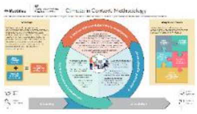


The Executive Summaries outline headline risks per theme, for both Central Asia and South Asia, with context drawn from the report sections. These summaries provide overviews of key climate related risks across the regions. These summaries are translated into 3 languages for South Asia and 1 additional language for Central Asia, for ease of sharing with regional partners.

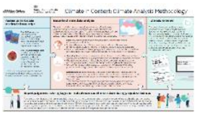
The Headline Risk Infographics contain standalone statements on headline key risks across the regions. These infographics can be used to identify the key risks by thematic area. These infographics are translated into 3 languages for South Asia, and 1 language for Central Asia, for ease of sharing with regional partners.



Country Profiles outline prominent climate risks for individual countries. The tables signpost to relevant sections in the report with more detail.

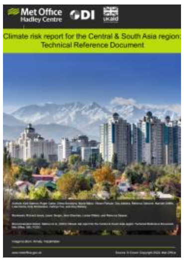


Section 1 outlines the purpose, methodology and the regional development context through which this report has been framed. This section can be used to understand the lenses through which the report has been written.



Section 2 provides an assessment of the region's climate. It begins with an overview of climate resilience and vulnerability of the region and then it provides a summary of knowledge about the current climate and its future evolution at the regional scale.

Section 3 assesses future climate risk by bringing together future climate analsysis with socio-economic analysis of future resilience and vulnerbality across seven key themes: agriculture and food security; water resources and water-dependent services; health; infrastructure and settlements; energy; environment; and blue economy and the marine environment. This section provides headline statements about key climate-related risks.



The Technical Reference Document (TRD) accompanies this report to provide more detail on the methods, data and analysis supporting the assessment in this report. The TRD also contains a glossary of terms and a table of acronyms.

Figure 4 (page 41) shows an infographic depicting the Climate in Context Methodology for the Climate Risk Reports. Further information regarding the data used and detailed methodology can be found in Section A of the TRD and on the Met Office website [here.](#)

Focus Box 1 explains why it is necessary to consider both exposure and vulnerability to climate hazards and the need for an interdisciplinary approach when interpreting compound risks associated with, or exacerbated by, climate change. Information on risk-informed development can be found in TRD Section A.

Focus Box 1: Exposure, vulnerability, response, and development

Risks are created by the interaction between physical climate hazards and individual or community exposure and vulnerability to those hazards, as well as their ability to respond (Figure 3, Begum et al., 2022). Exposure and vulnerability are separate, yet both emerge from socio-economic contexts and are exacerbated by uneven development dynamics such as: rapid urbanisation and demographic change, environmental degradation, weak governance, and lack of economic opportunity. IPCC AR6 also now considers response as an important component of risk and examines the effectiveness of adaptation solutions, the management of risks at higher levels of warming if climate change mitigation is unsuccessful, and the benefits of mitigation and emissions reductions (Begum et al., 2022).

The components of risk (hazard, vulnerability, exposure, and response) interact in complex ways (Figure 3, Begum et al., 2022). They can compound in single or multiple directions, cascade (e.g., with one event triggering another) and aggregate (e.g., more than one component occurring simultaneously).

Climate vulnerability and poverty are often mutually reinforcing. A growing body of evidence highlights the role climate risk plays in generating poverty and creating poverty traps (Hansen et al., 2019; Sachs et al., 2004), a problem exacerbated by the political marginalisation of many poor and climate vulnerable people (Wisner et al., 2003).

Climate change is interwoven with development challenges across the Sustainable Development Goals (SDGs). As factors such as economic inequality, education, gender, nutrition and health shape the risk profile of individuals and communities, supporting sustainable development indirectly supports their capacity for managing climate risk (Wisner et al., 2003; Schipper and Pelling, 2006).

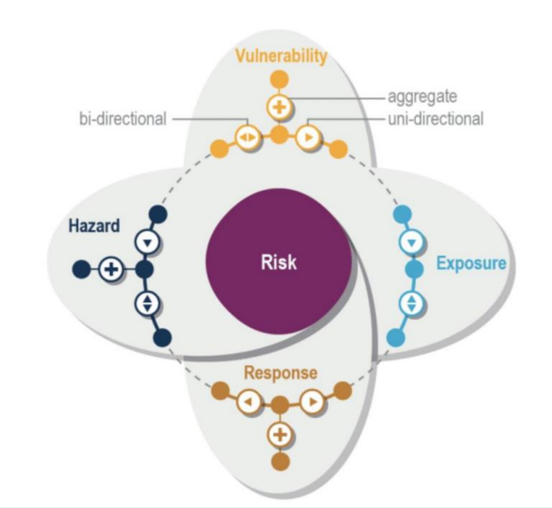


Figure 3: Climate risk is the product of the hazard, vulnerability and exposure to the hazard and the response to the hazard which interact in complex ways: compounding in single or multiple directions, cascading and/or aggregating. Image adapted from IPCC AR6 Working Group II (Begum et al, 2022).

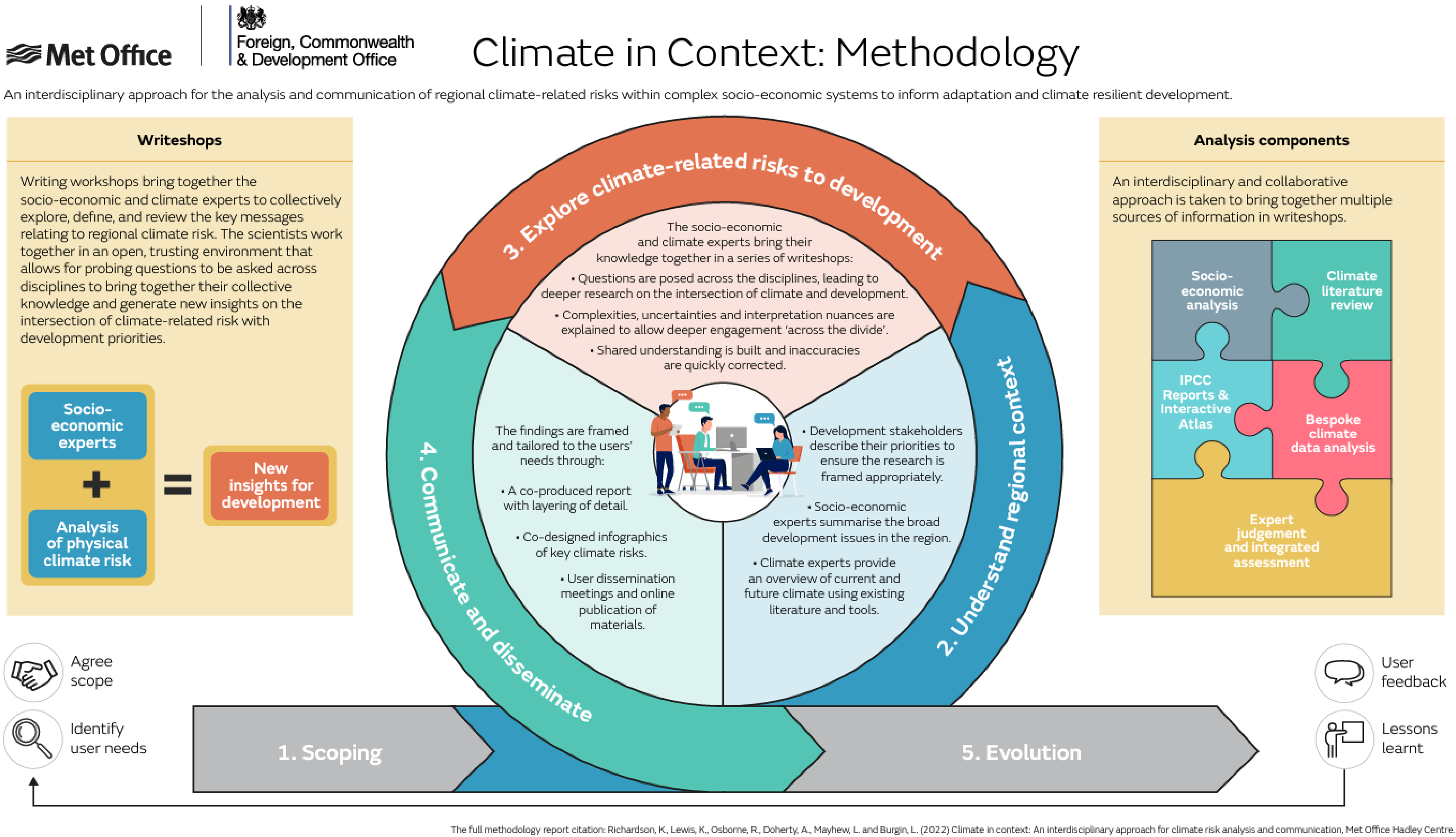


Figure 4: The climate in context methodology for the Climate Risk Reports. Full methodology report citation: Richardson, K., Lewis, K., Osborne, R., Doherty, A., Mayhew, L. and Burgin, L. (2022) Climate in context: An interdisciplinary approach for climate risk analysis and communication, Met Office Hadley Centre. Further information regarding the data used and detailed methodology can be found in Section A of the TRD and on the Met Office website [here](#).

Image location: Pokhara lake, Nepal

2 Current and future climate in the Central and South Asia region

Lead author: Kate Salmon, Met Office

2.1 Climate resilience and vulnerability overview for the Central and South Asia region

Central and South Asia have a combined population of just over two billion, with roughly 78 million (38%) in Central Asia and 1.97 billion (62%) in South Asia (data for 2022 from World Bank, 2022b; see also TRD Section F).[15] Annual population growth in Central and South Asia has been around 1.3% and 1.7%, respectively, over the last decade, considerably higher than the global average of 1.1%, although annual growth rates vary significantly between countries. Most of this growth will be absorbed by urban areas (World Bank, 2020; World Bank 2022b; see also TRD Section F), although populations in both regions are still predominantly rural: 52% in Central Asia and 64% in South Asia (data for 2022 from World Bank, 2022b; see also TRD Section F).

Disasters linked to natural hazards, particularly floods, tropical cyclones, heatwaves and droughts continue to rise in frequency and intensity in Central and South Asia, posing considerable infrastructure challenges. According to the EM-DAT database (the International Disaster Database), between 1995 and 2022, climate-related disasters inflicted a total of 114,915 human fatalities in Central and South Asia – over 99% of which were in South Asia (CRED-EM-DAT, 2023). In 2023, a total of 79 disasters associated with hydrometrological hazards were reported across Asia; of these 80% were associated with flood and storm events, with storms affecting the largest number of people and causing the most economic damage during 2023 (WMO, 2024).

On average between 1995-2022, such disasters have affected (injured, displaced, otherwise affected) nearly 58 million people annually in South Asia and one million in Central Asia, and caused an average annual economic loss of USD 8.5 billion in South Asia and USD 0.4 billion in Central Asia. A majority (more than 80%) of these disasters are linked to floods and tropical cyclones, particularly in India, Bangladesh and Pakistan. However, hazard-related mortality has declined across Central and South Asia over the last 40-50 years despite the rising exposure of populations. In Bangladesh, for example, the number of deaths directly related to tropical cyclones and coastal flooding has decreased significantly since the 1980s, even though the number of people exposed to those hazards has increased by around 50% (Haque et al., 2012; Lumbrusco et al., 2017; Lee et al., 2021). This is due to improvements in early warning and response, and the building of tropical cyclone centres and other defensive measures (Lee et al., 2021). Nevertheless, India, Yemen and Pakistan reported floods in 2023 as the natural hazard event that caused the greatest number of fatalities, highlighting the persistent vulnerability of populations in Asia to natural hazards, especially floods (WMO, 2024).

Economic growth over the past few decades in Central and South Asia has been accompanied by increasing energy demand, a trend projected to continue in the future (see section B of the TRDs). Despite major gains in improving electricity access, challenges remain across the

[15] Data for Afghanistan included under South Asia.

region including extending access to clean cooking fuels to improve health, reducing carbon dioxide emissions and relieving pressure on natural habitats as a source of fuel, particularly in Afghanistan, Bangladesh, Nepal and Sri Lanka where access to clean fuels is 35% or less (IEA, 2023).

Agricultural production, including forestry, fishing and livestock, provides a vital source of employment, income and food security across Central and South Asia, even though its contribution to GDP is diminishing as economies diversify and become more urbanised. Farming is becoming increasingly feminised as men (mainly) seek off-farm employment, leaving women more exposed to climate-related stresses, amplified by their lower incomes and more limited access to credit, property, extension services and other resources (Akter, 2021; ADB, 2021; Barooah et al., 2023). After marked increases in agricultural productivity since South Asia's Green Revoloution in the 1960s, productivity growth is slowing in both Central and South Asia due to soil degradation, salinisation, heavy fertiliser use[16], pesticide/herbicide resistance, water scarcity/salinisation in some areas, and climate change. This creates a key source of vulnerablity for the rural poor who's income is directly tied to the ehalth of the agricultural economy (Aggarwal et al., 2004; ADB, 2021; Dhanda et al., 2022).

Both Central and South Asia have made significant progress on health and broader social development outcomes over the last three decades, despite recent disruption from the Covid-19 pandemic and (in Afghanistan) conflict and fragility. However, environmental risks related to air pollution (indoor and outdoor) are growing in importance, and are now the leading cause of death in all South Asian countries except Sri Lanka and Maldives (IHME-GBD, 2019). Deaths attributable to inadequate water, sanitation and hygiene (WASH) remain significant, responsible for over one million deaths (mainly children) in India, Pakistan and Bangladesh *alone* in 2019 (IHME-GBD, 2019).

2.2 Climate overview for the Central and South Asia region

The Central and South Asia region experiences very diverse climates. Kazakhstan, Turkmenistan, most of Uzbekistan, southern Afghanistan, southern Pakistan, and areas of western India are arid. Eastern Uzbekistan, Tajikistan, and Kyrgyzstan have cold, temperate[17] or tundra[18] climates. Himalayan areas of NW India, northern Pakistan, and northern Nepal have tundra and temperate climates. Northern India, southern Nepal, and Bhutan are temperate and southern India, Bangladesh, Sri Lanka, and the Maldives are tropical.

Annual average precipitation is greatest in the mountainous regions such as western Kazakhstan, Kyrgyzstan and Tajikistan (Tian Shan mountain range); Tajikistan and NE Afghanistan (Pamir and Hindu-Kush mountain ranges), NE Pakistan (Karakorum mountain range) and northern India, Nepal and Bhutan (Himalayan mountain range). Bangladesh, NW India and Sri Lanka have greater precipitation driven by the seasonal monsoon between June

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[16] In Bangladesh, for example, the high use of synthetic fertilisers and pesticides is acidifying soil, worsening water quality and depressing crop yields. Crop residues used for household fuel also remove nutrients and organic matter from soils (World Bank, 2022a).
[17] Temperate climate zones are defined by temperature. Their coldest month averages between 0°C and 18°C, but at least one month averages above 10°C (Met Office, 2024).
[18] Tundra climates are classified if the warmest month in an area averages between 0°C and 10°C. Some plant life can grow in tundra climates, but the growing season is too short for trees (Met Office, 2024).

and September (Figure 6). The western coast of India also receives a large amount of rainfall during the monsoon, exacerbated by the orography of the Western Ghats, a mountain range stretching almost 1000 miles up the western coast of India. Climate variability across the region is also affected by changes in large-scale atmosphere-ocean circulation patterns such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). It is mostly dry all year round in the north and west of the region (Kazakhstan, Turkmenistan, Uzbekistan, Kyrgyzstan, Tajikistan and northern Afghanistan). It is coldest in the mountainous regions of Tajikistan, Kyrgyzstan and the Himalayas across northern Nepal.

The region is very mountainous further influencing the climate, with a significant range in elevation across the region (see Figure 2) from less than 50m for much of Bangladesh and western Kazakhstan, Uzbekistan, and parts of Pakistan to many areas between 3000-8000m in the Tian Shan, Pamir, Karakorum and Himalayan mountain ranges.

Many of the Central Asian countries contain a network of rivers feeding into two large inland seas heavily relied upon by the region; the Caspian Sea (basin includes Kazakhstan and Turkmenistan) and the Aral Sea (basin includes Afghanistan, Turkmenistan, Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan). Major rivers which feed into these inland seas include the Amu Darya (Afghanistan, Turkmenistan, Tajikistan, Uzbekistan), Syr Darya (Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan) and the Ural (Russia, Kazakhstan). Kazakhstan is also home to Balkhash-Alakol basin (~22 000km^2) which is important for irrigation, municipal and industrial water supply and Ob-Irtysh basin (which spans Russia and Kazakhstan).

In South Asia, some major rivers include Ganges (India, Nepal, Bangladesh), Indus (China, India, Pakistan), and Brahmaputra (China, India, Bangladesh). The Hindu Kush-Karakoram-Himalayan region (India, Nepal, Pakistan, Afghanistan, China, Tajikistan), known as the Asian Water Tower, is the largest global store of frozen water after the polar regions (thus also named the Third Pole) and currently provides a reliable water supply to almost two billion people (Yao et al., 2022).

The South Asia region is bordered to the south by the Indian Ocean, Arabian Sea and Bay of Bengal, and the Caspian Sea borders much of western Central Asia. Annual mean sea surface temperatures in the Arabian Sea and Bay of Bengal range from 25-31°C with March to May being the season for the warmest sea surface temperatures. There is less seasonal change in temperature nearer to the equator. South Asia experiences tropical cyclones from October to November causing heavy rainfall, high winds, storm surges, coastal flooding and inundation.

2.2.1 Regional climate overview and observed trends

Regional climate overview for Central and South Asia

Central Asia

Central Asia experiences a range of climates. Temperature and precipitation are characterised by a north-south divide (drier and colder in the north, warmer and wetter in the south) and mountainous topography in the southeast. Precipitation is generally low for Central Asia (except mountainous areas) with most precipitation falling during winter and spring (November to March). Natural variability in the climate can lead to warmer/wetter and cooler/drier periods. The dominant mode of natural variability is the North Atlantic Oscillation (NAO) which when positive, drives warmer, wetter conditions, especially in winter. Positive phases of ENSO, the North Annular Mode and East Atlantic/West Russia pattern also drive wetter conditions in Central Asia (see TRD Section C for more detail on drivers of climate variability).

Five major river basins exist in Central Asia, namely the Amu Darya (Afghanistan, Turkmenistan, Tajikistan, Uzbekistan), Syr Darya (Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan), Balkhash-Alakol (Kazakhstan), Ob-Irtysh (Russia, Kazakhstan), and Ural (Russia, Kazakhstan) River basins.

Northern and western Central Asia (Kazakhstan, Turkmenistan, and Uzbekistan) experience an arid climate with frequentdrought conditions. Temperatures are characterised by a north-south gradient across the year where southern areas are warmer than northern. Precipitation is low throughout the year with slightly higher precipitation in the mountainous area to the southeast of northern Central Asia. To the west of this arid area is the Caspian Sea.

Southern and eastern (higher elevation) parts of Central Asia (eastern Uzbekistan, Tajikistan, Kyrgyzstan, and northern Afghanistan) experience temperate, cold, and tundra climates. Temperatures in this area are cooler than in northern parts of Central Asia due to the mountainous terrain. Precipitation is generally low throughout the year. However, precipitation is still higher in this region compared to northern parts of Central Asia. This is due to the moderate precipitation it receives over the mountainous southeast. Precipitation mainly falls as winter snow in the mountainous areas of Tien Shan, Pamir, and Hindu Kush.

South Asia

South Asia experiences a range of climates. Temperature varies with topography across South Asia with colder temperatures at high elevations. Precipitation is controlled primarily by the Southwest Monsoon for most of the region. In the northwest of the region westerly disturbances (originating from the Atlantic) are important precipitation sources. The warmest time of year is pre-monsoon (March to May). ENSO can influence interannual temperature variability with warmer conditions occurring during positive phases. Tropical cyclones peak from October to November and influence precipitation patterns in South Asia.

The Hindu Kush Himalaya (northern Pakistan, Himalayan areas of NW India, and northern Nepal) experience a tundra climate. Temperatures are low to temperate throughout the year and precipitation is low with a small peak from June to August.

Southern Afghanistan, southern Pakistan, and areas of western India experience an arid climate. Temperatures peak during May to June and the wettest months are June to August however precipitation is very low throughout the rest of the year. The Arabian Sea is to the south of this area and experiences high sea surface temperatures, peaking from March to May.

Northern India, southern Nepal, and Bhutan experience a temperate climate. There is a pronounced rainy season June to August. This area has lower elevation except for far eastern India which is mountainous with the Brahmaputra River running through. Other rivers of significance include the Ganges and Yamuna.

Southern India, Bangladesh, Sri Lanka, and the Maldives experience a tropical climate with a small arid area in southwest India. Temperatures are high throughout the year with a pronounced Southwest Monsoon season between June and September. The Indian Ocean is to the south and the Arabian Sea is to the west. Bangladesh hosts three large river deltas: Ganges, Brahmaputra, and Meghna and is flood-prone especially during the monsoon. Sri Lanka is an island country that is mostly low-lying with mountainous terrain in the centre with forests. The Maldives are very low-lying small islands situated to the south of India.

Observed trends in regional climate for South and Central Asia

A long-term warming trend in annual mean surface temperature has been observed across the whole of Asia during 1960–2015, and the warming accelerated after the 1970s (Shaw et al., 2022). Minimum temperatures have increased at a slower rate (e.g., 0.24 ºC per decade in Central Asia) than maximum temperatures (e.g., 0.41 ºC per decade in Central Asia, 0.01-0.3 ºC per decade in South Asia) (Shaw et al., 2022; Zhang et al., 2019; Naveendrakumar et al., 2019). General warming has resulted in more frequent warm days and nights, and less frequent cold days and nights (Shaw et al., 2022). There have been more frequent heat extremes in the recent decades in most of Asia driven by anthropogenic (human-induced) global warming, El Niño and urbanization (Ranasinghe et al., 2021).

Over the last century (1901-2010) precipitation trends have been variable across Asia, with small, scattered regions of detectable increases and decreases. At higher latitudes in Asia, precipitation has increased. (Ranasinghe et al., 2021).

Central Asia

Most of Central Asia has experienced around 0.3°C–0.4°C degree of warming per decade during 1980-2015. The number of heatwaves in Central Asia has increased by 30% since the 1960s, and there have also been increases in the frequency, duration, and intensity of heatwaves during the period 1917–2016, particularly during the last 50 years (Yu et al., 2019), attributed to anthropogenic climate change (Fallah et al., 2023). Precipitation trends in Central Asia are highly variable reflecting the diversity in orography and climate drivers. Despite this, there has been a significant increase in precipitation over the last 50 years (Zhao and Zhang, 2016, Hu et al. 2016), with an intensification in extreme precipitation in arid Central Asia (Yao et al. 2021).

In northern and western Central Asia (Kazakhstan, Turkmenistan, and Uzbekistan), there is very high confidence that the shrinking of the Aral Sea due to irrigation diversions has increased surface air temperature in the surrounding region of around 2°C to 6°C (He et al., 2022). Central Asia is one of the most arid regions in the world with northern Central Asia experiencing increasingly serious water shortages and related conflicts due to the reduction of summer rainfall since the 1950s (Jiang and Zhou, 2021), combined with shifts of snowfall to rainfall, glacier retreat, river runoff changes and reliance on agriculture (Chen et al., 2018). This reduction in summer rainfall (-1.02mm/month per decade^{-1}) in northern Central Asia between 1958-2014 has been attributed to anthropogenic change in atmospheric circulation (Jiang and Zhou, 2021). In contrast, a wetting trend has been observed in mountainous areas of northern and western Central Asia (increases of 1.3mm-4.8mm per decade during 1960-2013) (Ozturk, 2023), although the scarcity and decline of mountain observation sites since the end of the Soviet Union in 1991 have increased the uncertainty of long-term temperature and precipitation estimates (Gutiérrez et al., 2021b).

In southern and eastern (higher elevation) parts of Central Asia (eastern Uzbekistan, Tajikistan, Kyrgyzstan, and northern Afghanistan), over the last 60 years, there has been an observed increase in extreme precipitation (over 100% increase in intensity and 20% increase in frequency), particularly in Kyrgyzstan and Tajikistan, attributed to anthropogenic climate change (Fallah et al., 2023; Zou et al., 2021). The proportion of precipitation falling as snow, rather than rain, has decreased in these regions (IPCC, 2021a), likely due to rising temperatures. This has increased the risk of water-related disasters and affects the availability of water from mountainous areas (Zou et al., 2021).

Overall, Central Asia has a distinct lack of Extreme Event Attribution (EEA) studies with only a few being focused on drought and extreme precipitation in (predominantly northern) Kazakhstan. Central Asian attribution studies typically assess trends over a longer period of time rather than trying to attribute specific extreme events as there is a lack of sufficient observational records to do this. Currently, there are no published attribution studies on observed changes to snow and associated impacts on spring melt, and glacial lake outburst flooding in the Karakorum and Tien Shen ranges which would be critical to understand the current impacts of climate change. Similarly, attribution studies investigating the role of anthropogenic warming to changes in river flow are not yet available in this region, especially for downstream countries prone to drought such as Kazakhstan. For more detail, please refer to the TRD Section B.

South Asia

In most areas of South Asia, observational records show an increase in average annual surface temperatures of between 0.1–0.2°C of warming per decade during 1980-2015. Changes in the South Asian monsoon have caused contrasts in precipitation trends across the region, with some areas experiencing a wetting trend and some a drying trend. The Southwest and Southeast Asian monsoon has weakened in the second half of the 20th century, due to anthropogenic aerosol forcing which has offset some of the anthropogenic warming (IPCC, 2021a). The cooling effect caused by anthropogenic aerosols has also complicated the attribution of extreme weather events in this region to anthropogenic climate change and remains a research gap.

In the Hindu Kush Himalaya (northern Pakistan, Himalayan areas of NW India, and northern Nepal) temperatures have warmed by 0.1°C–0.2°C per decade over the period 1980-2015. There has been increased winter precipitation, and the proportion of precipitation falling as rain, rather than snow, has increased in these regions (IPCC, 2021a). There has been an increase in monsoon precipitation of more than 0.25-0.75mm/month per year in the central monsoon belt of Pakistan between 1951-2012 (Latif et al., 2017). Anthropogenic climate change has caused more extreme rainfall leading to flooding in northern India in 2010, (Hirabayashi et al., 2021; 2013; Singh et al., 2014) and a series of flooding events in the Indus and Brahmaputra rivers 1951-2010 (Alifu et al., 2022). There is a lack of attribution studies related to snowfall in the Himalayas, particularly with relation to glacial lake outburst floods affecting predominantly populations in northern Pakistan and India (Taylor et al., 2023), however, there is one study which has attributed the unusual atmospheric conditions that led to an extreme snowstorm in Nepal in October 2014 to anthropogenic climate change (Wang et al., 2015).

In southern Afghanistan, southern Pakistan, and arid and semi-arid areas of western India, temperatures in this region have warmed by at least 0.4°C–0.5°C per decade over the period 1980-2015. Anthropogenic climate change has been found to have exacerbated heatwaves e.g., in 2015 in Pakistan and India (Wehner et al., 2016), especially pre-monsoon heat waves such as March-May 2022 (Zachariah et al., 2022).

In northern India, southern Nepal, and Bhutan average temperatures have increased during the winter and pre-monsoon seasons. There has been a drying trend observed with a decrease in mean rainfall over most parts of the eastern and central north regions of India and lower monsoon rainfall totals in central/ north India (Latif et al., 2017). During this same period, there have been a number of extreme rainfall events attributed to anthropogenic climate change which have led to river flooding, particularly in northern India (Singh et al., 2014; Alifu et al., 2022; Hirabayashi et al., 2021). Central and South Asia lack attribution studies for river and coastal flooding, constrained by the need for a hydrological modelling component, which introduces uncertainties through the requirement for additional data e.g., river discharge data which may not be accurate or available, making it a critical research priority in the region (e.g., Philip et al., 2019).

In southern India, Bangladesh, and Sri Lanka temperatures have increased by around 0.2°C per decade during 1980-2015. There have been significant increases in annual mean precipitation in some of the region (Ahmed et al. 2016; Alahacoon and Edirisinghe 2021), and extreme pre-monsoon rainfall events have been made more likely by anthropogenic climate change over the northeast region of Bangladesh (Rimi et al., 2018). There are also multiple cases of extreme heat and humidity recorded in the last few decades throughout India, including southern India and Sri Lanka (Kam et al., 2016; Wehner et al., 2016; Nanditha et al., 2020).

Sea surface temperatures in the Indian Ocean and Arabian Sea have risen more quickly than other regions, with the Indian and western Pacific oceans experiencing the fastest warming globally (Fox-Kemper et al., 2021). Occurrences of marine heatwaves (MHW), which are periods of extremely high ocean temperatures that negatively impact marine organisms and ecosystems, have approximately doubled in frequency globally since the 1980s (IPCC, 2021b). Incidents of MHW, driven by ocean warming and El Niño events, are increasing in the Indian Ocean, with the largest increase observed over the western Indian Ocean, followed by the north Bay of Bengal. These MHW events reduce monsoon rainfall over the central Indian subcontinent while enhancing it over the southern peninsula (Saranya et al., 2022). In the northern and southeastern Arabian Sea, there has been a rapidly increasing trend in the frequency and duration of MHW since the 1980s, with 75% of pre-monsoon and monsoon season days experiencing MHW in the period 2010-2016 (Chatterjee et al., 2022).

The rate of sea-level rise in the Indo-Pacific region has risen faster than the global average. The Indo-Pacific region has risen by 3.65 mm per year between 1993-2018, which is greater than the global average value of 3.25 mm per year for 1993-2018 (Oppenheimer et al., 2019). Surface ocean pH in the Indian Ocean has declined by ~0.1 unit relative to pre-industrial levels, whereas the western Arabian Sea has undergone more rapid acidification due to more acidic upwelling waters (Roxy et al., 2020).

Throughout the Maldives archipelago sea surface temperatures have risen at a rate of 0.11-0.15 °C per decade (Ministry of Environment and Energy, 2016; UNDP, 2013). The rate of sea-level rise in the Maldives was 3.6 mm per year between 2006-2015, which is greater than the global average value of 3.25 mm per year from 1993-2018 (Oppenheimer et al., 2019). All countries of South Asia hold vulnerabilities to sea-level rise. Coastal flooding also results in a higher risk of saline intrusion, damaging freshwater capture fisheries and decreasing freshwater availability for aquaculture (FAO, 2011). Further information on the impact of sea-level rise on coastal infrastructure and blue economy activities can be found in Section 3.4 and 3.7.

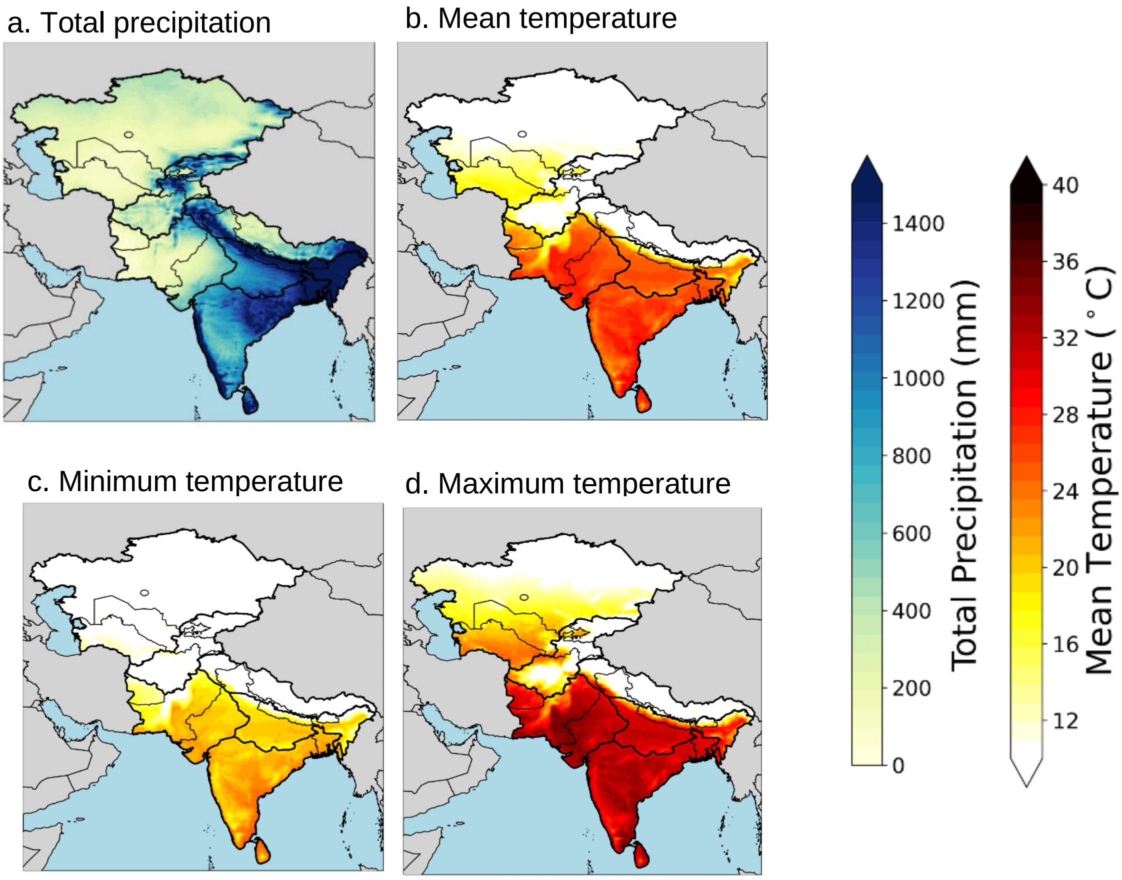

Figure 5: Baseline climate for the Central and South Asia region for the period 1981-2010. This time period was selected as the most widely used standard reference period for calculating climate averages. Maps show climatological average values of annual mean a) total precipitation (mm/year); b) mean temperature (°C); c) minimum temperature (°C); and d) maximum temperature (°C). Temperature and precipitation data come from ERA5 reanalysis dataset. These maps represent the average annual values over the 30-year baseline climate period (1981-2010). Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

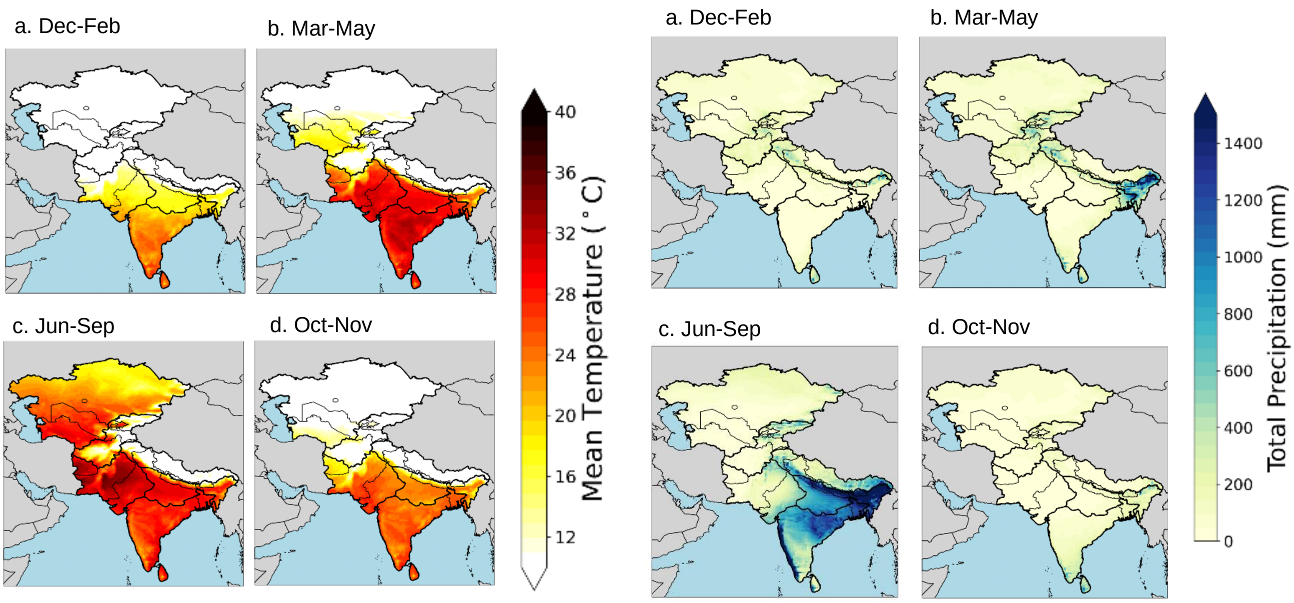

Figure 6: Seasonally averaged mean temperature (left) and total precipitation (right) for the Central and South Asia region over the baseline period (1981-2010) from the ERA5 reanalysis. Maps are used in this report for representational purposes. The Government of the UK does not necessarily endorse the political boundaries depicted in the maps.

Focus Box 2: Event Attribution

Climate attribution of long-term trends or individual extreme weather events (Extreme Event Attribution; EEA) such as a heatwave, a flood or a drought, identifies whether and to what extent human-caused greenhouse gas emissions are influencing weather and climate.

Geographical coverage of attribution assessments are uneven, and many more studies have been conducted for events and trends in developed countries than for countries in the global south, despite the global south being arguably more vulnerable to extreme events and trends driven by climate change. Confidence in climate attribution analysis relies on high quality observational records, climate models' abilities to simulate a particular type of event, and scientific understanding of how natural variability and climate change may influence the processes that cause the event. The availability of this information varies for each extreme event and region, posing a particular barrier to climate attribution studies in the Global South.

In general, both Central Asia and South Asia have a distinct lack of climate attribution studies compared to e.g., Europe or China. Available EEA studies are concentrated in the northern region of South Asia, with very few in Central Asia. In South Asia studies have focussed on assessing extreme heat and rainfall events whereas in Central Asia, studies have focussed on longer-term trends in extreme heat, drought and precipitation in northern areas (predomianlty Kazakhstan). Whilst there are a few studies in South Asia linking climate change to riverine flooding, more studies are required to capture the full extent of the impact of climate change on drought and flooding especially in downstream countries prone to flooding e.g. Bangladesh and upstream countries prone to drought e.g. Kazakhstan.

Further hydrological modelling is required in order to characterise the impact of climate change on e.g. coastal flooding, spring flooding (related to snowmelt), glacial outburst events which ultimately rely on higher density hydro-meteorological observational records for sufficiently long periods of time currently lacking in mountainous regions of South and Central Asia.

Impacts attribution studies (linking the climate hazard to the impact of the climate hazard) e.g. impacts of climate change on health events, ecosystem functioning such as the seasonality of crops are also lacking in both Central and South Asia.

Attribution of weather and climate-related events for Central and South Asia is discussed in more detail in TRD Section D.

2.2.2 Future climate over Central and South Asia

As mentioned in Section A of the Technical Reference Document, future climate over Central and South Asia is interpreted under a 'high greenhouse gas emissions pathway' (RCP8.5), or 'fossil-fuel driven development' scenario (SSP5-8.5) to model future climate evolution until 2050s unless otherwise stated. To supplement the information below, readers are referred to the accompanying TRD and the Country Reference Tables.

The section below presents the project trends applicable to the whole of South and Central Asia region, then details further trends specific to either Central Asia or South Asia. For more detailed climate information at national level, a separate analysis would be required.

Average annual temperatures will rise faster than the global average across the Central and South Asia region, but especially in Central Asia and the Himalayas. In general, average annual temperature rise will range from 2-6°C across Central and South Asia compared to a 1981-2010 baseline, with greater warming in Central Asian countries compared to South Asian countries.

For **Kazakhstan, Turkmenistan, Uzbekistan, Tajikistan, Kyrgyzstan, Afghanistan, Pakistan, northern India, and northern Nepal, and arid and semi-arid areas of western India** annual average temperatures will increase by ~2-6 °C compared to a 1981-2010 baseline. **Afghanistan, northern Nepal, and Karakorum-Himalayan mountain ranges** are more likely to experience 2-4°C warming by 2050 under RCP8.5/SSP5-8.5 scenarios.

For **southern Nepal, southern India, Bangladesh, Sri Lanka and the Maldives,** annual average temperatures will increase by ~1-3.5 °C compared to a 1981-2010 baseline.

The intensity and frequency of heat extremes, including heatwaves, will continue to increase across both Central and South Asia. Heat extremes have already been increasing across Asia due to the combined effects of climate change, El Niño and urbanisation (Ranasinghe et al., 2021).

Monsoon-dominated countries such as Pakistan, India, Sri Lanka, Bangladesh, will experience more intense 'moist' heatwaves due to greater humidity causes by rising temperatures combined with more rainfall by 2050.

For Kazakhstan, Turkmenistan, and Uzbekistan it is unlikely to become significantly wetter. For **eastern Uzbekistan, Tajikistan, Kyrgyzstan, and northern Afghanistan**, there will be greater precipitation throughout the year (~0-100mm/season) with more rainfall replacing snowfall.

Northern Pakistan, Himalayan areas of NW India, northern Nepal, southern Afghanistan, southern Pakistan and arid and semi-arid areas of western India will become wetter in the monsoon season (~0-200mm/season), as well as **southern Nepal, Bhutan, certain areas of northern India, southern India, Bangladesh and Sri Lanka** which will become significantly wetter (~0-400mm/season) during the monsoon season.

In the high mountain regions of Asia, especially the Hindu-Kush Himalaya, rainfall will continue to replace snowfall causing earlier snowmelt and a shift in seasonality of downstream river flow. Warmer winter and spring-time temperatures will cause earlier snow melt (Hock et al., 2019; Khanal et al., 2021) leading to springtime flooding in glacial/snowmelt fed rivers such as the Syr Darya, Amu Darya (Didovets et al. 2021), the upper Brahmaputra (Palash et al. 2023), Ganges, and particularly West Indus. Earlier snowmelt will lead to a reduction in lower-level summer river flow (Douville et al., 2021) causing summertime drought for downstream countries reliant on glacial-fed rivers (Li et al. 2020).

There is high confidence that 'peak water' will be reached for all Asian rivers before or around the middle of the century, after which river runoff will decline for Central Asian rivers due to declining snow and glacial melt, but may increase for South Asian rivers due to greater runoff from increased monsoon rainfall, espeically by the end of the Century (Hock et al., 2019).

Upstream countries across the region (**Tajikistan, Kyrgyzstan, northwest South Asia, Nepal**) relying on glacial-snowmelt dominated headwaters are most vulnerable to a reduction in river flow after 2050, compared to downstream countries where river flow is more dominated by rainfall (**southern Pakistan, Bangladesh**) (Khanal et al., 2021).

Heavy rainfall and drought events will become more intense and frequent in all areas of Asia, particularly notable by the 2080s (Ranasinghe et al., 2021). The mountainous region of South Asia (Mondal et al., 2022), and southeast mountainous region (**Tian Shan Mountains**) of Central Asia are expected to receive the heaviest of rainfall events in the region by 2050 (Gutiérrez et al., 2021b), in line with recent trends over the past few decades (Zou et al., 2021). This pattern will intensify by the end of the century (IPCC, 2021a). Monsoon rainfall will become more episodic and heavier on fewer rainy days, especially in the **Eastern Himalayas** (Hock et al., 2019).

Both South and Central Asia are projected to be affected by more severe (and longer lasting) hydrological droughts, irrespective of the warming level (Ranasinghe et al., 2021), with drier conditions in **western and southern Central Asia** (Hua et al., 2022; Jiang and Zhou, 2023), and **southwest South Asia** (Ullah et al., 2022).

Decadal climate information is important to consider when planning for the 2050s as natural variability such as El Nino, Indian Ocean Dipole, Interdecadal Pacific Oscillation and North Atlantic Oscillation can act to amplify or surpress long-term climate trends. It is also important to translate these medium-term changes in precipitation into impacts on water resources through concerted hydrological modelling of changes in river flows, and surface water availability across Central and South Asia.

Central Asia

Kazakhstan, Turkmenistan, and Uzbekistan will experience the highest temperature rise particularly in summer months (June to September). Daily minimum and maximum temperatures will to increase at roughly the same magnitude as the daily means, with Kazakhstan experiencing the hottest maximum daily temperatures in Central Asia (Hua et al., 2022). There is unlikely to be a significant increase in annual precipitation in **Kazakhstan, Turkmenistan and Uzbekistan**

Southern Central Asian countries of **Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan**, days greater than 40°C will increase by 40-50 more days greater than 40°C, compared to a 1981-2010 baseline (Gutiérrez et al., 2021b; Fan et al., 2022), and decline northward into **Kazakhstan** which will experience 10-20 more days greater than 40°C compared to a 1981-2010 baseline.

Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan burned areas are expected to increase by 2–8% in the 2030s and by 3–13% in the 2080s in compared with the 1971-2000 baseline (Zong et al., 2020; Pan et al., 2023). Rising summer temperatures (June to September) will lead to a greater number of wildfires in Central Asia particularly in the grassland area in **northern Kazakhstan.**

In the mountainous countries of **Tajikistan and Kyrgyzstan,** there is medium confidence of a wetter spring (March to May) potentially impacting river flow**.**

For Central Asian rivers such as the **Amu Darya** and **Syr Darya in west and northwest Central Asia**, higher temperatures will cause more evapotranspiration which will outstrip any increases in rainfall during the summer season by 2030, especially in **west and northwest Central Asia** ultimately leading to decreased river runoff by the end of the century (Gan et al., 2015; Hua et al., 2022). This drying trend could be significantly exacerbated by changes in the Interdecadal Pacific Oscillation (IPO). A negative phase of the IPO (occurred since the 1990s) has led to a decrease in precipitation and doubled the rate of soil moisture drying in the early growing season (Jiang and Zhou, 2023).

Western and southern Central Asia will experince dryer conditions leading to more severe (and longer lasting) hydrological droughts, irrespecitve of warming level (Hua et al., 2022; Jiang and Zhou, 2023).

Northern India, and higher altitude areas of Tajikistan and Kyrgyzstan will experience more landslides as a result of more extreme rainfall and permafrost melting (Cho et al., 2016; IPCC, 2021a).

Continued shrinking of inland seas such as the Caspian and Aral Seas, will exacerbate drought conditions in water-stressed Central Asia. Water levels in the Caspian Sea have fallen in the last few decades (Yao et al., 2023) and will continue to fall by between 9-18m in a medium to high emissions scenario by the end of the century (Prange et al., 2020). The shrinkage of the Aral Sea since the 1960s mainly driven by irrigation and/or damming, has and will continue to shrink, lead to aggravation of drought in **Kazakhstan and Uzbekistan** (Narbayep and Pavlova, 2022). Short-term increases in river flow (projected to continue up until 2050) due to snowmelt and glacier melting has partially slowed the shrinkage of the Aral Sea since 2005 which suggests that after peak flow is reached around the 2050s, a reduction in river flow could further exacerbate the shrinkage of the Aral Sea in the latter part of the century (Wang et al., 2020).

South Asia

In the South Asia region, anthropogenic released atmospheric ‘climate-cooling’ aerosols which are co-emitted with longer-lived greenhouse gases (CO_2, CH_4, N_2O) counter some of the greenhouse gas warming (Nair et al., 2023). These shorter-lived atmospheric aerosols will decline as carbon mitigation measures are implemented which could create a temporary enhanced warming effect in South Asia until greenhouse gas emissions are reduced sufficiently (Nair et al., 2023). For instance, there was a 18% reduction in atmospheric aerosols and 1% reduction in CO_2 across South Asia in 2020 due to the COVID lockdown which led to an increase in radiative forcing of 1.4 W m^{-2} over springtime (Nair et al. 2023).

In Northern Central Asia, and over India, Pakistan, Nepal, Bhutan, Bangladesh and Sri Lanka, winter temperatures will warm more than summer temperatures. In higher altitude regions of Central and South Asia warmer winter temperatures will cause earlier spring melt.

Northwest India and adjacent areas of Pakistan will experience 50-60 more days greater than 40°C by 2050 under SSP5-8.5, and **southern India and Sri Lanka** will experience a comparable number of days greater than 35°C compared to a 1981-2010 baseline (Ranasinghe et al., 2021).

Eastern Pakistan, northern and eastern India, Sri Lanka and Bangladesh will be particularly affected by moist heatwaves during the pre-monsoon (April to May) and monsoon (June to September) seasons (Im et al., 2017).

Eastern Pakistan and northwest India are currently particular hotspots for wildfire, followed by the **rest of India, Sri Lanka, and southern Nepal** (Vadrevu et al., 2019). The length and frequency of fire seasons are expected to increase particularly in India at 2°C of warming (which global mean temperatures will reach by 2040 if remaining on SSP5-8.5) (Ranasinghe et al., 2021; Sun et al., 2019). Greater surface windspeeds currently projected for **Pakistan and India** (low confidence for most of India), could also lead to greater wildfire spread (Cruz and Alexander, 2019).

South Asia will become significantly wetter (ranging from 0 to 400mm/season) in the monsoon season (June to September), with a reduction in winter precipitation in some regions. Across the South Asia subcontinent, a wetting trend is expected with annual precipitation expected to increase by 10–30% under SSP5-8.5 by the 2050s (Almazroui et al., 2020), partly due to mitigation of atmospheric aerosols which could intensify monsoon rainfall during June to September (Fang et al., 2023). Model consensus regarding increased monsoon rainfall improves towards the end of the century (Almazroui et al. 2020) likely due to the progressive heating of the Indian Ocean which will drive enhanced atmospheric moisture content and thus rainfall (Katzenberger et al. 2021).

South Asia monsoon will become shorter and more intense (Ashfaq et al. 2020), with increasing frequency and intensity of extreme rainfall events (Saha et al. 2023).

Southern Pakistan and adjacent areas of India will experiencing the greatest percentage increase in monsoon precipitation, whilst **Himalayas, Bangladesh, Bhutan and Sri Lanka and west coast of India** will see the greatest amounts of precipitation (~0-400mm/season) (Katzenberger et al. 2021).

Overall, the Hindu Kush-Karakoram region is likely to become signifciationtly wetter (up to 200mm/season) in the monsoon season but there is a large uncertainty in magnitude and direction of precipitation changes as model projections tend to overestimate precipitation in the northwest Himalayas and underestimate in the southeast Himalayas and Tibetan Plateau (Sanjay et al., 2017).

In **northern India, southern Nepal, Bhutan, and the eastern Himalayas**, winter precipitation will decrease compared to increases in the **Western Himalayas** (Almazroui et al., 2020).

In the Himalayan-Karakorum region, there is a high confidence of incereased glacial outburst flooding due to more new lakes forming at the base of steep mountainous areas as a result of more glacial meltwater combined with melting permafrost (Ranasinghe et al., 2021).

Soutwest South Asia will experience drier conditions leading to more severe and longer lasting hydrological droughts irrespecitve of warming scenario (Ullah et al., 2022).

In the Maldives, annual mean temperatures are expected to rise more slowly than the global average, with generally wetter conditions over the North Indian Ocean.

Sea-level rise will continue in the oceans around Asia and lead to greater damage from tropical cyclones, storm surges and coastal erosion along coastlines. In the Bay of Bengal, Arabian Sea and Persian Gulf, relative sea-level rise will increase by 0.2-0.3m by the 2050s under SSP5-8.5 and by up to 0.7m by the 2080s compared to a 1995-2014 baseline meaning the region's rate of sea-level rise is consistent with projected global sea-level rise (Ranasinghe et al., 2021). The low-lying **Ganges-Brahmaputra-Meghna delta in Bangladesh** is home to millions of people who are exposed to faster-than-global average sea-level rise accelerated by land subsidence which could double projected sea level rise to reach 85-140cm across the delta by 2100 (Becker et al., 2020). Climate change will drive more intense tropical cyclones in the post-monsoon season (October-November) particualrly in the Northern Bay of Bengal affecting **India, Bangladesh and Myanmar** (Fahad et al. 2023) which will cause higher storm surge heights on the **East Indian coast** (PLN and Kolukula, 2023), and extreme waves (Bhavithra and Sannasiraj 2022). For instance, under SSP5-8.5 by 2100, coastal populations of India will be over 200% more exposed to extreme storm surge flooding (>3 m) caused by super cyclonic storms equivalent to Cyclone Amphan. In **Bangladesh**, coastal populations will be >80% exposed. This increased exposure in both **India and Bangladesh** is driven by a 20% or 30% increase in storm surge height especially along the eastern Indian coast where river deltas allow storm surge water further inland. Exposure to storm surge flooding is significantly reduced in both India (>50% change in flood exposure) and Bangladesh (0% change in flood exposure) under a lower emissions scenario (SSP1-2.6), consistent with the 2°C Paris Agreement Goal (Mitchell et al. 2022). Sea-level rise and storm surges will continue coastal erosion with sandy shorelines in all areas at risk of retreating by more than 100m by 2100 under RCP8.5 and up to 350m in South Asia (Ranasinghe et al., 2021).

Sea surface temperatures will continue to warm in the oceans around South Asia leading to a greater number and more intense marine heatwaves. Ocean acidification is expected to worsen as the oceans absorb more anthropogenic carbon dioxide . By the 2050s, sea surface temperatures are projected to increase by 1.2-1.4°C under SSP5-8.5, warming to 3.0-3.3°C more than the 1971-2014 baseline by the 2100s in the Bay of Bengal, Arabian Sea and Gulf of Persia (Ranasinghe et al., 2021). The Persian Gulf (which is shallower and will warm more quickly) and Caspian Sea show greater levels of warming by the 2050s under SSP5-8.5 at 1.7 to 1.9°C and 2.3 to 2.4°C and by the 2100s at 3.8 to 4.2°C and 5.1 to 5.2°C, relative to 1995-2014 baseline. Ocean acidification, which can damage carbonate organisms, is very likely to continue with increasing levels of atmospheric carbon dioxide being absorbed by the oceans. Globally, ocean pH is projected to decline (become more acidic) by around 0.17 and 0.37 pH units by the 2100s (relative to the 1995-2014 baseline) for both scenarios SSP2-4.5 and SSP5-8.5 respectively. Higher sea surface temperatures and dissolved inorganic carbon (absorbed antrhopogenic CO_2) are associated with lower pHs in the Indian Ocean basin suggesting ocean acidification could be amplified by warming in the future (Madkaiker et al., 2023).

Warmer sea surface temperatures will lead to a greater number of more intense marine heatwaves during the pre-monsoon and monsoon seasons throughout Asian Oceans with year-to-year variability regulated or amplified by shifts in ENSO and the Indian Ocean

Dipole (Kumar et al., 2023). Anomalously high sea surface temperatures such as experienced in marine heatwaves may also act to intensify tropical cyclones, as occurred for Tropical Cyclone Amphan in the Bay of Bengal in 2020 (Rathore et al., 2022).

Tropical cyclones are unlikely to increase in frequency, but likely to become more intense (higher wind speeds, heavier rains) in the Northern Bay of Bengal during the post-monsoon season affecting Bangladesh, India and Myanmar (Fahad et al. 2023). Knutson et al. (2020) projects an average global increase in tropical cyclone rain rates of 12% and maximum surface wind speeds of 5% with 2°C warming. Current trends in tropical cyclones in the Bay of Bengal suggest pre-monsoon season (March to May) cyclones have increased in intensity more than post-monsoon season (October to November), although the Arabian Sea has seen more intense cyclones in both seasons (Wang et al., 2022).

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Image locations:
Top: Kabul, Afghanistan
Middle: Mumbai, India
Bottom: Bukhara, Uzbekistan

3 Climate risk impacts and interpretation for the Central and South Asia region

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3.1 Agriculture and food security

Image location: Turkmenistan

Summary of risks relevant to agriculture and food security

- The yields of most crops are projected to decline in South Asia because of rising temperatures, heat extremes, more frequent droughts and floods, and soil salinisation in coastal deltas. Impacts on crop yields in Central Asia will likely be more mixed, with crop production in cooler northern areas potentially benefiting from warming trends and/or higher rainfall.
- Crop yields across the rice-wheat cropping system of South Asia's Indo-Gangetic Plain are projected to decline by 5-15% with no adaptation by the 2050s due to the combination of heat, water stress, droughts, and flooding. The Indo-Gangetic Plain is home to around 400 million and provides much of South Asia's wheat and rice for domestic consumption and export. Rice farming and aquaculture in South Asia's Ganges-Brahmaputra-Meghna delta will face growing risks from sea level rise, soil and water salinisation, and more damaging storms and sea surges.
- Land degradation in Central Asia's irrigated lowlands, border areas, and arid rangelands is already costing the region around 3% of GDP/year and could be exacerbated by rising temperatures and greater aridity. Warming and wetting trends in cooler areas could benefit land-soil productivity and increase wheat and maize yields in Kyrgyzstan.
- In both South and Central Asia, the adoption of climate-smart agricultural practices could boost crop yields and mitigate some of the negative impacts of climate change, at least to the 2050s. The importance of irrigation in reducing crop heat/water stress will grow in importance in both regions, but water availability for irrigation is threatened by climate-driven changes to river flows and growing competition for water from other uses and users.
- Inland aquaculture (mainly South Asia) and livestock (Central and South Asia) play an increasingly important role in meeting food and income needs but are threatened by rising temperatures and more frequent droughts and floods. India and Bangladesh are by far the biggest aquaculture producers in South Asia and face the biggest losses. Livestock production in Central Asia accounts for 26-54% of agricultural GDP but livestock and pasture productivity may be reduced in areas with high temperatures and heat stress.
- The health and productivity of agricultural workers will be negatively affected by rising temperatures and heat extremes. Reductions in agricultural labour capacity will likely be highest in Bangladesh, India, and Pakistan – areas of peak heat-humidity stress – with impacts falling increasingly on women and the elderly.
- Food insecurity in both regions could potentially increase as the effects of greater climate variability and extremes translate into more unstable production and consumer prices. Poorer consumers, including growing numbers of urban poor, subsistence-orientated farmers, and landless tenant farmers, will likely be worst affected. These risks could hamper progress towards SDG2: *End hunger, achieve food security and improved nutrition and promote sustainable agriculture.*
- More research is needed on mixed farming systems (including livestock, fish), agricultural supply chains, and shifts in food access and affordability for different groups of people. Most sectoral studies have to date focussed narrowly on crop yields and production, mainly for key staples.

3.1.1 Context

Agricultural production, including forestry, fishing and livestock, provides a vital source of employment, income and food security across Central and South Asia, even though its contribution to GDP is diminishing as economies diversify and become more urbanised. Contributions to GDP range from roughly 5% in upper-middle income Maldives to over 30% in low-income Afghanistan, yet over 50% of both regions' population still live in rural areas and make a living linked directly or indirectly to the agricultural economy (World Bank, 2022d; see TRD Section F). As Asian economies become richer and more urbanised, food demand is increasing and shifting in composition, including towards animal products that are much more resource intensive (ADB, 2021).

Farming across the region is based mainly on rice and/or wheat production in multiple cropping systems, with arable land intensively used for subsistence and cash crops, often with livestock[19] integrated on the farm. Across Asia as a whole, rice-wheat cultivation covers over 13 million hectares of land with 57% in South Asia – mostly (~85%) in the Indo-Gangetic Plain (IGP) crossing northern and eastern India, most of eastern-Pakistan, most of Bangladesh, and the southern plains of Nepal (Dhanda et al., 2022).[20] Freshwater and marine fisheries also play a vital role in agricultural production and nutrition, particularly in South Asia. The rapid growth of aquaculture (fish and shrimp) has served to lower prices in domestic markets, benefiting poorer consumers (ADB, 2021).

Irrigated agriculture is well developed in high potential areas of both Central and South Asia, providing a buffer against rainfall variability but also withdrawing more water than any other sector. With the exception of Maldives, irrigation withdrawals account for over 60% of national water budgets, reaching 95% or more in Turkmenistan, Afghanistan and Nepal (data for 2020 from FAO, 2023c; see TRD Section F). Nonetheless, rainfed agriculture still accounts for most of the cultivated area in Kazakhstan, and in all South Asian countries except Pakistan and Bangladesh. For South Asia, therefore, most agricultural livelihoods are tied to seasonal rains, with smallholder systems based on the intensive farming of small plots of land. Over 85% of Indian farm households cultivate less than two hectares of land (Barooah et al., 2023). In Bangladesh, average land holdings are even smaller at less than 0.5 hectares (Devendra and Thomas, 2002).

Poorer farmers, both land holders or landless tenants, cultivate extremely small areas and rely on off-farm income in wider rural and (increasingly) urban economies[21] to make a living (ADB, 2021). Farming is also becoming increasingly feminised as men (mainly) seek off-farm employment, leaving women more exposed to climate-related risks, amplified by their lower

[19] For example, cattle used for draft power, milk and manure, plus chickens, goats, sheep, pigs and ducks.
[20] From a water perspective (drainage basin, or transboundary aquifer) often referred to as the Indo-Gangetic Basin – IGB.
[21] Remittance incomes – both national and international – also play a key role in diversifying income sources and reducing risk. Just before the COVID-19 pandemic began, in 2019, over 40 million people from South Asia were living outside their country of birth. In countries such as Nepal and Sri Lanka, international diaspora numbers are close to 10% of the home country's population. In parts of Bangladesh, roughly one-third of households out-migrate *temporarily* during the pre-harvest lean season (World Bank, 2022a). In Central Asia, Kyrgyzstan and Tajikistan rely heavily on remittances from international migrants, overwhelmingly men (ADB, 2021).

incomes and more limited access to credit, property, extension services and other resources (Akter, 2021; ADB, 2021; Barooah et al., 2023).

Agricultural productivity has increased markedly over the last 30-40 years, particularly since South Asia's Green Revolution of the late 1960s. Nevertheless, productivity is now stagnating in both Central and South Asia for a combination of reasons, including soil degradation and salinisation, diminishing returns from heavy fertiliser use[22], pesticide/herbicide resistance, water scarcity/salinisation in some areas, and climate change (Aggarwal et al., 2004; ADB, 2021; Dhanda et al., 2022). Across Asia, heavy use of fertilisers, particularly synthetic nitrogen, now accounts for roughly 12% of GHG emissions from agriculture (ADB, 2021; Menegat et al, 2022).[23] Some of these problems have their root causes in policies designed to promote agricultural production in the past by subsidising water, energy and other farm inputs – subsidies that have proved difficult to remove or reorientate despite their environmental impact and fiscal burden on governments (ADB, 2021; Rodella et al., 2023 – see also Section 3.2).

3.1.2 Crop production

The regional evidence base linking climate change with impacts on crop production and food systems in Central and South Asia remains limited (Shaw et al., 2022). Most studies are based on changes in average climate (temperature, rainfall) rather than extremes, focus on key staples (rice, wheat, maize) rather than food or farming *systems*, and rely on a limited number of control trials and modelling projections. These typically hold non-climate variables constant: technologies, varieties and farming practices are 'fixed' while climate variables change over time (Shaw et al., 2022; Bezner Kerr et al., 2022).[24] Projections are complicated by uncertainties around how different crops, in different conditions, may respond to higher levels of atmospheric CO_2 which can potentially boost plant growth and lower water uptake, but also reduce some important nutrients (FAO, 2015; Bezner Kerr et al., 2022).

Available evidence indicates that climate change will have broadly negative impacts on crop production in South Asia and more mixed impacts in Central Asia (ADB, 2021; Shaw et al., 2022; Bezner Kerr et al., 2022). Rising temperatures, heat extremes and changing rainfall patterns all affect crop areas, suitability, productivity, quality and harvest stability, though crop sensitivities vary. Differences in projected crop impacts by 2050 for different climate scenarios are minor, but from then on negative impacts become more pronounced, especially for rainfed crops under higher emission pathways (Bezner Kerr et al., 2022). Figure 7 summarises observed and projected impacts for key crops and crop categories for different regions of Asia. These mirror broader global trends: negative impacts in low latitude and tropical regions, and *potentially* positive effects (see below) at more northern latitudes (FAO,

[22] In Bangladesh, for example, the high use of synthetic fertilisers and pesticides is acidifying soil, worsening water quality and depressing crop yields. Crop residues used for household fuel also remove nutrients and organic matter from soils (World Bank, 2022a).

[23] From nitrogen manufacture, transport and field use (whole supply chain) in agricultural systems. South Asia and East Asia (including China) have the highest nitrogen application rates of any global region. Excluding China from the Asia region, India, Pakistan and Indonesia (in that order) have the highest country-level *emissions* from synthetic nitrogen use in agriculture, falling within the global top 10 emitting countries (Menegat et al., 2022).

[24] In addition, modelling does not generally account for the wider functioning of ecosystems, including the balance between crops, weeds and pests, and effects on pollinators (FAO, 2015; Bezner Kerr et al., 2022).

2015; Bezner Kerr et al., 2022). Individual country profiles on climate change and agriculture, including projections and policy options, are available from CIAT/World Bank.[25]

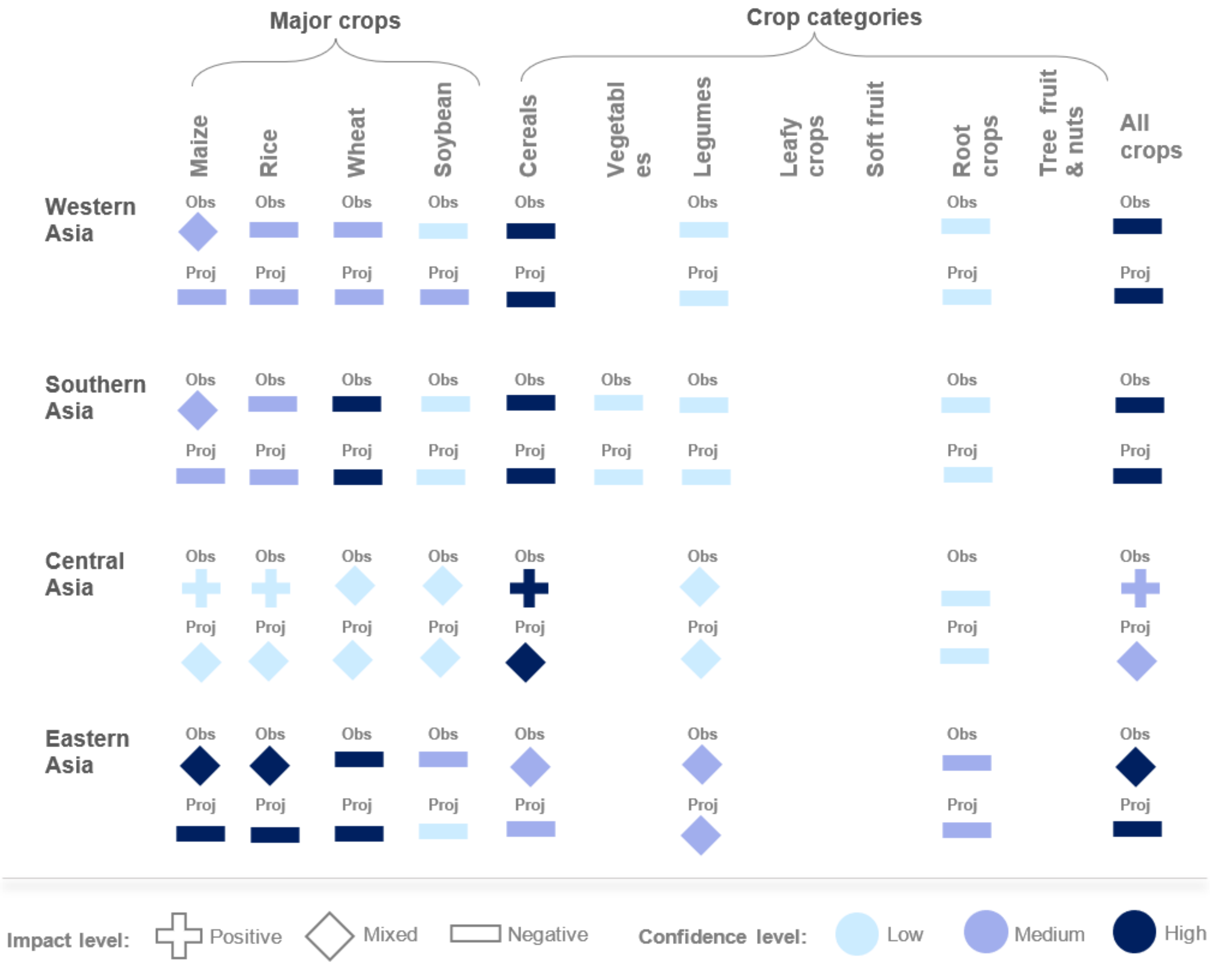


Figure 7: Observed (obs) and projected (proj) impacts of climate change on crop yields in Asia. Source: based on Bezner Kerr et al. (2022). The impact level is identified with the following symbols: + means positive impact level; - means negative impact level; and ◊ means a mixed impact level. The confidence level is identified by the colour: dark blue means high confidence; purple means medium confidence; and pale blue means low confidence. Empty fields indicate areas that are not assessed or where there is insufficient data. Note: Observed impacts (from Bezner Kerr et al., 2022) are based on the synthesis of >150 articles published since AR5, though study timespans often extend prior to 2014. The projected impacts to 2050 are the authors' own based on references listed for this section of the report.

Crop yields across the rice-wheat cropping system of the Indo-Gangetic Plain are projected to decline by 5-15% by the 2050s due to the combination of heat, water stress,

[25] Climate-smart country profiles developed by the International Centre for Tropical Agriculture (CIAT), the World Bank and others available here: https://ccafs.cgiar.org/resources/publications/csa-country-profiles. These focus mainly on South and Southeast Asia. The World Bank's Country Climate and Development Reports and shorter Climate Risk Country Profiles also provide accessible summaries of agricultural risks.

droughts and flooding (FAO, 2015; ADB, 2021, Shaw et al., 2022; Bezner Kerr et al., 2022). Heat stress is a particular risk, with temperatures across South Asia approaching critical levels for wheat and maize grown over winter (*rabi:* October to May*)*, and rice crops grown during the summer monsoon season (*kharif:* June to September). The IGP is home to 400 million people and provides much of South Asia's wheat and rice for domestic consumption and export. It also provides maize for food and fodder, and cash crops such as sugarcane and cotton (Chakraborti et al., 2023).[26] Nonetheless, productivity gains may still be achievable, with studies in South and Central Asia (see below) highlighting improvements in agronomic systems and climate-smart agricultural practices that could boost yields and offset the impacts of climate change (Bhatt et al., 2019). Focus Box 3 summarises risks to Asia's rice economy.

Output from South Asia's delta's that account for major shares of rice production for export and domestic consumption will be negatively affected by rising sea levels, salt water intrusion, more intense tropical cyclones and storm surges. Asia's mega deltas, including the Ganges-Brahmaputra-Meghna (India, Bangladesh), account for significant shares of rice production (over 30% for Bangladesh), with rice typically the only crop that can be grown during the monsoon season (see Focus Box 3).[27] Heat, salt and flood-tolerant cultivars are available, but storm surges and high winds associated with more intense cyclones will increasingly damage crops and agricultural infrastructure for food storage and transport.

Focus Box 3: Climate change and Asia's rice economy.

Asia accounts for over 80% of global rice production and 75% of global consumption. In contrast to other major staples traded on global markets, most production and consumption occurs within the region. The biggest regional producers are India (24%), Bangladesh (7%), and Pakistan (2%) (FAO, 2019 data), while India is a major exporter (Sekhar, 2018). Since the spike in world grain prices in 2007/08, countries have ramped up efforts to attain self-sufficiency and build reserves because of the perceived unreliability of international markets, with Bangladesh, for example, moving from deficit to surplus (Sekhar, 2018).

Although rice production will be less affected by climate change than wheat and maize (in part because it is more irrigated), yields in much of Asia are still projected to decrease compared to no warming scenarios. Heat stress is a key factor in the monsoon belt (see Section 2) where most rice is grown, especially where temperatures are already approaching critical levels during the susceptible stages of plant growth and grain filling (optimum temperature range 25-30°C; maximum 35-38°C for common cultivars). These areas and timings include Pakistan and northern India (October), south India (April, August), eastern India and Bangladesh (March to June) (see Wassman et al., 2009; Sekhar, 2018).

The most vulnerable areas to combined heat and water stress are rainfed, where cropping cycles are tied directly to the timing and intensity of monsoon rains. These include large areas of eastern India and eastern Bangladesh where droughts already cause significant yield losses and food insecurity. In currently irrigated areas, declines in water availability and/or pressure to release water/land to other uses (Yuan et al., 2022; Smolenaars et al., 2023) could potentially increase vulnerability.

[26] The IGP currently produces around 135 million metric tonnes of cereals. For India, production meets over 60% of the country's calorie demand (Chakraborti et al., 2023). Most production occurs in double- or triple-cropped systems.
[27] In the Ganges-Brahmaputra delta, incomes from traditional rice mono-cropping are supplemented (or replaced) by other activities such as riverine/offshore fishing, crab collection, honey collection, aquaculture and remittances (Hajra and Ghosh, 2018; Rahman et al, 2020).

Asia's deltas remain vital rice producing areas for Bangladesh (Ganges-Brahmaputra-Meghna), responsible for 34% of Bangladesh's rice production (Wassmann et al., 2009). While rice is adapted to fluctuating water levels and partially saline conditions, sea-level rise, salt intrusion, more intense tropical cyclones and storm surges (see Sections 2.1 and 3.7) will increase flood risks, salinity stress and crop damage. Dam building and water diversion in the upper reaches of major rivers is also reducing sediment and nutrient flows to deltas, with the former also contributing to *relative* sea-level rise – averaging around 7mm per year in the Ganges-Brahmaputra-Meghna delta over the last three decades, albeit with significant local variation (Rahman et al., 2020). However, some studies suggest that higher rates of sediment transmission to the delta (and accretion within it) associated with more intense monsoon rainfall in upper river catchments may be sufficient to offset climate driven sea level rise this century, provided sediment delivery is not interrupted by further dam building and river diversion (Raff et al, 2023).

Adaptation options are available to mitigate some of the risks highlighted above, and significant productivity gains in rice-based cropping systems in Asia are achievable (Li et al., 2017; Yuan et al., 2021; 2022). Rice cultivars with high heat tolerance are already grown in Iran and Australia, and changes in cropping practices, such as earlier or later planting, can reduce heat stress at critical grain-filling stages of plant growth. Cultivars with much higher tolerance of flood conditions, including temporary submergence, are also available (FAO, 2015; Sekhar, 2018; ADB, 2021), as are more resilient (to heat) alternatives to rice such as millet (Chakraborti et al., 2023).

In the Ganges-Brahmaputra-Meghna delta, many coastal communities have turned to farming shrimp and other types of aquaculture as rice yields have declined. Out-migration (temporary and permanent) is also a growing trend, driven by a combination of environmental 'push' factors (declining agricultural productivity) but mainly economic 'pull' factors (off-farm employment in towns and cities, especially Dhaka and Chattogram) (Hajra and Ghosh, 2018; Rahman et al, 2020). Household surveys indicate that relatively few people, even in the most exposed places, self-report as environmental migrants; the majority of respondents cite economic opportunities in rural non-farm and especially urban economies as their main motivation for moving (Safra de Campos et al, 2020 – see also Focus Box 4, Section 3.4).

Crop production in cooler areas of Central Asia may benefit from warming trends and/or higher rainfall. In more northern (cooler) areas of Central Asia with moderate summer temperatures and/or relatively cold winters, higher temperatures could potentially benefit crop production and extend areas suitable for multiple cropping (Thomas et al, 2021). In Kazakhstan, Central Asia's largest wheat producer and a major global exporter[28], areas suitable for currently cultivated cereal crops and livestock are shifting northward as summers grow longer and hotter and winters grow shorter and warmer (FAO, 2015; Aidan et al., 2020; World Bank, 2022b). In Kyrgyzstan, potentially positive impacts are projected to 2050, with warming trends potentially increasing the area and yield of important crops such wheat, maize, vegetables and potatoes, and reducing import needs for maize and wheat (CIAT/World Bank, 2018; Thomas et al, 2021). In contrast, the yields of important irrigated crops in Uzbekistan (cotton, wheat, apples, tomatoes, potatoes) could decline by 1-13% by 2050, mainly because of heat and water stress, and the yields of spring wheat in Tajikistan are expected to fall because the growing area is already warm during the summer months (Sutton et al., 2013b; Thomas et al, 2021). Cotton, a major contributor to foreign exchange in Uzbekistan, is heat tolerant, and yields could potentially increase if irrigation can be sustained and soil salinisation

[28] Kazakhstan is the ninth largest wheat exporter and fifteenth largest wheat producer globally (Aidan et al., 2020).

stabilised or reversed (Thomas et al, 2021; Bezner Kerr et al., 2022) - see also Section 3.2 on irrigation). For Central Asia as a whole, Thomas et al (2021) conclude that countries (and areas within countries) that either have moderate summers or grow a number of crops in a relatively cold winter (e.g. Kyrgyzstan) will benefit from climate change to the 2050s, while countries that grow many of the same crops in summer will experience losses.[29] Projections for 2050 for Bangladesh, Nepal, Bhutan, Kazakhstan, Kyrgyzstan and Tajikistan highlight mixed effects depending on local agro-ecological conditions, farming systems, crop types, and climate variables (CIAT/World Bank 2017; 2018; CIAT/World Bank/CCAFS and LI-BIRD, 2017; World Bank, 2022a; 2022b; 2022c).

Ongoing land degradation in hot spot areas of Central Asia, exacerbated by higher temperatures, more frequent and intense droughts and water scarcity, may undermine productivity gains from higher winter temperatures. Salinisation of irrigated lands, soil erosion and fertility depletion in rainfed and mountainous areas, the expansion of crop land into marginal (more fragile) areas, and the loss of rangeland vegetation are all driving land degradation in hot spot areas of Central Asia, reducing crop and pasture productivity – see also Section 3.6.2 (Mirzabaev et al., 2016; Quillerou et al., 2016). Salinisation affects roughly 50% of irrigated lands,[30] and is acute in almost all lowland irrigated areas in Turkmenistan, and the provinces of Uzbekistan and Kazakhstan bordering the Aralkum desert – the former Aral Sea (Hamidov et al, 2016; Mirzabaev et al., 2016) - see also Sections 3.2 and 3.7. Across large swathes of northern Kazakhstan, wind and aridity-linked soil depletion is a key issue (Mirzabaev et al., 2016). The annual cost of land degradation in the region due to land use and land cover change between 2001 and 2009 has been estimated at roughly USD6 billion (some 3% of regional GDP), with most caused by rangeland degradation (Mirzabaev et al., 2016; Quillerou et al., 2016). Underlying causes are complex but include the inappropriate expansion and poor management of irrigation and drainage in dryland environments, land tenure insecurity, and the breakdown of common property institutions regulating access to rangelands following the dismantling of collective farms (Mirzabaev et al., 2016). The studies highlighted above did not identify climate change as a causal factor in land degradation, but higher temperatures, increased aridity, and more frequent and intense climate extremes could be expected to exacerbate the problems identified.

The importance of irrigation in sustaining crop production and supporting livelihoods will increase across South and Central Asia as rainfall variability and rising temperatures make rainfed agriculture more precarious. While more water will be needed to buffer the effects of greater rainfall variability and heat, and to meet growing food needs, irrigation is under pressure to release water for other uses/users (Sutton et al., 2013a; Smolenaars et al., 2023). Irrigation coverage in both Central and South Asia is high compared with other global regions, with large tracts of land in the IGP and central Asian lowlands (except Kazakhstan) irrigated with diverted river water and/or groundwater (see Section 3.2). Although efficiency savings from irrigation are often proposed as a remedy for water scarcity and competition, as are crop changes (e.g., rice to millet, wheat to sorghum – see Chakraborti et al., 2023), most water savings come at the expense of return flows reused by others. This

[29] Projections based on CMIP5 and RCP8.5 climate data, and Decision Support System for Agrotechnology Transfer (DSSAT) crop modelling to 2050 (Taylor et al, 2021)
[30] Land salinisation prevalence: 33% of irrigated lands in Kazakhstan, 12% in Kyrgyzstan, 16% in Tajikistan, 96% in Turkmenistan, and 50% in Uzbekistan (Hamidov et al, 2016).

highlights the importance of robust water accounting that distinguishes between withdrawals, consumptive use, and non-consumptive returns (Perry et al., 2023; see also Section 3.2).[31]

The availability of water for irrigation is threatened by changing water flows from the mountains that feed Asia's rivers. Some 48 million farmers in the Indus, Ganges and Brahmaputrah mountains and 129 million farmers in the Indus and Ganges lowlands substantially depend – directly or indirectly – on snow and glacier melt for their livelihoods. The Indus basin (Pakistan, India, Afghanistan) is heavily dependent on meltwater flows in both upstream and downstream areas (see Section 3.2), supporting roughly 15% of annual rice production, 9% of annual wheat production, 28% of annual cotton production, and 17% of annual cotton output (Biemans et al, 2019; Lutz et al, 2022). Contributions in the Ganges (India, Nepal, Bangladesh) and Brahmaputra (India, Bangladesh) basins are less significant (Biemans et al., 2019; Lutz et al., 2022). However, these numbers assume *direct* use of meltwater by farmers from surface water canal deliveries, when the reality is much more complicated: farmers use surface water directly, but often prefer to pump groundwater on demand, with surface water used primarily to replenish groundwater (Shah, 2009; Rodella et al., 2023). This means changing river flows to 2050 and beyond may have less of an impact on farmers, and agriculture, than is often assumed – as long as groundwater storage is replenished from (projected) higher rainfall (see Section 3.2). The situation in Central Asia is more clear-cut: irrigation relying on predictable meltwater flows to major rivers will be threatened towards the end of the century as meltwater flows decline, with no compensating groundwater buffer of a comparable size.

Warming trends across both Central and South Asia will create more favourable conditions for crop pests and diseases and increase the costs of control. However, the regional evidence base on impacts and trends remains limited. Global studies looking at the temperature response of insect pest populations indicate yield losses for rice, maize and wheat of 10-25% per degree of global warming, with the biggest impacts in temperate zones (Deutsch et al., 2018). Negative impacts can also be expected because of the increased vulnerability of plants weakened by heat and water stress (FAO, 2015; Shaw et al., 2022). A key concern for rice producing areas is the spread of the invasive golden apple snail, which eats young and emerging rice plants and causes major production losses. Although the snail is already endemic throughout most of South Asia (in part because of past warming trends), increases in minimum winter temperatures – the key climate variable – may see habitat gains in rice-growing areas of southern Central Asia, such as the Zarafshan Valley in Uzbekistan and Kunduz Province in Afghanistan (Lei et al., 2017). For wheat, epidemics of stem and stripe rusts may also become more common, especially in Central Asia where warmer winters are expected (Bezner Kerr et al, 2022).

[31] Rice irrigation in north-west India is a case in point. Rainfall and irrigation water from canal infrastructure is captured in bunded fields, and much of the excess water recharges the underlying aquifer (a recoverable return flow), which is then pumped from boreholes during the dry season. Excess rainwater is therefore transferred, via 'inefficient' irrigation during the monsoon, to replenish groundwater storage and use during the dry season. More 'efficient' water management would not affect consumption during the monsoon season since this is capped by ET rates and would reduce groundwater recharge. And because flooding is generally a problem during the monsoon, increased infiltration from bunded fields also serves to reduce runoff and flood risk (Perry et al., 2023).

3.1.3 Freshwater fisheries and aquaculture

The sustainability and productivity of capture fisheries and aquaculture are threatened by rising temperatures and climate extremes, with the biggest regional risks projected for South Asia (Allison et al., 2009; Shaw et al., 2022). However, research and evidence remain limited. Impacts occur via rising water temperatures and biochemical changes in the aquatic environment (salinity content, oxygen concentration, acidification), and because of floods, droughts and storms that disrupt or damage aquatic environments and capture/processing infrastructure (FAO, 2015). South Asia is vulnerable because of the growing importance of aquaculture in supporting rural livelihoods – particularly for women – and in improving diets[32]. Moreover, most aquaculture production involves small-scale, artisanal operations that are more vulnerable to impacts, although larger commercial units are increasingly common (Shaw et al., 2022). Capture fisheries from rivers and lakes are also vulnerable, but their relative importance (vs aquaculture) is declining, and impacts are driven overwhelmingly by non-climate drivers – pollution and water diversions/withdrawals.[33]

India and Bangladesh are by far the biggest aquaculture producers and stand to lose most in terms of production, consumption and income due to more intense tropical cyclones, storm surges, and rising water temperatures. In India, inland aquaculture production increased from roughly 0.36 million tonnes in 1980 to 7.56 million tonnes in 2020, a twenty-fold increase. In Bangladesh, the acceleration was even larger – from around 0.08 million tonnes in 1980 to roughly 2.35 million in 2020 (FAO, 2023a). In both countries, production is mainly for domestic consumption rather than export (Suzuki, 2021); in Bangladesh fish account for roughly 60% of all animal protein consumed (see Section 3.7). However, shrimp farmers and fry catchers in Bangladesh are already affected by tropical cyclones, storm surges and extreme rainfall – risks that are projected to increase (see Section 2) (Kais and Islam, 2018 – see Section 2). Higher water temperatures have also lowered the growth rate of shrimps and increased their susceptibility to disease (Islam et al., 2016). While the transition to aquaculture combined with or away from rice farming in the Ganges-Brahmaputra delta is, in part, an adaptive response to climate change (see Focus Box 3), its expansion can also increase longer term risks. Specifically, the conversion of mangrove forests into aquaculture ponds has weakened natural flood defences, reduced biodiversity, and caused environmental pollution (see also Section 3.7). The status of the Caspian and Aral seas and aquaculture production in Central Asia is discussed in Section 3.7.

3.1.4 Pastoral livelihoods and livestock

Livestock productivity may be negatively affected by rising temperatures and heat extremes although regional evidence remains limited (Bezner Kerr et al., 2022; Shaw et al., 2022). Animal husbandry is integral to farming systems across Central and South Asia, particularly for smallholders, providing draft power, milk, hides, manure, meat and eggs, and an additional source of income/consumption alongside cropping (FAO, 2015; ADB, 2021). Demand for livestock products throughout Asia is also increasing, driving large increases in livestock populations in both Central and South Asia (Robinson, 2020; ADB, 2021). In Central Asia, livestock production (mainly for domestic markets, milk and beef) accounts for 26-54%

[32] Asia as a whole now accounts for around 88% of world aquaculture production (ADB, 2021). In Bangladesh, fish provide 60% of animal protein consumption (FAO, 2023a).

[33] All countries in South Asia, except for Sri Lanka, now produce more from aquaculture (farmed fish) than from inland capture (wild fish) (FAO, 2023a).

of agricultural GDP, largely from smaller household producers and family farms, and governments are looking to boost production for growing domestic markets and export.[34] Evidence from within both regions is limited, but wider analyses indicate that rising temperatures and heat extremes will likely increase heat stress in domestic animals and reduce their productivity, with the biggest impacts on larger animals – especially cattle (Thornton et al., 2022). Most domestic livestock have comfort zones in the range 10-30°C, depending on species and breed, in a context where days above 40°C are expected to increase in most southern Central Asian countries as well as northwest India and adjacent areas of Pakistan (see Section 2.2).

Impacts on pasture productivity may be more mixed, with gains in some cooler areas and loses in warmer areas where heat extremes will be a key factor. In Pakistan, rangeland productivity has slumped to 25% – 50% of its potential (World Bank, 2022d), though overstocking linked to the loss and/or fragmentation of rangelands across South Asia may be more significant (at least for mobile pastoralists) as pressure on land for other uses/users increases (Scoones, 2023; Singh and Kerven, 2023). India, Pakistan, Nepal and Bhutan contain many groups making their living mainly by raising livestock extensively on pastures, often migrating seasonally between the high-altitude Himalayas and the plains. However, restrictions on pastoral mobilities and loss of access to critical pastures has increased pressure on more limited areas (Singh and Kerven, 2023).[35] In Central Asia, evidence points to similar declines in pasture productivity linked to land degradation in hot spot areas (Mirzabaev et al., 2016; Quillerou et al., 2016 – see above and Section 3.6), although a study in Uzbekistan highlights potential gains to 2050 (Sutton et al., 2013b), and warming trends could potentially benefit winter fodder production from rangelands and planted fodder crops in cooler areas, helping to address winter fodder deficits experienced since the 1990s (Robinson, 2020).[36]

More frequent and/or intense droughts and floods pose risks to livestock and undermine income and production. In Pakistan, the livestock sector accounts for more than 50% of agricultural GDP – the highest share in the region - and has traditionally buffered the impacts of economic and weather shocks on low-income and land-poor households.[37] Successive droughts and floods, the widespread deterioration of pastures and rangelands, and increased risks of disease, are all undermining productivity (World Bank, 2022d). The 2022 floods that devasted Sindh province killed over 1.2 million livestock (Qamer et al., 2023), although droughts still remain the highest contributor to livestock deaths across Asia as a whole (ADB, 2021).

[34] The contribution of livestock to agricultural GDP is highest in Turkmenistan (54%) and Kyrgyzstan (48%), followed by Kazakhstan (38%), Uzbekistan (37%), and Tajikistan (26%) (Robinson, 2020).
[35] In addition, resource-sharing by livestock and wildlife is often seen as conflicting with conservation efforts (Singh and Kerven, 2023).
[36] Total pasture areas account for 80-95% of all usable agricultural land in five Central Asian republics. Kazakhstan alone has the fifth largest pasture area of any country globally (Robinson, 2020).
[37] Pakistan has the world's fifth-largest beef herd and produces around 6% of the world's milk (World Bank, 2022d). In India, livestock contribute roughly 26% to agricultural GDP and 16% of incomes for smaller farm households (Dash, 2017).

3.1.5 Agricultural workers

The health and productivity of agricultural workers will be reduced by rising temperatures and heat extremes. Estimates from the UN's International Labour Organisation (ILO, 2019) indicate that agriculture will account for 60% of global working hours lost to heat stress by 2030. Regional projections to 2030 suggest that for South Asia as a whole, over 8% of working hours could be lost to heat stress (compared with 6% in 1995), with peaks in Bangladesh (10%), India (9%) and Pakistan (9%) corresponding with areas of peak heat-humidity (ILO, 2019). These are also areas where large numbers of people are engaged in agriculture and other exposed (largely informal) occupations (see Section 3.3.6). More recent analysis for India, specifically, estimates that 160-200 million people could annually face a 5% chance of being exposed to a lethal heat wave as early as 2030, with a 15% increase in working hours lost by the same date assuming a 3ºC rise in temperature. Risks are skewed to areas in the northwest and east coast (Woetzel et al, 2020). This amounts to 2.5%-4.5%, or USD150-250 billion, of GDP (Woetzel et al, 2020).[38] Since agriculture is becoming increasingly feminised, and the agricultural work force is also ageing, impacts will fall disproportionately on women and the elderly (ADB, 2021).[39] ILO (2019) estimates are significantly lower in Central Asia, with 0.24% of agricultural working hours lost to heat stress by 2030 compared with 0.05% in 1995, with the highest shares in southern Central Asia, especially Turkmenistan (0.47% by 2030).

3.1.6 The bigger picture – food security

Impacts on agricultural production will likely lead to greater food insecurity, though pathways are complex and difficult to model. Food security[40] is shaped by access to and uptake of food, not just production and availability (FAO, 2015). Food security may be threatened by a combination of (1) declining output and availability; (2) lower access due to declining household incomes and price variability; (3) changing uptake/utilisation of food within the body affected by (for example) disease; and (4) lower stability as a result of more variable output, prices, and incomes (FAO, 2015). Untangling the climate signal from the many other determinants of food security is difficult, but a growing body of evidence indicates that warming trends, and the increasing frequency and intensity of climate extremes, will translate into higher agricultural prices and much greater output and price volatility. These impacts will, in turn, affect the purchasing power and real income of households, undermining food security and increasing poverty. These risks could hinder progress towards SDG2: *End hunger, achieve food security and improved nutrition and promote sustainable agriculture (United Nations, 2015).*[41] Levels of food insecurity and undernutrition in both regions have fallen significantly over the last two decades, but progress stalled both prior to and during the Covid-

[38] Analysis based on RCP8.5 to 2030 (average 2021-2040), considering average years and no adaptation, compared with average conditions in a 1998-2017 baseline.

[39] In Sri Lanka, for example, the share of agricultural workers aged 50 or over rose from one third in the mid-2000s to almost half a decade later (ADB, 2021).

[40] Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). For further information on the four dimensions of food security flagged here (availability, access, utilisation and stability) see: https://www.worldbank.org/en/topic/agriculture/brief/food-security-update/what-is-food-security

[41] United Nations Sustainable Development Goals in relation to the 2030 Agenda for sustainable development adopted by all United Nation Member states in 2015 see: THE 17 GOALS | Sustainable Development (un.org)

19 pandemic, with rising levels of food insecurity reported for a number of countries over the period 2017-2022 (FAO, UNICEF, WFP and WHO, 2023) – see also TRD Section F.[42]

Productivty gains are still possible, however, even if climate conditions are becoming more unfavourable for agriculture and production stability in many locations. While yields of major food crops are stagnating, both Central and South Asia (as regional blocks) still produce enough rice and wheat for their own consumption and for export, even if individual countries (e.g., Tajikistan) rely heavily on imports. To meet future needs, agricultural productivity will need to increase. Although there is limited scope to increase the harvested area given land constraints (South Asia), there is potential to raise yields through improvements in agronomic systems and practices, particularly in rainfed areas (Li et al., 2017; Yuan et al., 2022). However, periodic price spikes and/or longer-term price increases are still likely given the increasing frequency of climate extremes, and the combined effects of water, heat, and salt stress on agricultural output and production stability in both regions (Cai et al, 2016; Reyer et al, 2017; Jafino et al., 2020). In Pakistan, for example, the prices of key food increased by around 500% in the aftermath of the 2022 floods, and high food prices and persistent food insecurity in 2024 still partly reflects the impact of the 2022 flood on agricultural production (Reliefweb, 2024). Price rises generally are more likely to occur in 'tight' agricultural markets: those where stocks are limited and/or in remote areas where agricultural products are not widely traded.

The impacts of production and price volatility on poverty will depend on how vulnerable households make a living. Net sellers of food *could* benefit, though much depends on the interplay between output, prices and incomes. Net consumers of food will likely benegatively impacted, while those who depend on agricultural wages and profits may experience mixed impacts (Hallegatte et al., 2016). Poorer consumers – the growing numbers of households living in informal urban settlements[43] and subsistence-orientated farmers who struggle to feed themselves from own production – will be worst affected (Hallegatte et al., 2016; Bezner Kerr et al., 2022). Poorer households typically spend 40% or more of their incomes on food (Hallegatte et al, 2017; Wiggins, 2022), with estimates of 80% reported for poorer households in Tajikistan and Uzbekistan (Reyer et al, 2017). In South Asia, malnutrition and health deprivation levels among the urban poor can be as high as among the rural poor (FAO, UNICEF, WFP and WHO, 2023). In part, this is because government social protection programmes have traditionally focussed on rural areas rather than growing numbers of urban poor, highlighted during the Covid-19 pandemic when informal urban workers lost incomes but had limited or no safety nets to fall back on (Bastagli and Lowe, 2021).

Links between climate-induced ecosystem change, food security and poverty have not been systematically assessed but are likely to be important. Poorer rural households are more likely to depend on foraging and wild foods to meet food and income needs, smoothing consumption between season and years. One study in Bhutan, for example, demonstrated how harvesting of edible non-timber forest products, particularly mushrooms and plants, is a key a coping mechanism among poorer farmers in response to climatic shocks and food

[42] Comparing three-year averages, 2017-2019 to 2020-2022, so the trend is affected by Covid-19 restrictions. Food insecurity is rising in Uzbekistan, Kyrgyzstan, Afghanistan, Pakistan, Nepal and Sri Lanka. Not all countries report data – see TRD Section F.
[43] In India, Pakistan and Bangladesh combined, over 275 million people (40% of the urban population) live in informal urban settlements lacking one of more basic services (see Section 3.4 and TRD Section F).

insecurity (Chhay et al., 2023). While the safety net function of ecosystems is well-known, few studies have looked at links between climate-induced ecosystem change and food security (Noack et al., 2015; Hallegatte et al., 2016; Bezner Kerr et al, 2022).

3.2 Water resources and water-dependent services

Image location: Bhutan

Summary of risks relevant to water resources

- The water futures for Central and South Asia will be impacted by warming-induced glacier and snowpack melt in the mountain ranges where the regions' major rivers originate. These changes will have a key bearing on the ability to achieve SDG6: *Availability and sustainable management of water and sanitation for all.*
- River flows will become more variable, and the seasonality of river flows will change, with earlier meltwater peaks across all of Central and South Asia's major river basins. However, timings and impacts will vary across basins depending on rainfall and meltwater contributions to river flows.
- Globally significant irrigation economies for wheat, cotton, and rice will be impacted by declining meltwater flows in the Amu Darya and Syr Darya rivers of Central Asia, and the Indus River basin in South Asia. Rainfall in the Amu Darya and Syr Darya is unlikely to make up the meltwater deficit in Central Asia. In South Asia more intense monsoon rains and use of groundwater storage will help to compensate for meltwater losses, but population growth and rising demand for food will increase pressure on water resources.
- The role of groundwater storage in buffering more variable rainfall and river flow will grow in importance, especially on South Asia's Indo-Gangetic Plain, spanning large parts of Pakistan, India, Nepal, and Bangladesh. Groundwater status and trends in Central Asia remain poorly understood. Climate impacts on groundwater supply are uncertain, but in South Asia groundwater is intensively used already, and existing problems of over-exploitation and water quality deterioration may worsen in hot spot areas.
- Declining water quality poses risks to crop production (salt) and drinking water (salt and pathogens) in both Central and South Asia, with risks exacerbated by more intense rainfall events, flooding, higher temperatures, and droughts.
- Transboundary risk management will grow in importance as countries have to share more variable water supplies or the benefits that flow from them. This will require greater cooperation between upstream and downstream countries over water allocation priorities, volumes, and timings, particularly around upstream hydropower production and downstream irrigation.
- The lack of observational data at high altitudes on hazards linked to landscape instability, and changing cycles of melting and thawing and their impact on downstream river flows is a key source of uncertainty in the mountainous regions of Central and South Asia. More robust projections of future river flow depend on comprehensive monitoring in high-altitude areas, linked to more advanced atmosphere-cryosphere-hydrology models.

3.2.1 Context

The large river basins of Central and South Asia (Figure 8), and the groundwater resources that underlie them, collectively provide water for roughly two billion people. River basins originate in the mountain range of the Hindu Kush-Karakorum Himalaya and, to the west, the Pamir and Tian Shan mountains, often termed the Asian Water Tower (AWT) or Third Pole (Immerzeel et al., 2010; Cui et al., 2023 – see Figure 8). The AWT is the largest store of frozen water after the polar regions, releasing water in the summer months when snow and ice thaw, and smoothing-out variations in rainfall-derived flow that occur lower down in the catchments, albeit with significant inter-basin differences (Lutz et al., 2022; Yao et al., 2022; Cui et al., 2023). Table 1 summarises key basin characteristics.

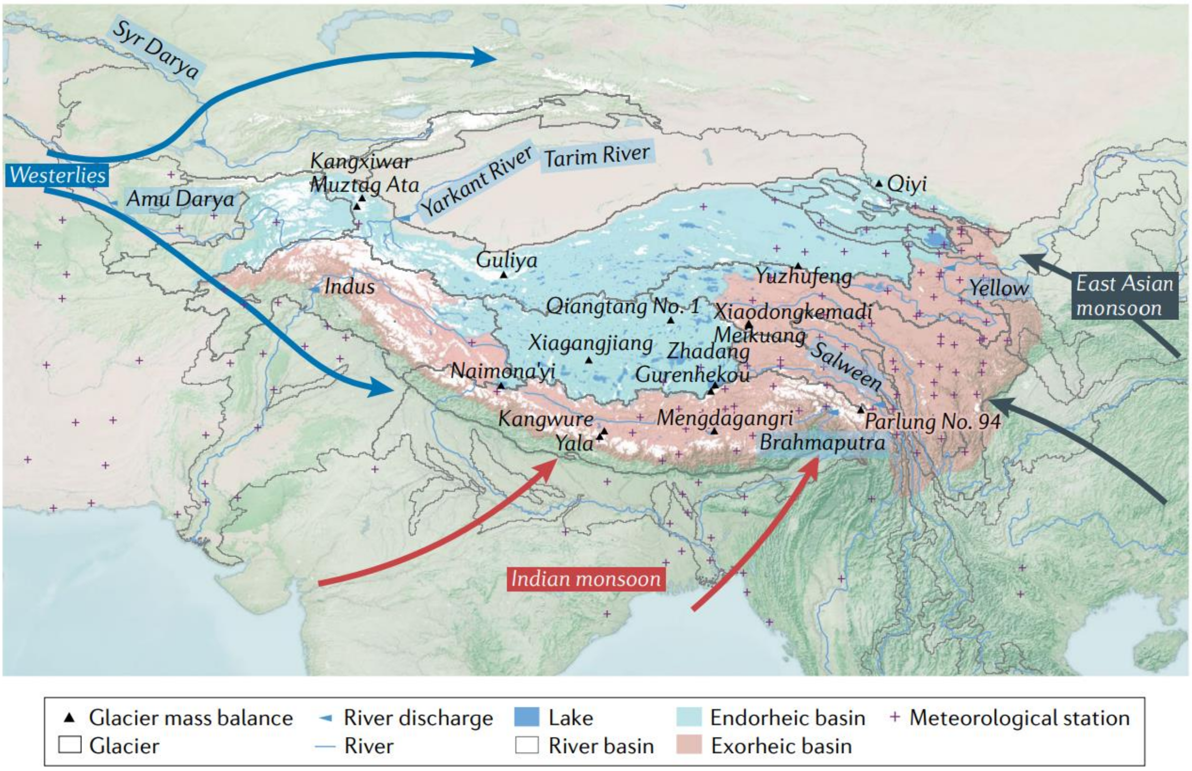


Figure 8: The Asian Water Tower. Source: Yao et al. (2022). Syr Darya and Amu Darya rivers drain internally into the Aral Sea vs. the Indus, Ganges, Brahmaputra which drain externally into the Arabian Sea and Bay of Bengal.

The two largest rivers in Central Asia, the Amu Darya (Uzbekistan, Turkmenistan, Afghanistan, Tajikistan) and Syr Darya (Kyrgyzstan, Uzbekistan, Kazakhstan), originate in the far western part of the AWT and drain into the inland Aral Sea basin (Figure 8 and Table 1). These provide roughly 90% of the region's river water, cover almost 40% of the land area, and are home to roughly 80% of the region's population (EPRS, 2018). In mountainous Kyrgyzstan and Tajikistan, where the rivers begin, hydroelectric dams provide a vital source of regional energy, with more developments planned (see Section 3.5). In downstream areas, the rivers irrigate the vast cotton and wheat fields of Uzbekistan and Turkmenistan via an extensive channel network (Conrad et al., 2020), ultimately draining into the land locked Aral Sea. Diversions since the 1950s have reduced inflows into the Aral Sea (Kazhkstan, Uzbekistan), causing it to dry up almost completely (EPRS, 2018; Conrad et al., 2020) – see also Section 3.7. Reliance on upstream flows from outside the country and intensive irrigation explain why Uzbekistan and Turkmenistan (plus Pakistan in South Asia) are classified as 'critically water stressed' (withdrawals exceed internal availability) with high water dependency ratios (reliance on external flows), even though *per capita* water availability across Central Asia compares favourably with other global regions (FAO, 2023; World Bank/CAWEP, 2020).[44]

The major river basins of South Asia originate in the Hindu Kush-Karakorum Himalaya (northern Pakistan, Himalayan areas of NW India, northern Nepal and Tibetan Plateau), and include the Indus, Ganges and the Brahmaputra (Pakistan, India, Nepal, Bangladesh, Figure 8 and Table 1). These basins (and their connected groundwater resources) provide water to over 1.5 billion people, mostly on the densely populated Indo-Gangetic Plain (IGP), spanning large parts of Pakistan, India, Nepal and Bangladesh. Intensive surface and groundwater development on the IGP has created the largest contiguous tract of irrigated land in the world, producing much of the region's rice and wheat and playing a key role in the region's Green Revolution since the late 1960s (Aggarwal et al., 2004; Shah et al., 2016; Mukherjee et al., 2023 – see Section 3.1). The groundwater resources of the Indo-Gangetic Basin (IGB) are vast in spatial extent and storage volume but are also the most intensively exploited globally (MacDonald et al., 2016; Mukherjee et al., 2023). Pakistan is the only South Asian country classified as 'critically water stressed', although water stress in Sri Lanka ('high stress') and India ('medium stress') is increasing (FAO, 2023).

The Kabul River (Afghanistan and Pakistan) cuts across Central and South Asia (western Karakorum and eastern Hindu Kush), originating in Pakistan and flowing into Afghanistan. The Kabul basin provides nine million people with water for irrigation, hydropower generation, and domestic water supplies across both countries, contributing ~16% of total annual water availability in Pakistan (Baig and Hasson, 2024).

In South Asia, the Indus, Ganges and Brahmaputra rivers originate in the Hindu Kush-Karakorum Himalaya (northern Pakistan, Himalayan areas of NW India, northern Nepal and Tibetan Plateau), with upstream flow predominantly driven by glacial snowmelt in the spring. River flow in downstream countries (southern Pakistan, northeast India, southern Nepal, Bangladesh) is further supplemented by monsoonal rainfall in June to September which forms a primary source of water for the Ganges, Brahmaputra, and eastern Indus rivers (Table 1).

In this section, we look at how the regions' major water resources[45] – both surface and groundwater – may be impacted by climate change in the coming decades and highlight some longer-term impacts (beyond the 2050s) where short-medium term and longer term projections differ The focus is on Central and South Asia's major river basins highlighted in Table 1. We also look at selected management risks as water supplies become more variable and demands increase.

[44] Water stress (monitoring data for SDG 6.4.2): water withdrawals as a percentage of available (renewable) water. Water dependency ratios: percentage of renewable water originating outside the country. See TRD Section F for FAO (2023) data for 2020.
[45] The major rivers focussed on in this report are those included in the Asian Water Tower. The Kabul River is mentioned additionally due to its socio-economic importance for Pakistan and Afghanistan.

Table 1: Characteristics of major river basins in Central and South Asia. GW= Groundwater. Sources: Various, including Armstrong et al. (2019); EPRS (2018); Biemans et al. (2019); Shaw et al. (2022).

	Central Asia		**South Asia**		
River basin	**Syr Darya**	**Amu Darya**	**Indus**	**Ganges**	**Brahmaputra**
Population (M)	>60 (combined)		260	>470	>62
Basin area (km^2)	249,068	451,074	820,659	943,244	514,383
Transboundary countries	Kyrgyzstan, Uzbekistan, Kazakhstan	Tajikistan, Afghanistan, Uzbekistan, Turkmenistan	China, India, Pakistan	India, Bangladesh	China, India, Bangladesh
Headwaters	Tian Shan mountains	Pamir mountains	Tibetan plateau, Himalayas, Hindu Kush	Himalayas	Tibetan Plateau, Himalayas
Upstream sources (>2000m)	Mainly glacier & snowmelt	Mainly glacier & snowmelt	Mainly glacier and snowmelt	Mainly rainfall, residual glacier & snowmelt	Mainly glacier & snowmelt
Downstream water sources (<2000m)	Mainly upstream meltwater	Mainly upstream meltwater	Mainly upstream meltwater	Mainly downstream rainfall	Mainly downstream rainfall
Changes in basin water supply (2050s)	Meltwater peaks; rainfall uncertain (major change unlikely).	Meltwater peaks; rainfall uncertain (major change unlikely).	Meltwater peaks, summer monsoon rainfall increases.	Meltwater peaks, summer monsoon rainfall increases.	Meltwater peaks, summer monsoon rainfall increases.
Upstream and downstream impacts (2050s)	Upstream flows increase, downstream flows more uncertain.	Upstream flows increase, downstream flows more uncertain.	Upstream and downstream flows increase. Groundwater uncertain.	Upstream and downstream flows increase. Groundwater uncertain.	Upstream and downstream flows increase. Groundwater uncertain.

	Groundwater uncertain.	Groundwater uncertain.			
Basin water availability to end century – more speculative	Meltwater declines, rainfall uncertain. Flows more variable, may diminish as meltwater contribution declines and evapotranspiration increases. Groundwater uncertain	Meltwater declines, rainfall uncertain. Flows more variable, may diminish as meltwater declines and evapotranspiration increases. Groundwater uncertain	Meltwater declines, rainfall increases. Flows more variable. Groundwater uncertain.	Meltwater declines, rainfall increases. Flows more variable, may increase. Groundwater uncertain.	Meltwater declines, rainfall increases. Flows more variable, may increase. Groundwater uncertain.

In this section, we look at how the regions' major water resources[46], both surface and groundwater, may be impacted by climate change in the coming decades and highlight some longer-term impacts (beyond the 2050s) where shorter and longer-term impacts may diverge. The focus is on Central and South Asia's major river basins highlighted in Table 1. We also look at selected management risks as water supplies become more variable and demands increase.

3.2.2 Water Resources and water-dependent services

Climate change is affecting the release of water from the Asian Water Tower, in turn affecting the quantity and timing of downstream flows. Over a long history, the AWT has maintained an equilibrium of water resources between liquid and solid states, and among different reservoirs. This equilibrium has never been entirely constant, but is now changing abruptly as temperatures rise, glaciers and snowpack melt, permafrost thaws and much warmer winter and spring-time temperatures are leading to more rainfall replacing snowfall in winter (Yao et al., 2022; MacAllister et al., 2022).

Glaciers and snowpack will continue to melt across the Asian Water Tower by the 2050s with an approximate meltwater peak to river flow, although patterns vary between basins (Yao et al., 2022; Cui et al., 2023). In some parts of the north-west (eastern Pamir, western Kunlun) glaciers have remained stable or have expanded, but this trend will be

[46] The major rivers focussed on in this report are those included in the Asian Water Tower. The Kabul River is mentioned additionally due to its socio-economic importance for Pakistan and Afghanistan.

reversed by increasing summer temperatures (Yao et al., 2022). In most other areas substantial losses have occurred over the last four decades (Yao et al., 2022). Looking ahead, rising temperatures will accelerate melting in all areas, with more than one-third of ice mass projected to be lost by the 2100s, in both high and low emissions scenarios (Yao et al., 2022). Glacier loss will be uneven with greater loss in the Ganges and Brahmaputra basins, compared to Central Asian river basins (Yao et al., 2022). Changes in snowpack accumulation, extent and melt timing will also affect river flows, especially as snowmelt provides the bulk of meltwater runoff in all basins. The snowmelt peak in spring-early summer occurs before summer glacier melt (Armstrong et al., 2019; Hock et al., 2019; Khanal et al., 2021) by up to several weeks (Biemans et al., 2019; IPCC, 2021 – see below). Across all basins, the seasonality of flows will change, the buffering role of the cryosphere will diminish, and flows will become more variable and rainfall dependent (Shaw et al., 2022; Cui et al., 2023).

Most studies suggest water supply to major rivers will increase to ~2050 and potentially beyond for South Asian basins, although river flow projections are uncertain because flows are affected by many different variables – within and between basins (Yao et al., 2022; Cui et al., 2023). Those variables include changes in: (a) rain/snowfall in different parts of the basin; (b) glacier mass and snow melt; (c) permafrost thawing; and (d) water storage – lakes and groundwater - as well as (e) changes in other hydrological drivers such as increases in warming-induced evapotranspiration (ET), land use -runoff conditions and dam building. A key source of uncertainty is the lack of observational data at high altitudes which makes hydrological modelling more difficult (Barandun, 2020; Yao et al., 2022; Drenkhan et al., 2023). More robust projections of future river flows depend on comprehensive monitoring in high altitude areas, linked to more advanced, coupled, atmosphere-cryosphere-hydrology models (Yao et al., 2022 – see Section 2). Despite these uncertainties, however, there is now broad consensus that *meltwater* contributions to river flows will peak around 2050 (Yao et al, 2022; Shaw et al, 2022; Cui et al, 2023). Thereafter, flow volumes and flow seasonality will depend on whether and how changing rainfall-runoff conditions compensate for declining meltwater flows. Those conditions vary between basins, summarised below.

The Amu Darya and Syr Darya basins (Kyrgyzstan, Uzbekistan, Kazakhstan, Tajikistan, Afghanistan, Turkmenistan) are highly vulnerable once meltwater flows decline because rainfall will remain low, threatening the viability of large scale, intensive irrigation for wheat and cotton. For north-western basins flowing into the Aral Sea, upstream and downstream hydrology is highly dependent on mountain meltwater: spring and early summer snowmelt followed by glacier melt bolstering flows in late summer (Armstrong et al., 2019; Barandun et al., 2020). Precipitation at higher elevations (in Tajikistan, Kyrgyzstan) may increase, but downstream areas of Kazakhstan, Turkmenistan and Uzbekistan are not projected to become wetter. In these downstream areas especially, higher rates of evapotranspiration from rising summer temperatures are expected to diminish rainfall-runoff contributions to river flow by the 2030s, leaving rivers even more dependent on (rising) meltwater to the 2050s (Armstrong et al., 2019; Gan et al., 2015; Hua et al., 2022; Yao et al., 2022). From then on, the river flow buffer provided by meltwater will diminish in both upstream/headwater and downstream areas as glaciers and snowpack recede, especially during low snow or drought years. Downstream irrigation economies may then be threatened (see management risks below and Section 3.1), and flows to the Aral Sea may decline further

(Armstrong et al., 2019; Yao et al., 2022)[47]. With the exception of Kazakhstan, all Central Asian countries rely on intensive irrigation for crop production, mainly for wheat and cotton which may be threatened by declining meltwater flows (EPRS, 2018; World Bank/CAWEP, 2020). Upstream areas of Tajikistan, Kyrgyzstan and Nepal, though less poplulated, also face risks from declining meltwater flows, including risks to hydropower infrastructure and power generation from more variable river flows and melting-induced landscape instability (see Section 3.5).

The Indus basin (India, Pakistan) is also vulnerable once meltwater flows decline, with risks to major wheat, cotton and rice-based irrigation economies. In common with The Amu Darya and Syr Darya in Central Asia, the Indus also receives significant amounts of meltwater from its large, high mountain catchment, and meltwater *also* contributes significantly to downstream flows in Pakistan (Biemans et al., 2019; see Figure 9 below).[48] Hence declines in predictable meltwater flows from roughly 2050 onwards will leave the basin increasingly dependent on more episodic and intense monsoon rainfall and groundwater storage (see 3.2.3 below). With roughly 60% of pre-monsoon irrigation (canal) flows in the basin currently originating from snow and glacier melt, longer-term impacts on meltwater- dependent wheat, rice, sugarcane and cotton production (after the c2050s meltwater peak – see above) could be significant, with changes in cropping decisions and/or more intensive groundwater use needed to support production – see also Section 3.1.2 (Biemans et al., 2019; Lutz et al, 2022). The eastern tributaries of the Indus are already more rainfall-dependent.

The wetter Ganges and Brahmaputra (India, Bangladesh, China) basins are more rainfall-dependent, and less vulnerable to declining meltwater flows than the Indus. The wetter and more humid Ganges and Brahmaputra basins are already more dependent on monsoon rainfall for intensive downstream irrigation, with meltwater augmenting monsoon inputs (Armstrong et al., 2019; Biemans et al., 2019 – see Figure 9). Here, the eventual loss of the meltwater buffer towards the end of the century may have less of an impact on food production and other uses as monsoon rainfall increases, although dry season (pre-monsoon) cropping on the Ganges floodplain, currently dependent on meltwater, is threatened (Armstrong et al., 2019; Biemans et al., 2019).

[47] The Aral Sea's volume has shrunk by 91% since the 1960s due to irrigation and damming (Ma et al., 2024, Section 2) leading to a sharp deterioration in living conditions, including loss of water-based livelihoods, prevalence of health conditions linked to dust and environmental degradation (Anchita et al., 2021).
[48] Close to its outlet in the Arabian Sea, Indus discharge still consists of 60-70% of meltwater originating from mountain snow and glacier melt (Biemans et al, 2019).

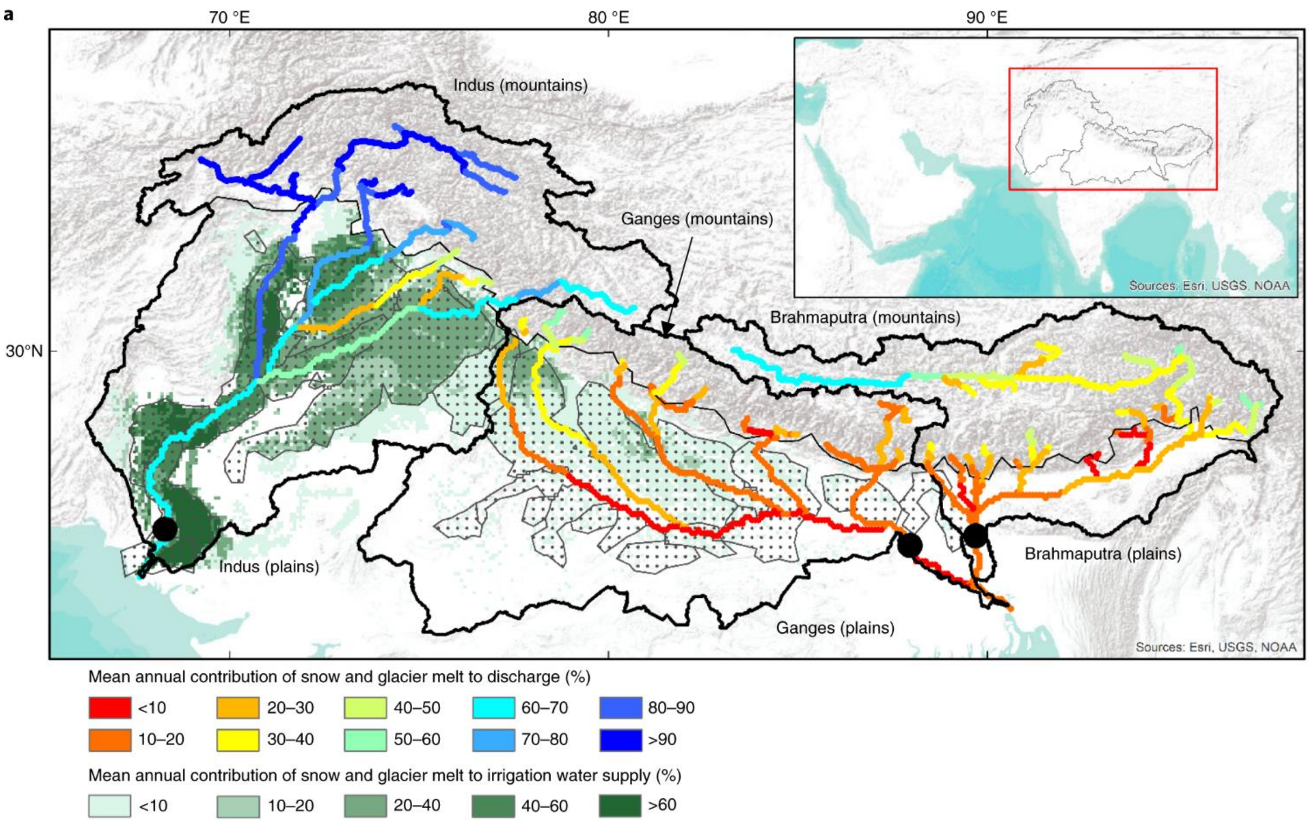


Figure 9: The contribution of snow and glacier melt to downstream discharge and irrigation supply, 1981-2010. Source: Biemans et al. (2019). Note: Central Asian basins not shown, but similar to Indus in terms of high upstream and downstream dependence on meltwater. Contribution to irrigation data do not distinguish between canal delivery and groundwater pumping.

Risks from floods, mudfow and landslide will likely increase in mountain areas as landscape instability increases, although attribution studies on melt/thaw-related risks are lacking. In mountain areas, compound hazards linked to glacier, snowpack and permafrost thawing will likely increase, with around 1 million people living near flood-prone glacial lakes in India and Pakistan (Taylor et al., 2023), although robust trend statistics on slope instability are lacking (Li et al., 2022). Most new hydropower projects in high mountain Asia are also being planned in locations closer to glaciers and glacial lakes, increasing their exposure to hazards (Li et al, 2022). In South Asia, hazards often occur in monsoon season and include landslides, rock-ice avalanches, debris and mud flows, and outburst floods from expanding glacial lakes and landslide-dammed lakes, all with the potential to damage infrastructure and disrupt livelihoods (Barandun et al., 2020; Li et al., 2022 – see also Section 3.4, Figure 11). Recent disasters include the rock-ice avalanche that triggered a flood in India's Chamoli district (Uttarakhand) in February 2021, destroying two hydropower projects and causing over 200 deaths, and the 2013 Kedarnath disaster (also in Uttarakhand) triggered by extreme rainfall and snowmelt, leading to a cascade of events – landslides, lake outburst, flash floods, debris flows – which killed over 6000 people and damaged at least 10 hydropower projects (Barandun et al., 2020; Li et al., 2022). Mountain floods in the Hindu Kush-Karakoram Himalaya and Tien Shan may impact downstream areas, especially in South Asia, where more intense monsoon rains are projected, with the Ganges, Brahmaputra and Indus basins all highlighted as flooding hotspots (Shaw et al., 2022). High mountain areas of Central Asia are also threatened with Tajikistan, for example, already experiencing high levels of landslide, mudflow and flood risks linked to landscape instability and glacier lake outbursts (World Bank/ADB, 2021).

Risks to drinking water quality will likely increase, especially in areas with more limited access to safe water and sanitation – rural and urban. Deteriorating water quality is a problem across Central and South Asia (Bekturganov et al., 2016; Caretta et al., 2022). Contamination of drinking water is a key concern given limited progress in meeting 'safely managed' targets for WASH, especially in South Asia.[49] Populations with limited or no sanitation and safe water – still predominantly rural, low income – are most exposed to health risks because heavy rains can flood, damage or destroy latrines and spread faecal matter into water sources. Where this happens, household demand for re-building may be compromised, undermining the commitment to open defecation free status explicitly targeted in SDG Target 6.2 (United Nations, 2015; Calow et al., 2017; UNICEF and GWP, 2022). In Central Asia, access to safe water and sanitation is higher, but water and sewerage systems are generally old (Soviet era) and poorly maintained, and most rural areas rely on onsite sanitation (World Bank/CAWEP, 2020). Within urban areas, risks to drinking water quality are also likely to increase, especially within informal settlements where onsite sanitation systems (pit latrines, septic tanks) are vulnerable to flooding, spreading sewage over wide areas. In cities such as Dhaka (Bangladesh) and Mumbai (India), most faecal sludge ends up in drains or the wider environment, and outbreaks of water-and vector-borne diseases linked to monsoon floods are common (see Section 3.3.4; 3.4.2).

Strong links are found between flood events and outbreaks of water-related disease linked to poor/disrupted water and sanitation services (Alderman et al., 2012; Philipsborn et al., 2016; Prüss-Ustün et al., 2019). Those diseases include cholera, hepatitis A and E, typhoid, polio and pathogenic E.coli (Alderman et al., 2012). Higher water temperatures can also encourage algal blooms and increase risks from cyanotoxins and natural organic matter in water sources, while higher runoff can increase contamination from fertilisers, animal wastes and particulates. Droughts can increase the concentration of pollutants in water bodies (Howard et al., 2016; Calow et al., 2018 – see Section 3.3).

3.2.3 The groundwater buffer – managing risks through natural storage

The role of groundwater storage in buffering more variable streamflows will grow in importance. Volumes held in storage in the Indo-Gangetic Basin (IGB) aquifer system are equivalent to three times the combined annual flows of the Indus, Ganges and Brahmaputra (MacDonald et al., 2016). The groundwater resources of the transboundary IGB extend over a vast area, and in some places are pumped at depths of over 350m (MacDonald et al., 2016). Over the past five decades, all IGB countries have witnessed a transformation in the way these resources are exploited, with millions of small private boreholes (c15-20 million)

[49] Access to safe drinking water (SDG 6.1) is 50% or less in Afghanistan, Nepal, Pakistan and Sri Lanka. Coverage is lowest in rural areas, but low-income households in growing urban (informal) settlements are increasingly exposed to health risks associated with flooding, poor drainage and inadequate WASH (see Section 3.3 and TRD Section F for data).

running on electricity or diesel (now shifting to solar)[50] pumping its shallower waters for irrigation. For farmers, groundwater resources are often preferred to canal (surface channel) flows because pumps can provide water 'on demand', and because pumping from storage provides a buffer against variability – rainfall and canal delivery (Shah, 2009; Rodella et al., 2023). India's northern Punjab region, for example, has the country's largest irrigation canal network, but 75% of irrigated areas depend on groundwater pumping from boreholes (Shah, 2009). As hydrological variability increases, and particularly once meltwater flows begin to recede later this century (see above), this buffering role will grow in importance to bolster, or potentially replace more erratic, monsoon dominated surface flows (Biermans et al, 2019; Lutx et al, 2022). .

Water withdrawals from groundwater storage will likely increase, but groundwater is already over-exploited in some areas. Falling water levels in the IGB – a symptom of groundwater over-exploitation – have been much discussed in the literature, with satellite data suggesting widespread and ongoing depletion (e.g. Rodell et al., 2009; Gleeson et al., 2012; Rodella et al., 2023). However, evidence based on *in situ* measurements points to hotspots of over-exploitation in some areas (north-west India, Punjab in Pakistan), and stable or rising water levels across the remaining 70% of the system since at least the beginning of the century. This is mainly because canal leakage and irrigation returns have redistributed water from rivers to land and groundwater (MacDonald et al., 2016). Hot spots where water levels have been falling rapidly coincide with areas of particularly intensive abstraction for irrigation and urban use – for example in and around major cities such as Lahore, Dhaka and Delhi where water quality is also affected by industrial pollution and untreated sewage (MacDonald et al., 2016). Beyond the IGB, groundwater stressed areas are concentrated in the arid and semi-arid areas of western and peninsular India, especially in Rajasthan, Maharashtra, Karnataka, Gujarat, Andra Pradesh, and Tamil Nadu, where groundwater is often pumped at great and increasing depths (Shah et al, 2009; Gioirdano, 2009).

Rapid growth in urban demand and the need to grow more food will likely extend over-exploitation hotspots and create new ones, although heavier monsoon rains could replenish storage. How the heterogeneous IGB groundwater system will respond to the stresses of climate change, shifting contributions of meltwater/rainfall, canal leakage and rising demand is uncertain, although heavier monsoon rains could increase recharge and replenish storage (MacDonald et al., 2016; MacAllister et al., 2022). A simple crisis narrative linking climate change with widespread depletion appears unjustified, both in the IGB and groundwater stressed areas of the arid/semi-arid west and south of India. Rather, changes in groundwater levels and water quality will continue to be driven largely by abstraction and contamination (MacDonald et al, 2015; MacDonald et al, 2016).

A broader concern is deteriorating water quality caused by salinisation and pollution, threats that may be exacerbated by rising temperatures and more intense rainfall events. In the IGB aquifer system, roughly 60% of the shallow aquifer (<5m) fails to meet drinking water standards because of salinisation, arsenic contamination and pollution

[50] A major contributor to GHG emissions. In India, data from the early 2000s indicate that groundwater pumping with electricity and diesel contributed 4-6% of the country's carbon emissions. The transition to solar will reduce this but creates other problems, not least the ability to pump water at zero marginal cost and accelerate over-exploitation (Shah et al., 2009; Rodella et al., 2023; Balasubramanya et al., 2024).

(MacDonald et al., 2016). The salinity problem has different causes, but rising temperatures and evaporation may make the problem worse, across the IGB but also in Central Asia where soil salinisation (linked to waterlogging from poor drainage) has been reducing crop yields for decades (Conrad et al., 2020).[51] In coastal areas of Pakistan, India and Bangladesh, the ingress of salty water into coastal aquifers (saline intrusion) is also a growing problem, driven by sea-level rise and groundwater pumping (Shaw et al., 2022 – see also Section 3.1). Arsenic contamination (and to a lesser extent, fluoride) is a well-known health issue in Bangladesh, India and Nepal and has natural origins. There are no clear links to climate variables although arsenic mobility is influenced by patterns of pumping with potentially indirect links to climate and other drivers outlined above (MacDonald et al., 2016).

Central Asia lacks the vast aquifers of the Indo-Gangetic Basin, so groundwater resources are unlikely to compensate for declining meltwater contributions to river flows and downstream irrigation from the 2050s. There is little published information on Central Asia's groundwater resources, but global groundwater assessments indicate that the region does not benefit from the wide and deep alluvial systems that provide water storage in the IGB (Gafurov et al., 2019; Scanlon et al., 2023). As a result, there is little opportunity for offset some of the loss or shift in meltwater and rainfall-runoff highlighted above.

3.2.4 Key management risks and policy choices

Higher monsoon rainfall in South Asia and water stress in downstream areas will continue to increase due to increasing demand particularly from irrigation. This is despite gains that could bemade in headwater supply up to the 2050s. Across Central and South Asia, water for irrigation accounts for most withdrawals (over 60% in all countries, except for the Maldives) and most consumptive use (see also Section 3.1). Irrigation withdrawals are expected to increase because of population growth, higher food demand, and increasing water requirements for crops in response to rising temperatures and evapo-transpiration. In the IGB (India, Pakistan, Nepal, Bangladesh), populations could potentially double (Ganges, Brahmaputra) or triple (Indus) during the twenty-first century (Lutz et al, 2022). Projections for cropland in the IGB suggest a 10-35% expansion to meet food needs over the same period (Biemans et al., 2019; Lutz et al, 2022), but land is already scarce and rapid urbanisation is increasing competition for resources (see also section 3.1). At the same time, agricultural and energy subsidies in both regions have incentivised the over-exploitation of water (Rodella et al., 2023; World Bank, 2023 – Uzbekistan).[52]

In Central Asia, growing and exporting large quantities of *irrigated* wheat and cotton (concentrated in Uzbekistan and Turkmenistan – see Section 3.1) may not be a viable long-term option[53] once meltwater flows decline, and much more limited groundwater storage (and low rainfall) is unlikely to plug the deficit.[54] In both regions, policy makers are confronted with difficult questions about how to support food production, rural livelihoods

[51] In Uzbekistan, roughly half the area equipped for irrigation suffers from soil salinization linked to high water applications, high temperatures and inadequate drainage (World Bank, 2023).
[52] Electricity subsidies that encourage over-pumping, and broader agricultural subsidies that skew cropping decisions. The World Bank estimates that over 60% of groundwater depletion in the Indian state of Punjab has been driven by government rice procurement policies (see Rodella et al., 2023).
[53] Uzbekistan, the most water stressed country in Central Asia, exports around 28 cm/year of 'virtual water' through its exports of wheat and cotton (Porkka et al., 2012; Zhou et al., 2021).
[54] Kazakhstan is the region's largest wheat producer, but most production is from rainfed lands.

and export earnings (from wheat and cotton) and mediate between the claims of competing uses, increasingly urban.

Transboundary risk management will grow in importance as countries have to share water or the benefits that flow from it – within national boundaries and across them. Combined, Central and South Asian rivers cross 12 country borders, and numerous (internal) provincial or state boundaries. Competition over shared waters can be a source of conflict or, more frequently, cooperation (Zeitoun and Warner, 2006; Caretta et al., 2022).[55] Declining meltwater contributions (after peak flow in 2050s) and greater rainfall in winter and spring will lead to lower and more erratic summer flows, especially in the Syr Darya, Amu Darya and upper Indus rivers. This necessitates investments in storage/diversions will increase the need for cooperation and investment in river basin organisations and treaty institutions charged with mediating between upstream and downstream. Similarly, cooperation will be needed to resolve conflicts over water allocation *within* countries: between cities and their rural hinterland, and between neighbouring provinces or states.[56]

Analyses of global transboundary river basins supports the view that there is more potential for conflict in areas already under water stress, but that robust treaties and water allocation mechanisms enable cooperation (Caretta et al., 2022 – *medium confidence*). Historically, conflicts over water have been more frequent in regions of water stress and high interannual flow variability, although other factors – power asymmetries, pre-existing political rivalries, ethnic tensions – often drive or influence 'water' conflicts (Zeitoun and Warner, 2006; Milman et al., 2013; Caretta et al., 2022). One of the earliest river basin agreements, the 1960 Indus Waters Treaty, has proved extremely robust, surviving three wars between India and Pakistan.[57] Similarly, the 1996 Ganges Treaty between India and Bangladesh has also endured. The presence of a water treaty and/or river basin organisation can increase cooperation and mitigate grievances over water allocation, but design principles are important. Joint monitoring and data sharing, allocation mechanisms, enforcement and conflict resolution procedures become key as climate-related flow variability increases. More specifically, flexible water allocation mechanisms able to deal with changing flows, including flood and drought conditions, will increasingly be needed to build institutional resilience and 'absorb' change (De Stefano et al, 2010).

In Central Asia, tensions between upstream and downstream states have grown since the break-up of the Soviet Union and the collapse of regional (joint) water and power coordination (EPRS, 2018; Pena-Ramos et al., 2021). Tensions over water allocation have contributed to political and economic disputes in Central Asia (EPRS, 2018; Pena-Ramos et al., 2021). With investment in upstream hydropower ramping up (e.g. Tajikistan's Roghun dam; the planned Kambarata-1 hydropower plant on the Naryn River in Kyrgyzstan), tensions may increase during dam filling, when downstream flows decline, and during dam operation, when the volume and timing of dam releases becomes significant. For example, upstream Kyrgyzstan and Tajikistan have an interest in releasing more dam water in the winter when

[55] Disputes over water have historically been resolved through peaceful means, though the absence of violent conflict may still lead to inaction, increasing vulnerability to climate hazards (Milman et al., 2013).
[56] India, for example, has a long history of disagreements between states over water allocation, and between cities (e.g. Hyderabad) and surrounding rural areas.
[57] There is currently no water cooperation between Afghanistan and Pakistan. Of the nine rivers that flow across the border into the Indus, none possess a formal agreement or mechanism to manage shared water resources (Shah et al., 2023).

electricity consumption peaks; downstream Uzbekistan and Turkmenistan need more water in spring and summer when irrigation demands peak (EPRS, 2018). Tensions could therefore increase as meltwater flows decline towards the end of the century (see above), though dialogue around the impact of climate change on river flows could potentially provide a ‘neutral’ entry point for more difficult conversations around who gets what and when (De Stefano et al, 2010). The International Fund for Saving the Aral Sea (IFAS) has been highlighted as a platform for water, energy, and environmental cooperation in Central Asia (CAWEP, 2023).

More recently, Afghanistan’s construction of the Qosh Tepa canal, diverting water from the Amu Darya (Uzbekistan, Turkmenistan, Afghanistan, Tajikistan) flowing through the north of the country, threatens to destabilise relations with downstream Uzbekistan and Turkmenistan. Uzbekistan, the most water stressed country in Central Asia, is concerned about diversions from a river that supports the country’s intensive irrigation, and will likely experience declining flows towards the end of the century (Ilkhamov, 2023; Ibraimov and Ali, 2023).[58] Looking ahead, major infrastructure projects funded under China’s Belt and Road Initiative (BRI) might change the wider regional water landscape, although BRI investments are typically delivered with ‘no strings’ in terms of risk screening for environmental, social and climate impacts (Davies and Mathews, 2021). The lack of explicit mention of water resources in the BRI could add further pressure to an already water-stressed region.

[58] Due for completion in 2027, the Qosh Tepa canal is intended to irrigate 500,000 hectares of land in Afghanistan's northern provinces of Balkh and Faryab. International agreements brokered during the Soviet era, and bilateral agreements reached subsequently, excluded Afghanistan from basin water allocation decisions (Ilkhamov, 2023).

3.3 Health

Image location: Pushkar, India

Summary of risks relevant to health

- The health outcomes sensitive to climate change in Central and South Asia are heat stress, diarrhoeal and water-borne diseases linked closely with undernutrition, health conditions linked to air pollution and, in South Asia, vector-borne diseases. Risks will be unevenly spread, exacerbating health inequalities linked to wealth, location, gender, and age. These risks could hinder progress towards SDG3, *Ensuring healthy lives and promoting well-being for all ages, and SDG 2, Ending hunger and improving nutrition.*
- Heat-related mortality and morbidity will increase as heatwaves become more frequent and intense. The most vulnerable are the elderly, infants, pregnant women, people living in informal settlements and those engaged in outdoor manual labour. South Asia will experience the greatest cumulative exposure to heatwave events (measured in person days) and heat-related mortality of any global region. In India, 160-200 million people annually could face a 5% chance of being exposed to a lethal heat wave as early as 2030.
- Air pollution from fires, dust storms, and haze will be exacerbated by higher temperatures, heatwaves, and more intense droughts. South Asia is home to 37 of the world's 40 most polluted cities, and air pollution is already the leading risk factor for all-cause mortality across the region (except for Sri Lanka and Maldives), and among the top five risk factors in Central Asia.
- The prevalence of diarrhoeal and water-borne diseases, key contributors to undernutrition, will increase because higher temperatures, more intense rainfall events and floods can accelerate the growth and spread of dangerous pathogens, especially where access to safely managed drinking water and sanitation is lacking. South Asia already has one of the highest levels of undernutrition in the world (31%), with 54 million children under five facing a lifetime of physical and cognitive deficits as a result. Levels of undernutrition are much lower in Central Asia but still reach 10% in Kyrgyzstan and 13% in Tajikistan.
- In South Asia, the seasonality and spatial distribution of vector-borne diseases such as malaria and dengue will be affected by rising temperatures and changes in rainfall, with new areas of exposure in cooler mountains and potential declines in hotter lowlands. Interventions in most countries have thus far limited risks; malaria incidence has declined by over 80% in the last two decades because of effective vector control.
- Many of the causal pathways linking climate variables with health outcomes are difficult to untangle, with different non-climate factors involved. Given the likely significance of heat and nutrition-related impacts in the region, including links between heat and air pollution, further research on these topics is a priority.

3.3.1 Context

Both Central and South Asia have made significant progress on health and broader social development outcomes over the last three decades, notwithstanding recent disruption from the Covid-19 pandemic and (in Afghanistan) conflict and fragility. Between 1990 and 2020, South Asia recorded the fastest decline in under-5 child mortality (72%) and the highest increase in life expectancy (c10 years) of any global region. Over the same period, the share of the population living on less than USD 1.90/day[59] fell from almost 60% to 12% (IHME-GBD, 2019; Sherburne-Benz et al., 2021). Similar though less significant long-term trends for the same metrics are found in Central Asia (WHO, 2022a).

Despite these gains, measures of healthcare access and quality still place Central and South Asia towards the bottom of the global (regional) rankings, albeit with improving scores (Lancet Global Health, 2022). Synthesising data from the latest Global Burden of Diseases, Injuries and Risk Factors Study (GBD), the Healthcare Access and Quality (HAQ) Index for South Asia is the second lowest in the world, after Sub-Saharan Africa. Central Asia ranks fourth, after Sub-Saharan Africa, South Asia and Southeast Asia (Lancet Global Health, 2022).[60] Moreover, regional metrics obscure major disparities in health access and outcomes between and within countries linked to economic status (e.g., poverty), location (rural, urban, informal settlement), age, gender, and ethnicity. For the poorest groups, the safety nets that protect people from shocks remain precariously thin. South Asia has the lowest social protection coverage rate and the highest share of out-of-pocket health financing (52%) of any global region, impoverishing around 60 million people annually as a result (Sherburne-Benz et al., 2021).

In common with other global regions, the leading causes of morbidity and mortality are changing, with non-communicable diseases (NCDs) such as cancer, cardiovascular disease and chronic respiratory illnesses increasing, and communicable, maternal, neonatal, and nutritional diseases decreasing, albeit with significant local variations. Environmental risks related to air pollution, both indoor and outdoor (ambient), are growing in importance, and are now the leading cause of death in all South Asian countries except Sri Lanka and Maldives (IHME-GBD, 2019). Deaths attributable to inadequate WASH remain significant, responsible for over one million deaths (mainly children) in India, Pakistan and Bangladesh *alone* in 2019 (IHME-GBD, 2019).

3.3.2 Assessing risks to health from climate change

Climate change is likely to increase risks to health from heatwaves, flooding, drought, air pollutants, vector and water-borne diseases, and undernutrition, and amplify inequalities in health outcomes between areas and different groups of people (Rocque et al., 2021; Cisse et al., 2022 – *high confidence*). Collectively, these risks could further limit progress towards SDG3: *Ensuring health lives and promoting well-being for all at all ages* (SDG3; United Nations, 2015). However, the evidence base remains limited, with relatively

[59] Defined as extreme poverty by the World Bank. Note: increased to USD 2.15 per day in September 2022.

[60] Note: the HAQ uses 32 causes of preventable (amenable) mortality to measure health care access and quality over time in a comparable way across countries. GBD country groupings differ slightly to those defined for this report – see notes for Table 2.

few empirical studies focussed on low/middle income countries, and complex (often indirect) climate-health pathways to unpick.[61]

One of the most widely quoted[62] empirical assessments of climate-related health impacts looks at cause-specific mortality to 2030 and 2050 based on a mid-range (A1b) emissions/development scenario – roughly equivalent to IPCC's current RCP4.5. Because of the long lead times between emissions of GHGs, changes in climate and health outcomes, the choice of scenario makes little difference to results for 2050 (WHO, 2014). An updated study using CMIP5 and CIMP6 data would be beneficial, though unlikely to change the relative significance of different mortality influences.

The study focusses on health outcomes known to be climate-sensitive (WHO, 2014; Jafino et al., 2020), with results for Global Burden of Disease (GBD)[63] defined South and Central Asia (and Southeast Asia for comparison) highlighted in Table 2. Numbers are for annual mortality attributable to climate change: additional deaths caused by climate change in 2050. In contrast to most climate impact modelling (e.g. for crop yields – see Section 3.1), results from the WHO study are generated by comparing two future scenarios (with and without climate change), rather than one future with climate change compared with an historical baseline (after vs before).

Table 2: Additional deaths projected to be caused by climate change under A1b emissions and socio-economic scenarios, 2050. Source: WHO (2014). Note: [a] undernutrition (stunting) estimates for children <5yrs; [b] diarrhoeal disease estimates for children <15yrs; [c] heat estimates for people >65yrs. For more information on assumptions and methods, see original report. Regional groupings as for GBD: Central Asia: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan. South Asia: Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan. GBD groupings differ slightly to target countries reviewed in this report but exhibit similar cause-of-death patterns.

	Malaria	**Dengue**	**Undernutrition [a]**	**Diarrhoeal Disease [b]**	**Heat [c]**
Central Asia	0 (0 to 0)	0 (0 to 0)	314 (66 to 563)	26 (12 to 38)	1889 (1077 to 2173)
South Asia	9343 (2998 to 13,488)	209 (140 to 246)	16,530 (-1582 to 34,642)	7717 (3522 to 11,421)	24,632 (20,095 to 31,239
Total	*9343* *(2998 to 13,488)*	*209* *(140 to 246)*	*16,844* *(-1516 to 35,205)*	*7743* *(3534 to 11,459)*	*26,521* *(21,172 to 33,412)*

[61] Because (1) most health data e.g. from global burden of disease studies focus on current exposures and historical risk patterns; (2) attributing health impacts to climate change, rather than natural variability, remains challenging; and (3) many climate-health linkages are complex, with multiple interactions and feedback loops (WHO, 2014; Cissé et al., 2022; Di Napoli et al., 2022).
[62] Still cited in the latest IPCC AR6 reports, e.g. Cissé et al., 2022; Shaw et al., 2022.
[63] Global Burden of Disease (GBD) regions are grouped into seven super-regions that exhibit similar cause-of-death patterns.

While the numbers should be viewed as indicative estimates rather than hard projections, and a more contemporary study would probably assess morbidity *and* mortality[64], the results highlight the growing importance of extreme heat, particularly in hotter, more humid and populous parts of South Asia. Malnutrition and diarrhoeal disease, which are closely linked, also remain prominent, though with complex causal pathways and uncertainty intervals. Vector borne diseases, in particular malaria, will also continue to pose risks in South Asia as transmission extends into hitherto cooler areas, though case incidence is on a long-term downward trend. Flood and storm-related mortality were discounted in the WHO study due to inadequate data but are discussed elsewhere in this report (Sections 3.2, 3.4, 3.5 and 3.7).

3.3.3 Vector borne diseases

Rising temperatures and changing rainfall patterns, including more intense monsoon rainfall, will affect the seasonality and spatial distribution of vector-borne diseases, most importantly for malaria in South Asia (Cissé et al., 2022 – *high confidence*). Higher temperatures support faster development of the malaria parasite within mosquitoes and lead to more frequent bites, although the relationship is non-linear. Transmission potential is optimised at around 28-30°C; beyond 35°C the survival of the vector declines (WHO, 2014). Conversely, rising temperatures above a critical minimum, around 15-18^{o}C, may increase transmission. Rainfall and humidity also affect transmission, with the onset of the rainy season associated with increasing cases (Sarkar et al., 2019). In India, the intensity of El Niño events has been positively correlated with malaria incidence (Dhiman and Sarkar, 2017), and Pakistan saw at least a four-fold increase in malaria cases after the floods of 2022, as well as outbreaks of acute diarrhoea (including cholera) and other water-borne diseases (WHO, 2023). Most of those who die from malaria are children under 5 (WHO, 2014).

Rising temperatures and changing rainfall patterns in South Asia, with more intense monsoon rainfall, will create new areas of malaria exposure and contract others, with an overall estimate of 9300 additional deaths in South Asia attributable to climate change by 2050 (WHO, 2014 – Table 2). Projections from WHO are based on a combination of temperature and rainfall changes (mean temperature of the coldest month, maximum monthly rainfall) and changes in GDP/capita as a proxy for different aspects of welfare and economic status that correlate with prevention (WHO, 2014). The more recent climate projections outlined in this report (Section 2) corroborate those used for the WHO study, i.e. a shift towards a hotter and (for South Asia) wetter climate. Socio-economic development has a dominant influence on the long-term *contraction* of malaria risk (vs geographic exposure), however: without GDP growth and considering climate change and population increase only, the population at risk increases from 113 million to roughly 463 million in 2050 (WHO, 2014).

India is most exposed to malaria with an overall increase in months of transmission, but with reductions expected in some hotter areas (Sarkar et al., 2019; Cissé et al., 2022). For example, some areas of northern and western India, as well as interior parts of some southern and eastern states, are projected to have temperatures 1-4°C warmer in all seasons. This may result in extended transmission months as previously cooler months become suitable/more suitable for malaria transmission (Sarkar et al., 2019). Other parts of lowland,

[64] Because many of the impacts will be non-fatal. Assessing health outcomes by both mortality and morbidity (the prevalent diseases) provides a more encompassing view on health outcomes, with the sum of both referred to as the 'burden of disease' measured in 'Disability Adjusted Life Years' (DALYs). One DALY represents one lost year of healthy life.

hotter India in the north and east may become less suitable as temperature thresholds (>35°C) are breached for more of the year (Khormi and Kumar, 2016). In Nepal, vector-borne diseases such as malaria, dengue, chikungunya, Japanese encephalitis, visceral leishmaniasis, and lymphatic filariasis are mostly endemic in the lowland Terai and hills, with around 80% of the population at risk. Projected temperature rises of 2-6°C will likely increase exposure as transmission extends further into the country's highlands (which were previously cooler at higher altitudes), with malaria cases already reported at 2000m (Dhimal et al., 2015).

Dengue incidence and/or transmission is positively correlated with temperature and rainfall, with an additional 200 deaths a year projected for South Asia by 2050 due to climate change (WHO, 2014 – Table 2; Cissé et al., 2022). Although dengue-suitable areas are found throughout tropical and sub-tropical climates, mostly in urban and semi-urban areas (in contrast to malaria), infection is often asymptomatic or results in only mild illness. Nonetheless, suitable areas for dengue transmission are expected to expand beyond their current extent as temperature and rainfall increases (Cissé et al., 2022). Although dengue related deaths are rare, outbreaks across Asia in summer 2023, including Nepal and Bangladesh, had already caused over 100 deaths by July 2023. Outbreaks have been linked to floods, high temperatures and the potential impacts of the El Niño weather event creating more favourable breeding conditions for mosquitos (SCF, 2023).

Whether elevated risks from vector-borne diseases translate into higher morbidity and mortality will depend on efforts to tackle vector breeding and transmission pathways and many other non-climate factors. Across the WHO Southeast Asia region, including Bangladesh, Bhutan, India, Nepal and Sri Lanka, malaria case incidence has declined by 82% over the last two decades; India accounts for around 80% of remaining cases. Sri Lanka was certified malaria free in 2016 and has remained so since (WHO, 2022b). Other factors significantly influencing transmission include land use change, urbanisation and living conditions, making future projections uncertain. Land-based interventions aimed at reducing runoff and conserving water/soil may inadvertently increase risks by pooling water and creating breeding grounds for mosquitoes.

3.3.4 Diarrhoeal and water / food-borne diseases

The prevalence of diarrhoeal disease remains one of the leading causes of child mortality and morbidity throughout Central and South Asia and is sensitive to both changes in temperature and rainfall (WHO, 2014; IHME-GBD, 2019; Cissé et al., 2022). Children who die from diarrhoea (including cholera) often suffer from underlying malnutrition, which makes them more vulnerable to diarrhoea. Each diarrhoeal episode, in turn, makes their malnutrition worse. Diarrhoea is also a leading cause of undernutrition in children under 5 (WHO, 2017; Prüss-Ustün et al., 2019 – see below), with most infections occurring via faeces-contaminated water and, to a lesser extent, food. South Asia is more affected than Central Asia, with the highest under 5 death rates linked to diarrhoeal disease found in India, Bangladesh, and Pakistan (IHME-GBD, 2019), linked mostly (around 60%) to unsafe water, sanitation and hygiene behaviours (Prüss-Ustün et al., 2019). In 2019, deaths attributable to inadequate water, sanitation and hygiene (WASH) accounted for over one million deaths (mainly children) in India, Pakistan and Bangladesh alone (IHME-GBD, 2019; Prüss-Ustün et al., 2019).

Rising temperatures across Central and South Asia will increase risks from diarrhoeal disease, with an overall estimate of 7700 additional deaths/year projected due to climate change by 2050, overwhelmingly in South Asia (WHO, 2014; Cissé et al., 2022 – Table 2). The only climate variable considered in the WHO projection is temperature. Although current knowledge of temperature-diarrhoea relationships over time remains limited, most studies indicate rising temperatures increase bacterial infections (for viruses the picture is less clear), ranging from a 3% to 11% increase in risk per 1°C of temperature increase (WHO, 2014; Carlton et al., 2016; Philipsborn et al., 2016). Emerging research in Bangladesh also indicates that higher temperatures *and* more rainfall (not just floods, or seasonal spikes in rainfall – see below) are associated with a higher prevalence of bacterial diarrhoea (Grembi et al., 2022; Nguyen et al., 2022).

Evidence also highlights a causal relationship between heavy rainfall, floods, drought, cyclones and outbreaks of water-related disease, including cholera, hepatitis A and E, typhoid, polio and pathogenic E.coli (Alderman et al., 2012; Cissé et al., 2022 – *high confidence*). This is because rapid onset climate events can damage or destroy basic health infrastructure, and/or flush pathogens into drinking water sources and the wider environment (Howard et al., 2016; Nijhawan and Howard, 2022). Hence the spike in water-related diseases following the floods in Pakistan in 2022 (see above), and regular outbreaks of water-related disease in cities such as Dhaka (Bangladesh) and Mumbai (India), where annual monsoon floods mix sewage and other waste over wide areas, but particularly into flood-prone informal settlements with poor sanitation and drainage (Patankar, 2015; Hallegatte et al, 2017; World Bank, 2018). The combination of rising temperatures and more frequent and intense droughts and heavy rainfall events across both Central and South Asia can be expected to increase risks from a wide range of water-related diseases (Cissé et al., 2022; Shaw et al., 2022). Those risks will be elevated significantly for those populations with limited or no access to safe water and sanitation, mainly in South Asia, but also including poorer areas of Central Asia. In Tajikistan, for example, almost 50% of the population still lack access to safely managed drinking water, and the country's high rates of water-borne disease and undernutrition are strongly associated with unsafe water supply and sanitation – see also Section 3.2 and TRD for data (World Bank, 2017).

Rising air and water temperatures are associated with increases in food-borne diseases, although transmission pathways are complex (Cissé et al., 2022 – *high confidence*). Risks can occur throughout the food chain and involve a wide range of pathogens. Access to reliable, affordable energy for cooling (Section 3.5) is a key food safety concern, but also includes the cooling needs of health services that require cold chains for transporting temperature-sensitive medical products. These include vaccines which typically require consistent cold storage at 2°C to 8°C to maintain their efficacy – for e.g., cholera, polio, tetanus, malaria, diphtheria, typhoid, Covid-19 (SDC, 2022). Rising temperatures and climate-related interruptions to electricity supply could therefore compromise a wide range of public health interventions.

3.3.5 Undernutrition

Climate variability and change contribute to undernutrition and disease susceptibility, although pathways are complex and difficult to untangle (Phalkey et al., 2015; Cissé et al., 2022 – *high confidence*). Climate variables such as rainfall, extreme weather events, seasonality and temperature have all been linked to nutritional outcomes via impacts on food security and health, although many non-climate drivers related to location, wealth, age, and gender are also important (Lieber et al., 2022). Undernutrition itself has different dimensions, though the commonly used indicator is childhood (under 5 years old) stunting.[65]

Modelling suggests climate change may significantly increase the risk of undernutrition, with an estimate of 17,000 additional deaths/year attributable to climate change by 2050, overwhelmingly in South Asia (WHO, 2014 – Table 2). The estimate is based on a chain of model outputs that combine climate, crop production, food trade and nutritional variables. Uncertainty intervals are large, reflecting difficulties in isolating the climate signal in (multi-factor) pathways to impact noted above, but projected increases are driven largely by temperature-related reductions in agricultural production and food availability. More recent research, summarised by Lieber et al. (2022), highlights the impacts of droughts, floods and climate variability (adopted as climate change proxies) on nutritional outcomes, showing a strong positive relationship with undernutrition, especially for droughts. WHO (2014) estimates may therefore under-estimate risks for both Central and Southeast Asia based on the latest CMIP5 and CMIP6 climate modelling that project more frequent and intense climate extremes across both regions (Section 2).

South Asia already has one of the highest undernutrition (stunting) levels in the world (31%), with 54 million children under five facing a lifetime of physical and cognitive deficits as a result (Wali et al., 2019; Sherburne-Benz et al., 2021; UNICEF/WHO/World Bank Group, 2023). Most of these children are in India (32% stunting), Pakistan (34%), Bangladesh (26%), Bhutan (23%), Afghanistan (33%) and Nepal (27%) where, despite long-term poverty reduction, one-in-four children receive a minimally acceptable diet (World Bank, 2019; UNICEF/WHO/World Bank Group, 2023). The Maldives (14% stunting) and Sri Lanka (16% stunting) fare much better, with more than 50% of children receiving adequate diets (World Bank, 2019; UNICEF/WHO/World Bank Group, 2023). South Asia also has the highest under 5 child wasting[66] prevalence of any sub-region in the world, with peak prevalence (over 15%) in India (UNICEF/WHO/World Bank Group, 2023). Nutritional outcomes also have a gender bias because scarce food is given preferentially to boys (Liebert et al., 2022; FAO, IFAD, UNICEF, WFP and WHO, 2022). Childhood stunting levels in Central Asia are much lower than for South Asia, but still reach 10% and 13% in Kyrgyzstan and Tajikistan, respectively (UNICEF/WHO/World Bank Group, 2023).

A combination of climate change, poverty, state fragility, and the enduring secondary effects of the Covid-19 pandemic are undermining efforts to tackle undernutrition and will continue to shape future trends. The impacts of climate change on undernutrition will be most apparent in the aftermath of extreme events – droughts and floods in particular – projected to increase in intensity and frequency across both Central and South Asia (see Section 2). In Afghanistan, for example, successive droughts and food price inflation, against a backdrop of state fragility, have contributed to widespread food insecurity and undernutrition, with roughly 70% of households struggling to meet basic food and non-food needs (World

[65] Stunting refers to a child who is too short for his/her age, and results from a failure to grow both physically and cognitively. It is caused by chronic or recurrent undernutrition.
[66] Wasting is a relatively short-term condition, with data captured at the time of survey. Child wasting is the life-threatening result of poor nutrient uptake and/or recurrent illness. Children suffering from wasting have weakened immunity, are susceptible to long-term development delays, and face an increased risk of death (UNICEF/WHO/World Bank Group, 2023)

Bank, 2022c)[67] and 35% of the population is expected to face acute food insecurity between May and October 2023 (WFP and FAO, 2023).

3.3.6 Temperature extremes

Globally, climate change is projected to increase heat-related mortality and decrease cold-related mortality, redistributing mortality rates across locations. In Central and South Asia, impacts will be overwhelmingly heat-related[68] because of the numbers of people living in areas already experiencing high summer temperatures of 40°C or more. Those areas include the arid and tropical regions of South Asia such as southern Afghanistan, southern Pakistan, India, and Sri Lanka, and the southern Central Asian countries of Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan (see Section 2). Impacts are already evident. For example, the 2015 heatwave in India and Pakistan, combined with very high humidity, likely led to more than 3600 deaths (Wehner et al., 2016).[69] In 2022, over one billion people in India and Pakistan experienced temperatures of over 40°C for consecutive days (Kim et al., 2023), with heat also contributing to a large number of fires and poor air quality The probability of the 2022 event was estimated to have increased by a factor of 30 due to climate change (Zachariah et al., 2022).

South Asia will experience the greatest cumulative exposure to heatwave events (measured in person days), and heat-related mortality, of any global region, with an additional 25,000 additional deaths/year estimated for 2050 (WHO, 2014; Jones et al., 2018; Cissé et al., 2022). High temperatures affect mortality and morbidity through heat stroke, dehydration, and the exacerbation of respiratory and cardiovascular conditions, with the latter contributing most to excess deaths (Cissé et al., 2022; *very high confidence*). Heat stress occurs when the body is unable to regulate its temperature between 35-37°C. South Asia is most vulnerable because of the region's high (and rapidly growing) populations, rapid urbanisation and combination of summer heat and humidity (see below)).

Projections of heat-related mortality for Central Asia are much lower than for South Asia, with roughly 1900 additional deaths in 2050, despite southern Central Asia's high and increasing summer temperatures and heatwaves (WHO, 2014). This is because of lower populations and much lower humidity levels in Central Asia. However, WHO (2014) projections likely under-estimate heat-related mortality in *both* South and Central Asia because they do not account for more recent and accurate climate projections based on CMIP5 and CMIP6.

Combinations of heat and humidity pose the biggest risks to health and are exacerbated when overnight temperatures do not drop below 20°C and allow sufficient cooling. Rising temperatures combined with greater rainfall in monsoon-dominated areas will lead to more deadly 'moist' heatwaves (due to greater humidity) by 2050. Countries and areas likely to experience more moist heatwaves, both pre-monsoon (April-May) and monsoon

[67] Land aridity can also exacerbate floods. In July 2023, heavy rainfall following three years of drought led to flooding in new areas, killing over 30 people and damaging infrastructure: https://reliefweb.int/disaster/ff-2023-000133-afg

[68] Reductions in cold-related mortality and morbidity could be expected in mountainous areas of the Hindu Kush and Himalayas, and potentially the lowland plains of Central Asia, although literature review for this report did not find any data on this.

[69] Daily high temperatures exceeded 45°C in many places throughout India and Pakistan for several days in a row. Hospitals were overwhelmed with patients suffering from heat-related symptoms.

(June-September), include: eastern Pakistan, northern and eastern India, Sri Lanka and Bangladesh. High overnight minimum temperatures already occur during the summer in the majority of South Asia (India, Sri Lanka, Bangladesh, and southern parts of Afghanistan, Pakistan, Nepal, and Bhutan) and are projected to occur more frequently, and during more months of the year, in the future. A threshold of around 35°C (wet bulb ambient air temperature)[70] is often cited as a 'survivability' limit, beyond which even short periods of exposure can present risk of serious ill-health and death (Im et al., 2017), although more recent research suggests the limit may be lower (Vecellio et al., 2022). India could potentially become one of the first places in the world to experience heat waves that cross the survivability limit for a healthy person sitting in the shade, with 160-200 million people annually facing a 5% chance of being exposed to a lethal heat wave as early as 2030 (Woetzel et al, 2020).

Risks vary between rural and urban areas and between population groups. The most vulnerable to heat-related health problems are the elderly, infants, pregnant women, people living in cramped conditions and outdoor workers. High rates of urbanisation, and particularly the growth of informal settlements within urban areas, will increase the risks of heat stress (Jones et al., 2018; Cissé et al., 2022). Risks will be amplified for those without electricity or income for air conditioning or fans to cool their homes (see Section 3.5). In South Asia especially, a large share of the urban population live in informal settlements (over 50% in Afghanistan, Pakistan and Banglades – see TRD Section F), and many work as informal outdoor labourers – some 90% in India, and 80% in Pakistan - including both the urban and rural workforce (Sherburne-Benz et al., 2021). Recent data from Tamil Nadu, India, highlight links between occupational heat exposure and adverse pregnancy and foetal outcomes, with heat-exposed women experiencing a doubled risk of miscarriage (Rekha et al, 2024). Impacts on the agricultural labour force in terms of working hours potentially lost to heat stress are discussed in further in Section 3.1.5.

Risks are typically higher in urban areas because of the 'heat island' effect. Despite urban-rural temperature differentials of 1-5ºC often cited in the literature, heat island effects can be much bigger. In the 2022 Indian heatwave, May *night-time* temperatures in Delhi and several smaller villages exceeded 35ºC, peaking at about 39ºC, while nearby rural fields cooled to around 15ºC, a difference of over 20ºC (NASA, 2022). Moreover, satellite observations and outdoor weather station data may under-estimate intra-urban hotspots shaped by settlement characteristics and the properties of residential structures, as well as the *indoor* heat exposure typically experienced by the urban poor living in cramped conditions without cooling (Tasgaonkar et al., 2022; Kim et al., 2023). Cities in South Asia (see also Section 3.4) are expected to receive more than 200 million new residents (or about the entire population of Pakistan) by 2030, and with most of the urban infrastructure of 2050 *yet to be built*, policymakers will need to plan for a progressively more urban and warmer future (International Finance Corporation, 2017; Kim et al., 2023). Some cities have already prepared heat plans based around early warning systems and changes to building density, materials, and access to green/blue spaces.[71] At a country level, India became one of the first countries

[70] A measure of humid heat stress, recognising that the body's ability to regulate temperature depends on humidity (and hence evaporative cooling through sweating), not just air temperature.
[71] Ahmedabad in the Indian state of Gujarat was the first South Asian city to develop an urban heat strategy, focussing on awareness raising, early warning, and measures to reduce heat exposure through e.g. a Cool Roofs Programme. Other cities have followed suit, including Karachi, Surat, Andhra Pradesh, and Telangana (Kim et al., 2023).

in the world to launch a comprehensive cooling action plan – the India Cooling Action Plan (ICAP) – in 2019 to address the country's cooling needs while reducing climate impacts. In June 2022, Bangladesh published its own National Cooling Plan, and Pakistan aims to follow suit in 2026 (see World Bank 2022).

3.3.7 Air quality

Climate change can contribute to air pollution by increasing the risk of wildfires and dust storms (Shaw et al., 2022 – *medium confidence*). Rising temperatures, more intense droughts and heatwaves in Central and South Asia increase the risk of wildfires, soil desiccation (cracks on the soil surface due to drying) and soil loss, creating smoke and dust storms with links to respiratory and cardiovascular problems (Hashizume et al., 2020; Lwin et al., 2023 - see also Section 2). The Central Asian drylands, accounting for roughly two thirds (400 million ha) of Central Asia's land area (mainly Kazakhstan, Turkmenistan, and Uzbekistan), are particularly vulnerable as climate change will likely exacerbate ongoing land degradation driven by poor rangeland management, inappropriate irrigation and the breakdown of common property institutions regulating rangeland access (Quillérou et al., 2016; Hashizume et al., 2020 – see also Sections 3.1, 3.6). In 2021, a summer heatwave in Kazakhstan dried up vegetation and soils to a depth of 50cm leading to a winter duststom extending into Uzbekistan and the Fergana Valley, with particulate levels far exceeding WHO-defined safe standards. Longer-term analysis confirms a link between summer heatwaves and duststorm intensity (Nishonov et al, 2021).[72] Adverse effects on health from low air quality linked to dust storms could be exacerbated by a projected 1-1.5% increase in average wind speed in Kazakhstan, as well as higher temperatures and greater aridity (Turgali et al., 2021).

Sand and dust storms from the former Aral seabed in Uzbekistan – the 60,000km^2 Aralkum Desert – have already led to the loss of over two million tonnes of soil carbon valued at USD207M and significant health impacts for the surrounding population (Akramkhanov et al., 2021 – see also Section 3.6 and 3.7). Aerosols from the desert also contain salt and toxic chemicals accumulated over many years from upstream irigation returns (Nishonov et al, 2021). Important feedback loops also exist between changes in land cover/use and local climate. For example, the shrinking of the Aral Sea (Section 3.7.1, 3.7.3) caused by upstream irrigation diversions has contributed to rising air surface temperatures in the surrounding region (He et al., 2022).

Higher temperatures and heatwaves can aid the formation of surface ozone, causing or exacerbating respiratory problems (Shi et al., 2020; Cissé et al., 2022). Surface ozone is created through the interaction between pollutants (e.g., car emissions) in the presence of heat and sunlight. This remains a research gap as there are few studies have attempted to isolate the contribution of climate change to ozone-related mortality. One global analysis to the end of the century (Silva et al., 2017) projected increases across all global regions, but with deaths concentrated in East Asia, North America and India, albeit small in number (e.g. India: 8 deaths/year/million people) compared with other causes of death.

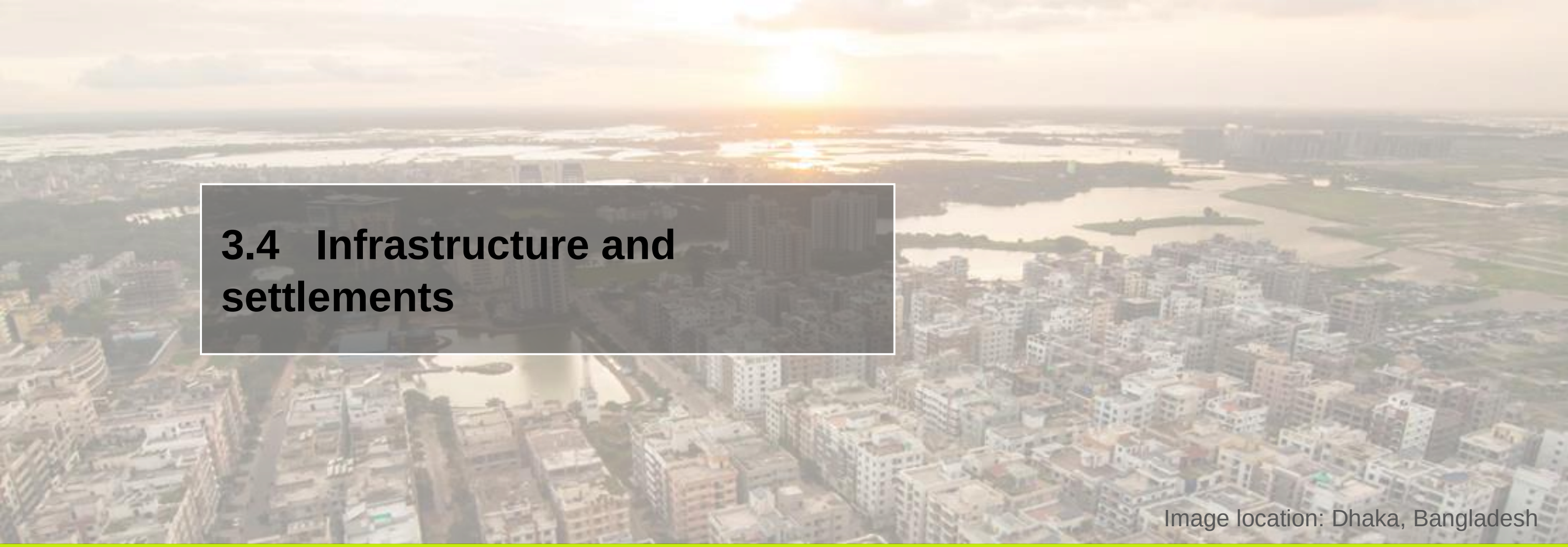
Although the contribution of climate change to air pollution-related mortality and morbidity remains uncertain, air pollution is a growing threat and a leading cause of

[72] Temperatures reached 46.5^{o}C in Kazakhstan in summer 2021, contributing (with high winds) to dust storms affecting Tashkent and the Fergana Valley later in the year, with very high levels of atmospheric particulate matter (PM_{10} and $PM_{2.5}$) (Nishonov et al., 2023).

mortality and morbidity across Central and South Asia. Indoor and outdoor air pollution is now the leading risk factor for all-cause mortality across South Asia (with the exception of Sri Lanka and Maldives), and among the top five in Central Asia (IHME-GBD, 2019). In South Asia, roughly 60% of the population now live in areas where concentrations of fine particulate matter ($PM_{2.5}$) from small soot and dust particles exceed WHO (2021)-defined safe limits by a factor of seven or more; on the densely populated Indo-Gangetic Plain, by a factor of 20 or more (World Bank, 2023a).[73] Irfan (2024) reports that South Asia is now home to 37 of the world's 40 most polluted cities, with 60% of its population exposed to hazardous pollution levels. In Bangladesh, an assessment of environment-related risk estimates some 272,000 premature deaths in 2019 *alone* from four factors: ambient (outdoor) air pollution; indoor air pollution; unsafe water and sanitation; and lead exposure in adults (World Bank, 2023).[74] Collectively, these risks accounted for 32% of all premature deaths in the country, with an annual cost equivalent to 18% of GDP. Indoor and outdoor air pollution accounted for nearly 55% of premature deaths in 2019 (World Bank, 2023b).

Pollution from urban and non-urban sources can form extended 'airsheds' shaped by climate and geography. Air pollution can travel long distances, creating 'airsheds' that cross municipal, state and national boundaries (World Bank, 2021). For example, in Dhaka (Bangladesh), Kathmandu (Nepal) and Colombo (Sri Lanka), only one-third of city air pollution originates within those cities (World Bank, 2023a). Major non-urban sources include household (solid fuel) stoves/fires, the burning of waste and crop stubble, brick kilns, forest fires, dust storms, and the inefficient application of mineral fertiliser that releases ammonia and other gases – see also Section 3.1.1 (World Bank, 2023a).

[73] WHO Global Air Quality Guidelines (2021) for $PM_{2.5}$ based on strong epidemiological evidence showing causal relationships between $PM_{2.5}$ air pollution exposure and all-cause mortality, as well as acute respiratory infections, heart disease, lung cancer and stroke. Exposure may also contribute to type II diabetes, neonatal mortality and, potentially, neurological diseases such as Alzheimer's, though the evidence for these is less strong (WHO, 2021).
[74] Illegal recycling of used lead acid batteries close to homestead areas is often responsible for lead exposure. See: https://www.unicef.org/bangladesh/en/stories/i-forget-lot-things-while-im-studying-lead-poisoning-wreaks-havoc-childrens-lives#:~:text=Millions%20of%20children%20affected%20by%20lead%20poisoning&text=In%20Bangladesh%20alone%2C%20it%20is,death%20due%20to%20lead%20exposure.



3.4 Infrastructure and settlements

Image location: Dhaka, Bangladesh

<u>Summary of risks relevant to infrastructure and settlements</u>

- Climate risk and poverty will increasingly coincide in Central and South Asia's growing urban areas where robust infrastructure provision lags behind urban expansion. By around 2045, both regions will be predominantly urban.
- South Asia is one of the most flood-exposed regions of the world in terms of absolute exposure (numbers of people exposed to coastal and river floods) and relative exposure (proportion of the population exposed to such floods). Roughly 370 million people in South Asia (20% of the population) are currently exposed to significant flood risk, with 100 million (30%) of those living in urban areas, mainly in Pakistan, India, and Bangladesh.
- Poorer urban households living in informal settlements are most exposed to climate hazards since land and housing markets push people into riskier places with poorer services and inadequate housing. Informal urban populations are concentrated in South Asia, with the highest shares in Pakistan (56%), Bangladesh (52%), and India (49%) – some 278 million people in total. Extreme rainfall and flooding, and more frequent and intense heatwaves, pose the biggest risks to exposed households.
- Cities in South Asia are expected to receive more than 200 million new residents (or about the entire population of Pakistan) by 2030, and with most of the urban infrastructure of 2050 yet to be built, policymakers will need to plan for a progressively more urban, warmer, and wetter future.
- Climate-related shocks and trends can contribute to both increases and decreases in migration, with no clear overall trends for Central and South Asia. Of the two regions, South Asia has the highest *potential* for displacement, with estimates of 17-41 million additional 'climate migrants' by 2050; for Central Asia estimates range between 1.7 and 2.4 million displaced people. However, definitions, assumptions, and projections are contested, and estimates of climate-induced migration may over-simplify drivers of change.
- Extreme weather events can damage and disrupt all modes of transport. Current annual transport damages as a share of GDP are highest in Tajikistan, Kyrgyzstan, Bhutan, and Nepal – mainly from floods and cyclones. Damages could be expected to increase substantially as climate hazards intensify.
- South Asia's densely populated coastal settlements, port infrastructure, and maritime trade face threats from more intense cyclones, storm surges, and floods, as well as sea-level rise. Cities confronting the fastest changes in sea levels are those where land is rapidly subsiding - Chittagong (Bangladesh) and Ahmedabad (India).
- Risks to infrastructure and settlements highlight the need to *build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation* (SDG9) while also making *cities and human settlements inclusive, safe, resilient, and sustainable* (SDG11).

3.4.1 Context

Infrastructure systems and the services they provide are critical for socio-economic development. Climate hazards can damage assets, disrupt network connectivity and trade over wide areas, and undermine progress on economic development and poverty reduction (Hallegatte et al., 2019). Across both Central and South Asia, there are concerns over the severe and persistent shortage of resilient infrastructure, with existing and emerging climate hazards highlighting gaps in provision and posing threats to assets and services (Hallegatte et al., 2019; Hajat, 2020).

Central and South Asia have a combined population of just over two billion, with roughly 78 million (38%) in Central Asia (including Afghanistan) and 1973 million (62%) in South Asia (data for 2022 from World Bank, 2022d; see also TRD Section F).[75] Annual population growth in Central and South Asia has been around 1.3% and 1.7%, respectively, over the last decade, considerably higher than the global average of 1.1%, although annual growth rates vary significantly between countries. Most of this growth will be absorbed by urban areas (World Bank, 2020; World Bank 2022d; see also TRD Section F), although populations in both regions are still predominantly rural: 52% in Central Asia and 64% in South Asia (data for 2022 from World Bank, 2022d; see also TRD Section F).

Based on data from the International Disaster Database (EM-DAT), climate-related disasters resulted in roughly 115,000 human fatalities in Central and South Asia between 1995 and 2022, with over 99% of deaths in South Asia (CRED-EM-DAT, 2023).[76] On average between 1995-2022, such disasters have affected (injured, displaced, otherwise affected) nearly 58 million people annually in South Asia and one million in Central Asia and cause an average annual economic loss of USD 8.5 billion in South Asia and USD 0.4 billion in Central Asia. A majority (more than 80%) of these impacts are linked to floods and tropical cyclones, particularly in India, Bangladesh and Pakistan.

South Asia is one of the most flood-exposed regions of the world in terms of absolute exposure (numbers of people exposed to coastal and river floods) and relative exposure (proportion of the population exposed to such floods) (Rentschler and Salhab, 2020). Roughly 370 million people in South Asia are currently exposed to significant flood risk– some 20% of the region's population. Absolute numbers are highest in India (225 million people), Pakistan (72 million) and Bangladesh (52 million); relative exposure is highest in Bangladesh (32%) – see Focus Box 7 in Section 3.7.1 for further details (Rentschler and Salhab, 2020). A similar pattern emerges with urban flood exposure, with roughly 110 million urban residents (30% of the total flood-exposed population; over 15% of the urban population) classified as 'highly exposed' to pluvial (flash) floods, mostly in Pakistan (44 million), India (41 million), and Bangladesh (23 million) (FAO, UNICEF, WFP, WHO, 2023).

Despite the increasing exposure of populations and the increasing frequency and/or intensity of some climate extremes in certain parts of Asia, hazard-related mortality has declined across both regions over the last 40-50 years. In Bangladesh, for example, the number of deaths directly related to cyclones and coastal flooding has decreased significantly since the 1980s, even though the number of people exposed to those hazards has increased by around 50% (Haque et al., 2012; Lumbrusco et al., 2017). This is due to improvements in early warning

[75] Data for Afghanistan included under South Asia.
[76] The International Disaster Database, EM-DAT: see https://www.emdat.be/

and response, and the building of cyclone centres and other adaptive or defensive measures (Lee et al., 2021).

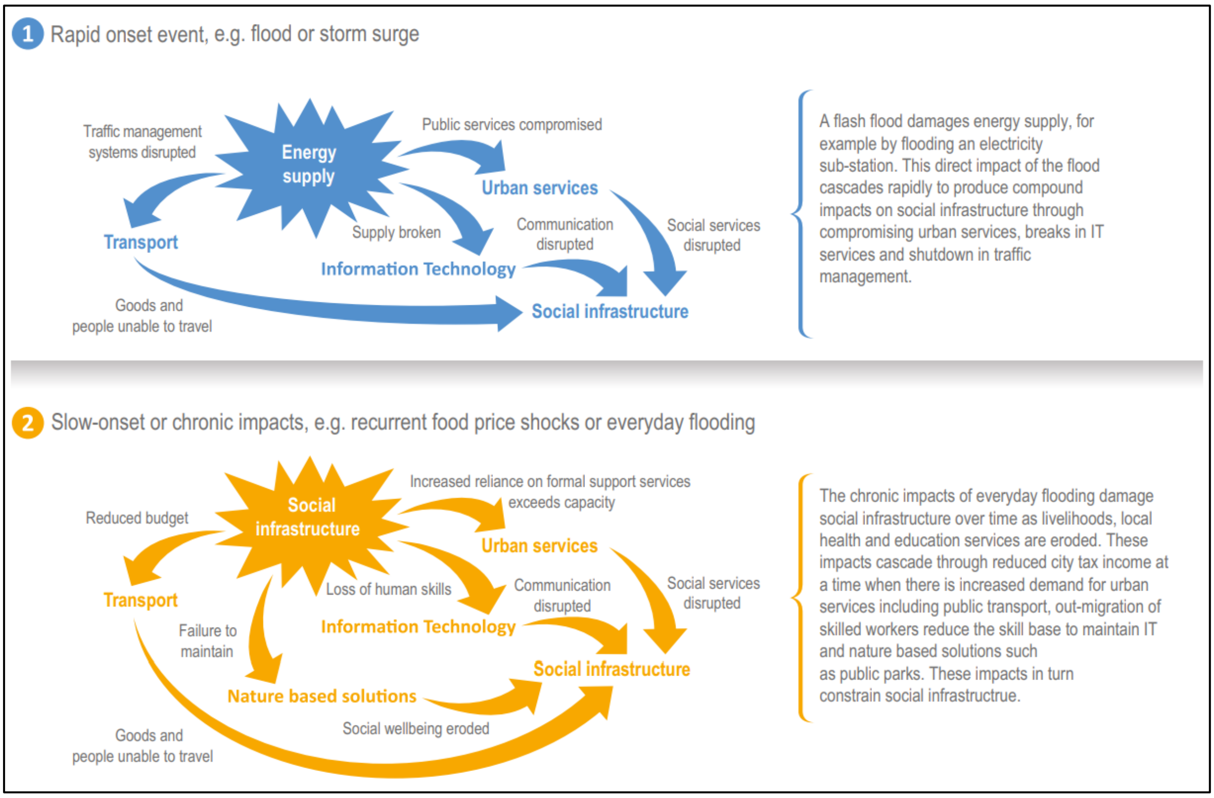


Figure 10: Climate impacts cascading through infrastructure networks. Source: IPCC (2022).

Nonetheless such hazards still cause significant economic and social damage as the secondary consequences of infrastructure asset losses cascade through economic activities, sectors, and output – Figure 10 (Panwar and Sen, 2019; Hallegatte et al., 2019; Tasri et al., 2022). For example, disruption and damage to transport networks can cause travel delays and hinder the supply of emergency services to affected populations in the immediate aftermath of events (He et al., 2022), and affect people's access to markets, jobs, health care and fuel over the medium to longer-term (Hallegatte et al., 2017; He et al., 2022). For this reason, more recent vulnerability and resilience assessments consider integrated systems and cascading risks rather than individual assets (for illustrations, see Dawson, 2015 and Thacker et al., 2017).

3.4.2 Housing and settlements

Rapid urbanisation in Central and South Asia is increasing pressure on fragile and overstretched urban infrastructure, particularly housing. This highlights the need to *build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation* (SDG9) while also making *cities and human settlements inclusive, safe, resilient and sustainable* (SDG11; United Nations, 2015). Although the populations of both Central and South Asia are predominantly rural (see above), rapid urbanisation driven by natural growth, rural-urban migration and the transformation of rural villages/towns into urban centres will tip the balance. Urban populations will likely surpass the rural populations in Central and South

Asia by 2030 and 2045, respectively (UNDESA, 2018), though timings will vary between countries: in Tajikistan, Afghanistan, Nepal, and Sri Lanka, over 70% of the population is still rural; Turkmenistan and Kazakhstan are already largely urban (data for 2022 from World Bank, 2022d; see also TRD Section F). Not all urban settlements are classified as 'urban' by government, so these numbers may underestimate urbanisation trends (see below).

Rapid urban growth has resulted in the expansion of informal settlements and 'secondary' towns and cities where infrastructure provision lags behind urban expansion and households are exposed to multiple hazards (Dodman et al, 2022; WDI, 2022). Many of the fastest-growing urban areas are 'spontaneous' extensions and neighbourhoods emerging beyond or across administrative boundaries that are not officially recognised as urban.[77] A key feature of urban growth – in both secondary towns/cities and larger urban centres – has been the expansion of informal settlements lacking one or more basic living conditions or services (e.g., safe water and sanitation, drainage, durable housing). In South Asia, 56% of the urban population in Pakistan, 52% in Bangladesh and 49% in India – some 278 million people in total - live in informal settlements (data for 2022 from World Bank, 2022d; see also TRD Section F). Cities in South Asia are expected to receive more than 200 million new residents (or about the entire population of Pakistan) by 2030, and with most of the urban infrastructure of 2050 *yet to be built*, policymakers will need to plan for a progressively more urban, hotter, and more flood-prone future (International Finance Corporation, 2017; Kim et al., 2023). In Central Asia, roughly 73% of the urban population in Afghanistan and 17% in Tajikistan (around nine million people in total) live in informal settlements, but numbers are much lower in other Central Asian countries (data for 2022 from World Bank, 2022d; see also TRD Section F).

Lower-income populations living in informal settlements are most vulnerable to climate-related hazards as they are more likely to be pushed into exposed (often low-lying, flood-prone) areas where land is cheaper and more accessible (Hallegatte, 2016; Dodman et al., 2022). As a result, poorer households are disproportionately exposed to climate hazards, and typically lose a much larger fraction of their wealth when they are impacted - pushing people into poverty and/or keeping them poor (Winsemius et al., 2018). The city of Dhaka (Bangladesh), for example, has a population of over 20 million (metropolitan area), up from just 336,000 in 1950, with 300,000 to 400,000 new migrants arriving annually (World Bank, 2007: Ross et al., 2016; Haquea et al., 2022). Roughly one-third of its residents live in informal settlements, many living in flood-prone areas where monsoon rains mix flood water, industrial waste and sewage over wide areas. Almost all faecal sludge ends up in drains, canals and the wider environment, with no safe conveyance, treatment or disposal (Ross et al., 2016). Similarly in Mumbai (India), informal settlements are located in areas with chronic flooding, causing regular outbreaks of disease and problems with transport, power supply, drinking water, and food and fuel availability (Patankar, 2015).

Climate change could contribute to internal migration, permanent or temporary, and some studies have attempted to quantify the potential for climate-induced migration in Central and South Asia. Scenario modelling by the World Bank focussing on the slow onset

[77] For example, the population growth rate in peri-urban areas around Kolkata (India) has been 22.8% compared to 4.4% population growth in the core region of the city over the period 2001-2011 (Mondal and Banerjee, 2021).

impacts[78] of climate change on livelihoods suggests that by 2050, Central Asia could see between 1.7 million and 2.4 million additional 'climate migrants', with out-migration hotspots along the southern border of Kazakhstan, pockets surrounding the Ferghana Valley in Uzbekistan and Tajikistan, and the area around Bishkek, due to projected decreases in water availability and crop productivity (Clement et al., 2021). Key in-migration hotspots identified included the area around Tashkent, lower elevation areas of southern Tajikistan (including Dushanbe), and rainfed croplands in northern Kazakhstan because of more favourable agroecological conditions. For South Asia, additional climate migrants were estimated at 17 to 41 million by 2050, with up to one third in Bangladesh (Rigaud et al., 2018). Potential in-migration hotspots identified include the southern Indian highlands, Himalayan areas of NW India and parts of Nepal (Rigaud et al., 2018).

Evidence to date on migration drivers and trends is mixed, however, with no simple causal chain or robust estimates of climate-induced migration based on commonly agreed methodologies (Fiddian-Qasmiyeh, 2019; Boas et al, 2019; Selby and Daoust, 2021). Climate-related shocks and slow-onset changes can contribute to both increases and decreases in migration, with no clear overall trends for the region (Nayda Schwerdtle et al., 2020; Selby and Daoust, 2021). Most research indicates that while climate threats shape the scale and nature of migration, climate change does not act in isolation to drive mobility (Fiddian-Qasmiyeh, 2019; Nayda Schwerdtle et al., 2020). Rather, the evidence highlights climate as one of many 'push' and 'pull' factors, with no simple causal chain or robust estimates of climate-induced migration based on commonly agreed methodologies – see Focus Box 4 (Gemenne et al., 2011; Fiddian-Qasmiyeh, 2019; Selby and Daoust, 2021).

Focus Box 4: Climate change and migration: global and regional evidence

The impact of climate change on the movement and distribution of people has been much debated. Commonly cited articles have put the number of global 'climate migrants' at anywhere between 100 million and two billion by 2100 (see e.g. Geisler and Currens, 2017). However, the empirical basis for this scale of displacement is absent (Gemenne, 2011; Fiddian-Qasmiyeh, 2019; Boas et al, 2019; Selby and Daoust, 2021). Rather, the evidence points to climate as one of many possible drivers, with no simple causal chain (Gemenne, 2011; Boas et al, 2019; Nayda Schwerdtle et al., 2020; Selby and Daoust, 2021).

A rapid evidence review commissioned by FCDO (Selby and Daoust, 2021) reinforces the view that almost all forms of migration are multi-causal: affected by complex combinations of 'push' and 'pull' factors as well as by migrant agency, aspirations and capabilities. Climate change coincides with other transformations and hazards, many of which may be exacerbated by climate change but typically have roots elsewhere – job losses, land acquisition, land degradation, declining farm sizes, conflict and so on.

Drawing on the studies reviewed on migration in the Bay of Bengal and other regions (Selby and Daoust, 2021), Bangladesh (Gray and Mueller, 2012; Safra de Campos, 2020) and the Ganges-Brahmaputra delta (Rahman et al., 2020), we summarise as follows:

- Climate-related shocks can contribute to increases and decreases in migration; there is no upward trend in long-term migration linked to climate extremes.

[78] Impacts acting through slow-onset changes in water availability, crop productivity, and sea-level rise augmented by storm surges (Rigaud et al., 2018; Clement et al., 2021).

- Movement in response to climate-related shocks is mainly internal or local rather than long-distance or international; evidence on whether it is mainly temporary or permanent is mixed.
- There is no evidence (so far) of global climate change-induced sea-level rise contributing to migration. Out-migration from the Bangladesh portion of the Ganges-Brahmaputra-Meghna delta is influenced by many different factors including environmental risks, but mainly by employment opportunities in urban areas (Dhaka and Chattogram especially).
- There is strong evidence that local experiences and attachments to place are often privileged over concerns about future climate change.
- Poorer individuals and households are particularly affected by both migration pressures and barriers to movement. Lower wealth accumulation in rural settings may hinder large-scale migration from risky areas, contributing to spatial poverty traps.
- A limited body of evidence indicates that climate change narratives among authorities and elites (e.g. around sea-level rise and displacement) may contribute to migration pressures.

To conclude, although the potential for climate change to disrupt livelihoods and *contribute* to migration decisions is clear, the attempt to distinguish between 'climate migrants' and 'non-climate migrants' and quantify 'new' mobility resulting from climate change is flawed (Boas et al, 2019). Research needs to better explore the non-linear complexity of mobility in the *context* of climate change and include affected populations in the research effort (Boas et al, 2019).

Risks to housing infrastructure in South Asia have been highlighted by numerous extreme events over the recent past, particularly floods, landslides, tropical cyclones, and heatwaves (see Table 3). For instance, floods and landslides in Nepal in 2017 damaged around 192,000 houses, inflicting an estimated loss of USD 188 million – some 50% of total infrastructure damages (GoN, 2017). Floods and landslides in Kerala (India) destroyed over 234,000 houses, leaving more than 220,000 people homeless. Estimated economic losses were estimated at USD 916 M, roughly 30% of total infrastructure losses (GoK, 2018). In 2022, floods in Pakistan affected more than 33 million people, causing more than 1,700 human fatalities and economic costs of USD 30 billion (GoP, 2022). Housing infrastructure faced the major brunt of the impact as more than two million houses were destroyed or damaged, with damages to housing estimated at USD 6.2 billion – around 60% of total infrastructure damages. The Pakistan floods are estimated to have pushed nearly nine million people into poverty (GoP, 2022). South Asia will also experience the largest cumulative exposure to heatwave events (measured in person days) and heat-related mortality of any global region, with densely populated informal settlements at high risk (see Section 3.3.6). Combinations of heat and humidity pose the biggest risks to health, with southern Afghanistan, eastern Pakistan, northern, central and eastern India, Sri Lanka and Bangladesh likely to be worst affected to the 2050s.

Major human and economic losses from flood and landslide events in mountain areas is a growing risk in both regions. In Central Asia, major flood events have included 2010 Kazakhstan floods causing over 40 human fatalities and USD 40 million in economic losses, and the 2010 Tajikistan floods that resulted in over 70 fatalities, caused losses or more than USD 200 million and damaged over 1,000 houses (World Bank, 2016). The magnitude of reported damages in Central Asia (vs South Asia) is comparatively low. This partly down to the lack of disaggregated data by economic sector (specifically for the infrastructure sector) in Central Asia, but also because of lower population densities and exposed infrastructure. In mountain areas of both regions, however, landscape instability will likely become a much bigger problem as snowpack, glaciers and permafrost melts and snowfall is replaced by rainfall, with a number of recent disasters in India and Tajikistan (see Sections 3.2.2 and 3.5.2). Landslides and mudflows are currently estimated to cost Central Asian countries 1.2 - 2.2% of of GDP annually (World Bank, 2023).

In mountain areas, rising temperatures causing snowmelt and increased monsoon rainfall will likely exacerbate landslides, rock-ice avalanches, mud flows and lake outbursts, contributing to major infrastructure losses. Recent research (Otto et al., 2023) concluded that climate change was likely to have increased the extreme monsoon rains that contributed to the 2022 floods in Pakistan (see Focus Box 5). However, robust trend statistics on slope/landscape instability, and climate attribution studies linking changes in climate to landscape and flood impacts, are not available – see Section 3.2.2 and Section D of TRD (Li et al., 2022).

Table 3: Estimated economic losses to housing infrastructure caused by major disasters in Central and South Asia (in USD millions, current prices). Source: Authors' compilation from post-disaster needs assessment (PDNA) studies and government estimates for respective events; CRED-EM-DAT (2023). 'USD m' refers to 'United States Dollar in millions'.

Extreme event/disaster	Affected population	Total economic losses (in USD m)	Total infrastructure losses (USD m)	Losses to housing sector (USD m)	Housing sector losses as % of infrastructure losses
Cyclone Sidr, Bangladesh 2007	2,300,000	1675	1061	839	**79%**
Floods, Sri Lanka 2017	879,778	469	320	207	**65%**
Floods, Nepal, 2017	1,688,474	585	395	188	**48%**
Floods, Kerala-India 2018	5,400,000	4392	3151	916	**29%**
Floods, Pakistan, 2022	33,000,000	30139	10545	6222	**59%**
Cyclone Fani, Odisha-India 2019	1,650,0000	3454	1889	439	**23%**
Floods, Kazakhstan 2008	13,000	154	-	-	-
Floods, Tajikistan 1992	63,500	547	-	-	-
Floods, Tajikistan 2010	6708	204	-	-	-

Extreme heat, Tajikistan 2008	2,000,000	840	-	-	-

Focus Box 5: Climate change event attribution of Pakistan floods 2022

There is a growing body of research that attributes the influence on extreme weather events from human-induced climate change using climate models. A recent World Weather Attribution study by Otto et al. (2023) found that climate change likely increased the intensity of monsoon rainfall in Pakistan during 2022. Using weather data and computer simulations, the study compared the present climate with the climate of the past, with about 1.2°C increase in temperature since the late-1800s. The study considered a 60-day period of heavy rainfall over the Indus river basin between June and September 2022 and a 5-day period in Sindh and Baluchistan provinces.

The study noted that *"the 5-day maximum rainfall over the provinces Sindh and Baluchistan is now about 75% more intense than it would have been had the climate not warmed by 1.2°C, whereas the 60-day rain across the basin is now about 50% more intense, meaning rainfall this heavy is now more likely to happen"*. However, the study highlighted uncertainties in the estimates for the 60-day event definition, with existing models struggling to simulate these rainfall characteristics.

Looking at a projected 2°C increase in temperature since pre-industrial times, the study found that rainfall intensity will significantly increase for 5-day events.

Source: Otto et al. (2023)

While disasters are often framed as natural events, with causality that links climate extremes directly to damage, impacts are shaped by the exposure and underlying vulnerability of people and infrastructure. Simple 'natural disaster' framings can divert attention away from dynamic place-based vulnerabilities and their socio-political causes, reducing human agency to only the contribution it makes to the hazard part of the risk equation (Hulme, 2011; Lahson and Ribot, 2021). In reality, risks are clearly influenced by (for example) the concentration of poor households in flood-prone informal settlements (see above), or the failure to build and maintain adequate flood defences (Lahsen and Ribot, 2021; Otto et al., 2023). Linking extreme weather events to climate change is one attribution step; explaining an associated crisis and its costs is a very different one (Lahsen and Ribot, 2021).

3.4.3 Transportation

Risks posed to livelihoods, businesses and economies from extreme weather events are exacerbated where transport networks are fragile and have little redundancy, as extreme weather events can damage and disrupt all modes of transport including roads, railways, airports and maritime operations (Hallegatte et al., 2019; Dodman et al., 2022). Analysis by Koks et al. (2019) based on detailed asset mapping highlights the economic exposure of transport systems (road and rail) to natural hazards – cyclones, earthquakes, surface flooding, river flooding and coastal flooding (see Figure 11).The expected annual damage (EAD) to road and rail networks in Central and South Asia, mainly from floods and cyclones, was estimated at over USD 1 billion[79]. Impacts vary depending on country size, economic status, asset density and asset value. For instance, EAD to transport infrastructure in absolute terms is substantially higher in India (USD 340 million), Pakistan (USD 99 million), Bangladesh (USD 90 million), Uzbekistan and Kazakhstan (USD 45 million each), while EAD as percentage of GDP is higher in Tajikistan, Kyrgyzstan, Bhutan and Nepal. Study estimates do not consider climate futures, but costs could be expected to rise significantly given

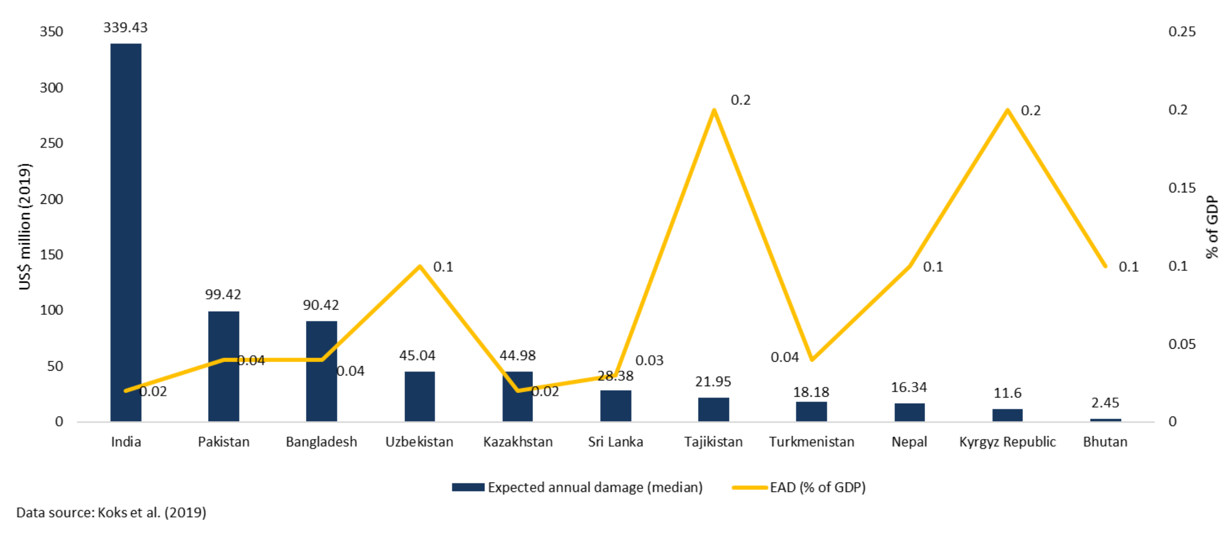


Figure 11: Expected annual damage (EAD) of multi-hazards to road and rail infrastructure in Central and South Asia (median values for 1 in a 100-year event). Source: Koks et al. (2019).

projected increases in the frequency and intensity of extreme rainfall events and the intensity of cyclones (Section 2). Estimates are for direct damages and do not include the costs of transport delays and disruptions, or wider economic impacts (see below).

The longer-lasting secondary consequences of direct asset losses such as disruptions to electricity supply, impacting transport services has significant impacts on users yet are rarely estimated (Dawson et al., 2018; OECD, 2018; Hallegatte et al., 2019). For example, cyclone Fani that hit the coastal state of Odisha, India, in 2019 caused estimated damages of USD 439 million to transport infrastructure (about 18% of total infrastructure losses), but also disrupted electricity supplies for all economic sectors in the following months (GoO, 2019). Roughly 10% of Kazakhstan's transport infrastructure is exposed to natural hazards, particularly from flooding. In 2019, the additional cost to firms in Kazakhstan from lower utilisation of transport infrastructure due to natural hazards was USD1.1 billion, or 0.5% of GDP (World Bank, 2022b). A recent study by He et al. (2022) demonstrates the indirect impacts of floods on urban economic systems through disruptions to road networks, resulting in city-wide travel delays and cascading impacts (see Focus Box 6). Analyses of the spatial distribution of hazards and key points of network vulnerability (for transport and ICT especially) can help prioritise investment, but the necessary evidence is often lacking – a key evidence gap.

[79] These are median estimates for 1 in a 100-year event. The study uses a variety of sources of cost data, fragility curves, and assumed parameters for each hazard to estimate infrastructure damages. This specifically includes direct damages to road and rail assets, and do not include the indirect costs from transport delays and disruption, or wider economic impacts (see Koks et al., 2019).

Focus Box 6: Indirect impact of floods on urban road networks

A recent study by the World Bank examines the direct flood exposure and indirect travel disruptions due to floods on road networks in 2,564 populated urban settlement clusters spanning 177 countries and regions of the world. The study identifies flooding as the dominant cause of weather-related disruption to the transport sector because of its impact on capacity and connectivity (via failed routes, travel delays, increased travel time and distance).

Countries such as Pakistan, India and Bangladesh have road networks that are more sensitive to flood impacts. In Bangladesh, on average, a 1000-year flood could cause 80-90% route failure, resulting in more than 4 minutes of travel delay and a travel distance increase of more than 2 kilometres. Similarly, in India, 50-60% of the routes could fail resulting in a travel delay of more than 10 minutes and a travel distance increase of more than 6 kilometres. These average travel disruptions also include many extremes whereby the travel delay can be more than 2 hours and travel distance increase can be more than 82 kilometres.

Such disruptions on an aggregate level could lead to system-wide effects on economic activity and population livelihood and well-being. This is particularly true for countries in South Asia where levels of failed routes are high alongside high poverty rates.

Source: He et al. (2022).

3.4.4 Information and communication technology (ICT)

Digital infrastructure and the continuity of services that ICT provides could be disrupted by climate extremes. ICT is increasingly important to the operation of all infrastructure networks because of the role it plays in monitoring, remote operation, clock synchronisation, and coordination of emergency response during extreme events (Dawson et al., 2018). Greater interdependency also increases the risks of cascading failures across entire infrastructure systems and services – from financial transactions to transport, education and health (Hallegatte et al., 2019). Climate extremes including storms, floods, and heatwaves can damage or disrupt ICT infrastructure including 'first mile' infrastructure (e.g., submarine cables or terrestrial cross border links), 'middle mile' infrastructure (e.g., fibre optic cables, data centres) and 'last mile' infrastructure (e.g., mobile towers, WiFi and internet cables) (Sandhu and Raja, 2019; Dawson et al., 2018). Risks are summarised in Table E3 in the TRD.

Power generation and transmition needed for ICT and other infrastrucutre systems could be compromised by rising temperatures, heatwaves and changes in water availability across both Central and South Asia. Electricity generation from thermal power plants that dominate the energy mix in Turkmenistan, Kazakhstan and Uzbekistan (Central Asia) and Pakistan, Bangladesh, India, Sri Lanka and Maldives (South Asia) are sensitive to changes in water availability for cooling and, to a lesser extent, the temperature of intake water (see Section 3.5). High temperatures, floods and high winds can also damage, disrupt or lower the performance of electricity networks - generators, substations, and transmission lines (see Section 3.5).

Recent climate extremes affecting Pakistan and India have highlighted ICT vulnerabilities. In Pakistan, for example, floods in 2022 caused more than USD 3.6 billion in estimated losses and damages to power, telecommunication and transport infrastructure, more than 35% of total infrastructure losses (GoP, 2022). Damage to telecommunications infrastructure included damage to fibre optical transmission lines, feeder cables, and transmission towers. In India, telecommunication services in the coastal districts of Odisha were severely impacted after the landfall of tropical cyclone Fani in 2019, causing damage to power and telecom infrastructure and disruption to mobile and internet services in 11 of the most affected districts, extending over several months. Cyclone Fani caused estimated damages of USD 64 million to the telecom sector – unprecedented in the state's history. The post-disaster needs assessment estimated total recovery needs for the telecom sector at USD 69 million (GoO, 2019).

3.4.5 Coastal settlements and ports

Coastal settlements in South Asia face threats from more intense tropical cyclones, storm surges and floods, as well as rising sea levels. Coastal cities, particularly in India, Bangladesh, Sri Lanka and Pakistan have large populations and concentrations of economic assets. They will be increasingly exposed to compound risks as rising sea levels exacerbate the effects of cyclones, storm surges and flooding linked to low elevation and constrained drainage (see Figure 12). Nonetheless, coastal cities such as Mumbai and Chennai (India) continue to attract large numbers of migrants because of job opportunities, even though the cities may be more exposed than rural areas and migrants may little choice but to settle in risky places (Patankar, 2015; Hallegatte et al, 2016; 2017).

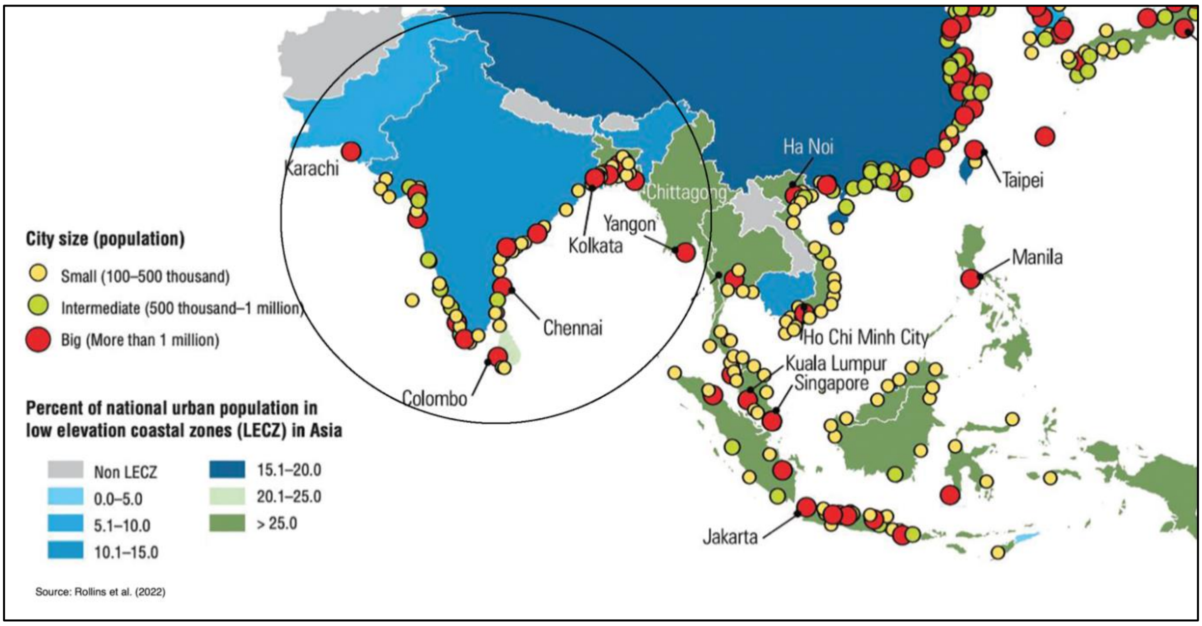


Figure 12: High concentration of human settlements in coastal cities and low-laying areas in Southern Asia. Source: Rollins et al. (2022).

Risks are already evident in some of South Asia's major coastal zones around India and Bangladesh. In 2020, for example, tropical cyclone Amphan affected more than 13 million people and damaged over 1.5 million houses in West Bengal in India (Nagchaoudhary and Paul, 2020). Further, the tropical cyclone affected nearly 2.6 million people and damaged more than 260,000 houses in Bangladesh (IFRC, 2021). In 2019, tropical cyclone Fani in Odisha, India, inflicted a total infrastructure loss and damage of USD 1.9 billion, of which 87%

was absorbed by the energy and housing sectors. In Sri Lanka, floods and landslides caused significant damage to coastal infrastructure (total infrastructure damage of USD 320 million) and displaced more than 100,000 people in coastal settlements (GoSL, 2017).

Rising sea levels, coastal erosion and flooding are a growing threat to coastal settlements and infrastructure in South Asia (see also Focus Box 7, Section 3.7). Sea-level rise in the Bay of Bengal could range between 0.5 and 0.7 meters by 2100 under a mid-level emission scenario, while it could be 20 cm more under a warmer RCP 8.5 scenario (World Bank, 2022c). In Bangladesh, sea-level rise (and coastal flooding) could inundate up to 17% of the country's land area by 2050, putting millions of people at risk. Damage to coastal infrastructure, currently estimated at USD 300 million/year, could double by 2050 (World Bank, 2022c). In India, 27 million coastal residents could be inundated by the end of the century with a 50-70 cm rise in sea levels (2°C warming scenario) (Kulp and Strauss, 2019). However, flood risk projections for South Asia's deltas also depend on sediment flows and accretion, with some studies indicating that increased sediment delivery to the Ganges-Brahmaputra-Meghna delta could compensate for accelerated (climate-driven) sea level rise (Raff et al, 2023 – see Section 3.7, Focus Box 7).

Coastal ports and maritime trade may also incur heavy losses, with ports in India already exposed to costly climate hazards. Ports are essential nodes for national and regional economies as well as global supply chains. However, their location exposes them to cyclones and extreme waves, with damage and disruption that can affect port infrastructure, maritime transport and trade (Verschuur et al., 2023). Based on an assessment of current port-specific and wider trade risks, Verschuur et al. (2023) identified Mumbai, Marmagoa (west coast) and Vishakhapatnam, Paradip and Haldia (east coast) in India as South Asia's high-risk ports, with annual median risks estimated at between USD5 million and USD25 million. Of these, risks were highest for Vishakhapatnam – among the global top 50 'at risk' ports – with cyclones and floods the main hazards. For maritime trade, annual median risks were less than USD1 billion for all South Asian ports, far less than for some Southeast Asian ports in Viet Nam and Philippines (Verschuur et al., 2023).

Land subsidence compounds the effects of climate-induced sea-level rises. For some coastal cities, land subsidence is the main driver of change (Tay et al., 2022). Climate-driven sea-level rise is caused by melting ice sheets and ocean warming. However, land subsidence caused by groundwater overexploitation, loading from buildings and the combined effects of groundwater pumping and reduced sediment deposition also causes *relative* sea-level rise. Based on high resolution satellite imaging, Tay et al. (2022) show that the cities experiencing the fastest changes in relative sea level (>20mm/year) are in Asia. For South Asia, these include Chittagong (Bangladesh) and Ahmedabad (India). Significant variation within cities is also evident, providing policy makers with an opportunity to identify local hotspots and limit building loads within them, irrespective of actions taken by the rest of the world to address climate-driven sea-level rise (Tay et al., 2022).

3.5 Energy

Image location: Nurek Dam spillway, Tajikistan

Summary of risks relevant to energy

- Closing remaining gaps in clean cooking fuel provision (mainly in South Asia), increasing the share of renewables in electricity generation (in Central and South Asia), and mitigating risks to power generation and distribution posed by climate change (Central and South Asia) will be needed to achieve SDG7: *Ensure access to affordable, reliable, sustainable and modern energy for all*.
- Electricity production from thermal power plants may be negatively affected by more variable water supplies (for cooling) and higher water temperatures. Electricity generation from thermal power plants burning fossil fuels dominates the energy mix in Turkmenistan, Kazakhstan, Uzbekistan (Central Asia), and Pakistan, Bangladesh, India, Sri Lanka, and Maldives (South Asia).
- Risks to hydropower arise from greater river flow variability to the 2050s, warming-induced landscape instability, and the need to balance power generation with other (transboundary) priorities including downstream irrigation, sediment flow to deltas, and flood-drought management. Hydropower plays an important role in electricity production in Kyrgyzstan, Tajikistan, Afghanistan, Nepal, and Bhutan, with further investments planned on the upper reaches of key rivers.
- Wind and solar potential remain largely untapped in both Central and South Asia, although investment is increasing. Power outputs from solar projects are sensitive to changes in the frequency of very warm, cloudy and/or hazy conditions, and projections to the 2050s suggest reductions in PV potential of 3-8% for parts of Central Asia. Very high winds associated with more intense storms can damage wind infrastructure and force shutdowns, and deposit dust/sand on solar panels reducing their output.
- Electricity transmission and distribution infrastructure will be negatively affected by higher temperatures and climate extremes that can limit, disrupt, or damage electricity supply. Transmission and delivery losses remain high in many countries, especially in Central Asia, disrupting power supplies, imposing higher costs on businesses, and undermining household welfare.
- Energy demand will rise substantially across both Central and South Asia, with higher summer cooling demands during more intense heatwaves far exceeding any savings from reduced winter needs. In India, overall energy demand is projected to rise by 15% by 2050 because of higher cooling demand with daily summer demand peaks increasing by 20-30%. Government projections do not typically account for climate-related increases in overall and peak demand, but meeting these needs will require greater grid flexibility, storage capacity, and peak generation capacity.
- Climate risk assessments are needed for all types of power generation and transmission projects to support energy and wider economic resilience – particularly for major, long-lived investments in hydropower, solar, and wind.

3.5.1 Context

Economic growth over the past few decades has been accompanied by increasing energy demand, a trend that will continue to the 2050s. Central and South Asian economies have returned to growth after Covid-19 related disruptions (ADB, 2023a; Usov, 2023). In Uzbekistan, for example, electricity demand was projected to reach 76TWh in 2022, and almost double to 138TWh in 2030. India's energy consumption has almost doubled since 2000, primarily met by coal, oil, and biomass used as a fuel source in thermal power plants (IEA, 2021a).

Electricity access in South and Central Asia has improved recently with the number of people lacking access decreasing significantly from 440 million in 2010 down to 78 million in 2020 (IEA, IRENA, UNSD, World Bank and WHO, 2022). Central Asia achieved near-universal coverage across both urban and rural areas, but there are variations across South Asia. Electricity access is universal (or nearly so) in Bhutan, Sri Lanka,Maldives, India, and Nepal.[80] However, access rates for Pakistan and Afghanistan vary between sources reflecting different definitions and data collection methods.[81] In Pakistan, the International Energy Agency (IEA) reported 79% access in 2019, while 94% was reported to track progress on SDG7 (United Nations, 2015). Similarly, there are discrepancies for Afghanistan, where the IEA reports 72% access, while 98% was reported for SDG7 tracking.

Despite major gains in improving electricity access, challenges remain across the region before it can achieve SDG7: *Ensure access to affordable, reliable, sustainable and modern energy for all*. Those include extending access to clean cooking fuels to improve health, reduce CO_2 emissions, and relieve pressure on natural habitats as a source of fuel, particularly in Afghanistan, Bangladesh, Nepal and Sri Lanka where access to clean fuels is 35% or less (IEA, 2023). Questions also remain over who will benefit from major new investments in power generation when network penetration into rural areas, especially, remains limited in many countries (Hallegatte et al., 2019).

[80] See country profiles tracking progress and trends on achieving the Sustainable Development Goals for all 193 UN Member States

[81] See links for further information on defining electricity access for SDG reporting purposes and on different reporting methodologies.

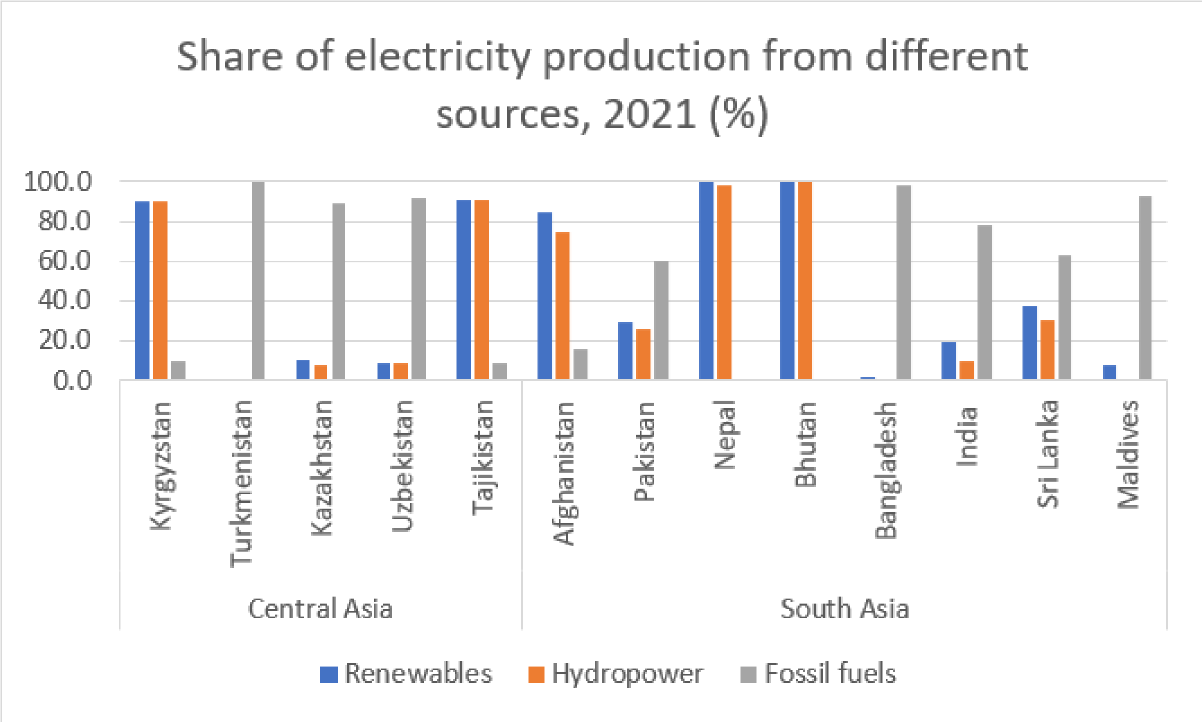


Figure 13: Percentage share of electricity production by source, per country, across Kyrgyzstan, Turkmenistan, Kazakhstan, Uzbekistan, Tajikistan, Afghanistan, Pakistan, Nepal, Bhutan, Bangladesh, India, Sri Lanka, and the Maldives for 2021. Blue bars indicate renewable electricity production, orange bars indicate hydropower electricity production to highlight how much/little hydropower accounts for shares of renewable electricity production per country, and then grey bars indicate fossil fuel electricity production for comparison with renewables (and hydropower). Data sources: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023) – with major processing by Our World in Data.

Central and South Asia have a varied electricity generation mix with high dependency on fossil fuels but also a growing share of hydropower for some countries. Hydropower is the main source of electricity generation in Kyrgyzstan (86%) and Tajikistan (89%). Coal dominates the energy mix in Kazakhstan, while natural gas is prevalent in Uzbekistan and Turkmenistan, with fossil fuels accounting for 87%, 93%, and 100% of electricity generation, respectively. The penetration of modern renewables such as solar and wind remains far below Central Asia's potential though Kazakhstan and Uzbekistan are both looking to increase their share in the energy mix.

In South Asia, hydropower accounts for almost all electricity production in Bhutan (c100%) and Nepal (98%), and a significant share in Afghanistan (75%), Sri Lanka (31%), and Pakistan (26%). Coal, gas, and oil dominate electricity production in India (78%), Bangladesh (99%) and Maldives (93%), and accounts for a significant share in Pakistan (59%). As a country with a rapidly developing economy and the largest population in the world, India's energy pathways will have global significance. While much of the commissioned coal capacity is yet to be added to the mix, the country is also looking to capitalise on its potential for renewable electricity production.

3.5.2 Power generation

Electricity systems, critical to global decarbonisation efforts, are under pressure from extreme and slow-onset weather events such as heatwaves and sea-level rise (IEA, 2020). Power generation infrastructure has long lifetimes – 25 to 40 years for utility-scale solar, 60 to 80+ years for TPPs, and 80+ years for hydropower – and therefore needs to be resilient to future climate risks and other threats (Opitz-Stapleton et al., 2022). Thermal power plants and hydropower installations, in particular, involve major investments in fixed and largely irreversible/inflexible systems where the risks of 'locking in' climate vulnerabilities are higher. Solar and wind installations, in contrast, can be developed incrementally to meet demand and, if necessary, modified to account for new data and changing conditions.[82]

Thermal power plants that need water for cooling contribute to, and are affected by, water stress, while higher temperatures may also reduce their efficiency (Dodman et al, 2022). Thermal power plants (TPPs) burn fuels such as coal and gas to make heat, with water used to generate steam (powering turbines for electricity production) and for cooling (Rodriquez et al, 2013). Most consume much more water than other energy technologies, making them vulnerable to water shortages where other demands are increasing, and where reliable water supplies are threatened by more variable rainfall and drought (Luo, 2018a; Rodriguez, 2013). In India, where almost 90% of thermal power generation (mainly from coal) depends on freshwater for cooling, estimates suggest that water consumption by TPPs could rise 9% by 2050, with over 30% of capacity installed in high water-stress regions (IRENA and WRI, 2018; Luo et al, 2018a; IEA, 2021a). However, shutdowns forced by water shortages between 2013 and 2016 have already cost Indian power utilities an estimated USD1.4 billion in lost revenue (Luo et al., 2018a). With most TPPs yet to be constructed, the government has adopted policies to reduce their water consumption (IEA, 2021b). In addition, higher air and water temperatures expected to the 2050s could reduce TPP generation efficiency. Assessments vary, but a 1°C increase in the temperature of water used as coolant yields a decrease of between 0.1% and 0.7% in power output (Cook et al, 2025; Mima and Criqui, 2015). Data for water supply and temperature-related constraints on TPP electricity generation are scarce; most countries do not collect or disclose information on TPP water withdrawals, consumption, and efficiency (Luo et al, 2018b). However, similar water-related disruptions to electricity generation could be expected for other countries (beyond India) relying heavily on fossil fuel-powered TPPs for electricity generation (Wang et al, 2019 – see Figure 13).

Central and South Asia's solar potential is significant but underexploited. A number of countries are looking to capitalise on solar potential and have large-scale photovoltaic (PV) programmes completed or underway. Investments in ground-based and floating solar projects are accelerating in a number of countries. In Central Asia, Uzbekistan plans to increase its share of renewables in electricity generation to 25% by 2030, with solar PV and wind farms with capacities ranging between 100 MW to 1,000 MW under development (IEA, 2022). The country has significant solar and wind resources, potentially allowing it to become the Central Asian hub for renewables generation and power trading, but would need to extend network infrastructure into thinly populated, high potential areas (IEA, 2022). [83] India, which has about 750GW of solar potential, wants to generate 50% of its electricity from renewables

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[82] General guidance around decision making under uncertainty for different kinds of projects/investments is provided by Ranger (2013).

[83] See Panwar et al. (2022) for further discussion of planned energy infrastructure and solar and wind potential in Kyrgyzstan, Uzbekistan and Tajikistan.

by 2030 increasing overall renewable energy capacity to 500GW. It has already expanded solar capacity from 1GW in 2011 to 60GW in 2021 (Ministry of New and Renewable Energy, 2024; Jaiswal and Gadre, 2022), including modest expansions in floating solar.[84] Meanwhile, Pakistan plans to increase its share of solar and wind to 30% by 2030. The country has added large-scale solar PV including the Quaid-e-Azam Solar Park with 400 MW capacity, and another with 600 MW under construction, to its energy portfolio (IRENA, 2018; Opitz-Stapleton et al., 2021). Despite risks to PV from extreme heat and potential changes in cloud cover (see below), and the need to regularly clean PV panels with potable-grade water, no clear climate risk or environmental impact assessment was conducted for the Quaid-e-Azam Solar Park[85] (see Opitz-Stapleton et al., 2021 for case study). Similar concerns around extreme heat and cleaning needs (plus scouring of panels) linked to more frequent duststorms have been highlighted for solar projects in Uzbekistan, Tajikistan and Kyrgyzstan (Opitz-Stapleton et al, 2022).

Solar PV outputs are sensitive to changes in cloud cover, aeosols and temperature, and projections to the 2050s suggest modest decreases in PV potential. However, changes in solar radiation, in contrast to temperature, remain uncertain. Despite the growing importance of solar PV systems for electricity production, few studies have assessed the impact of climate change on PV output in Central and South Asia, or other global regions (Feron et al., 2021; Dodman et al, 2022). However, PV outputs and intermittency are known to be sensitive to changes in the frequency of warm, cloudy and hazy conditions, with clouds and aerosols reducing power outputs, and high air temperatures reducing PV cell performance (Kaldellis et al., 2014; Wild et al, 2015; Feron et al, 2021). Analysis by Feron et al (2021) based on two emissions scenarios to 2050 (RCP4.5 and RCP8.5) indicates that for South Asia, impacts on PV solar potential are not significant in winter or summer months, but there is a --3% decrease in PV potential in Central Asia in both seasons. In summer, this reduction is likely driven by rising temperatures which decrease solar cell performance. These changes, introduce an additional element of planning complexity for those countries investing heavily in solar (see above). In particular, lower outputs and/or greater power intermittency in some areas could make it harder to balance power production and consumption within grid systems, requiring more investment in grid stabilisation, storage, and alternative sources of electricity (Feron et al, 2021). Results above do not account for changes in atmospheric pollution (e.g. from duststorms, PM2.5) or the potential accumulation of dust/sand on PV panels in the absence of regular cleaning which can have a significant impact on PV effiiciency.[86]

[84] In the South Asia region, floating solar projects are now operational in India, as well as Maldives and Bangladesh. Pakistan and Sri Lanka are in the early stages of exploration. See: https://blogs.worldbank.org/en/energy/india-unlocking-potential-floating-solar-power

[85] This utility-scale Quaid-e-Azam Solar Park is part of the Pakistan-China Energy Corridor (CPEC), a component of China's Belt and Road Initiative (BRI). Located in northern Punjab, summer temperatures already reach 50ºC and panels have to be cleaned with increasingly scarce potable water (brackish water can damage PV panels). CPEC also includes investment in coal-based thermoelectric generation (Opitz-Stapleton et al, 2021).

[86] Panat and Varanasi (2022) report that PV efficiency can drop by 30% per month due to dust accumulation on panels. They report that while the siting of major PV projects in deserts (e.g. Bhadla Solar Park, India) has advantages in terms of land availability and sunlight, cleaning needs may not be adequately considered.

Both Central and South Asia have significant untapped wind potential. India has 195GW of technical offshore wind potential alone (ESMAP, 2019), with plans to install 30GW capacity by 2030. Meanwhile neighbouring Bangladesh, which set a target of 5GW offshore and onshore wind by 2030, is also looking to tap into its offshore potential with a 500MW offshore wind farm in the Bay of Bengal (Gardham, 2023). Pakistan has both offshore and onshore potential in Balochistan and Sindh provinces (ESMAP, 2020; World Bank, 2021). Kazakhstan's wind potential is extensive at around 350GW, with recent agreements indicating plans to add 3GW of wind power (Samruk Kazyna, 2017; Reuters, 2023). Uzbekistan plans to have 25% of electricity generation from renewables by 2030 and add 12GW of wind power, with several large-scale wind farms planned (Usov, 2022; see Panwar et al., 2022 for further discussion of modern renewables potential).

With a lifetime of around 20 years, wind installations will need to contend with higher temperatures and wind speeds (Duffy et al., 2022; Opitz-Stapleton et al., 2022). While blade icing caused by extreme cold may continue to cause problems in mountain areas, extreme heat is likely to become more of a problem as temperatures rise. Heatwaves can lead to wind turbine shutdown if temperatures exceed standard operating limits between -30°C to 50°C (Opitz-Stapleton et al., 2022). Wind turbines have different operational wind speed ranges (typically 3 m/s to about 25 m/s or 30 m/s) and speeds above that can cause damage and lead to shutdowns (Duffy et al., 2022). Across Central Asia, some models project a decrease in average wind speed by 1-1.5% under SSP1–RCP2.6 and SSP5–RCP8.5 scenarios, primarily during the summer months (although model certainty is low except over northern Kazakhstan) (Gutiérrez et al., 2021). These small changes in wind speed are unlikely to pose a risk to wind power generation in Kazakhstan (Turgali et al., 2021). During Hurricane Maria in 2017, a Puerto Rican wind farm closer to the eye of the storm which could have experienced strong winds around 70 m/s was badly damaged unlike other wind farms that likely experienced wind speeds of up to 50 m/s (Duffy et al., 2022). Typhoon-Class offshore wind farms able to cope with high wind speeds are available on the market, albeit at higher cost. Joshi et al. (2022) notes that site-specific risk analysis for energy infrastructure will be critical in the future, as many of India's renewable-rich east and western states already experience regular cyclones. These are expected to intensify to 2050 with potentially higher wind speeds.

Climate-related hydropower insecurity could become a critical source of economic and social risk across Central and South Asia. In Kyrgyzstan and Tajikistan, where hydropower dominates current electricity production and future energy projects, the average age of HPPs was 60 and 44 years, respectively, in 2022, and both countries were vulnerable to seasonal variations in water supply and power generation (Panwar et al., 2022). In both countries, higher maximum and minimum temperatures and extreme heat events impact glacial melt and snow cover in the mountains of Pamir, Pamir-Alay, and parts of the Tian Shan. Accelerated glacier and snowmelt could mean higher hydropower potential for some areas though this is likely to decline towards the end of the century as meltwater dwindles (see Sections 2.2 and 3.2). Critical points where glaciers contribute less to peak flows and river baseflows have already been reached in the Small Naryn basin and will be reached in the 2040s for the Big Naryn, with implications for hydropower management (Opitz-Stapleton et al., 2022).

Risks to long-lived hydropower projects arise from designs based on historic rather than future climate, landscape, and river flow conditions. For both existing and new hydropower schemes, risks are linked to landscape instability (see below), greater river flow variability, the ability to balance power generation with other priorities (including the maintenance of environmental and sediment flows for rivers) and flood management (Hallegatte et al., 2019; Opitz-Stapleton et al., 2022). Guidelines for factoring-in climate change into hydropower have only recently been published (IHA, 2019), and whether safeguards apply will likely depend on funding conditionalities and financing periods.

There are almost 100 large hydropower plants concentrated in the upper Indus–Ganges–Yangtze (India, Nepal, Pakistan, China) river basins. A further 650 are under construction or planned, mostly in close proximity to glaciers and glacial lakes. The hydropower potential of high mountain Asia remains considerable (Figure 14), exceeding 500 GW, or enough to support over 350 million homes (Li et al., 2022). However, new hydropower plants are being planned in locations closer to glaciers and glacial lakes in higher altitude areas, making them more hazard-prone (Li et al., 2022). Climate-driven landscape instability resulting in avalanches, landslides, debris flows, lake outbursts and higher sediment loads is already posing risks to hydropower projects and wider infrastructure in mountain areas - see Section 3.2 (Opitz-Stapleton et al., 2022; Li et al., 2022). Extreme rainfall and snowmelt triggered landslides, the Chorabari Lake outburst, flash floods and debris flows during the 2013 Kedarnath disaster in India, damaging over 10 hydropower plants. Run-of-river hydropower generation with limited water storage dominates the electricity mix in Nepal and Bhutan. Such schemes are more dependent on seasonal (monsoon) rainfall, and power generation could therefore be become more unreliable with greater rainfall variability and more frequent/prolonged droughts (see Sections 2.2 and 3.2).

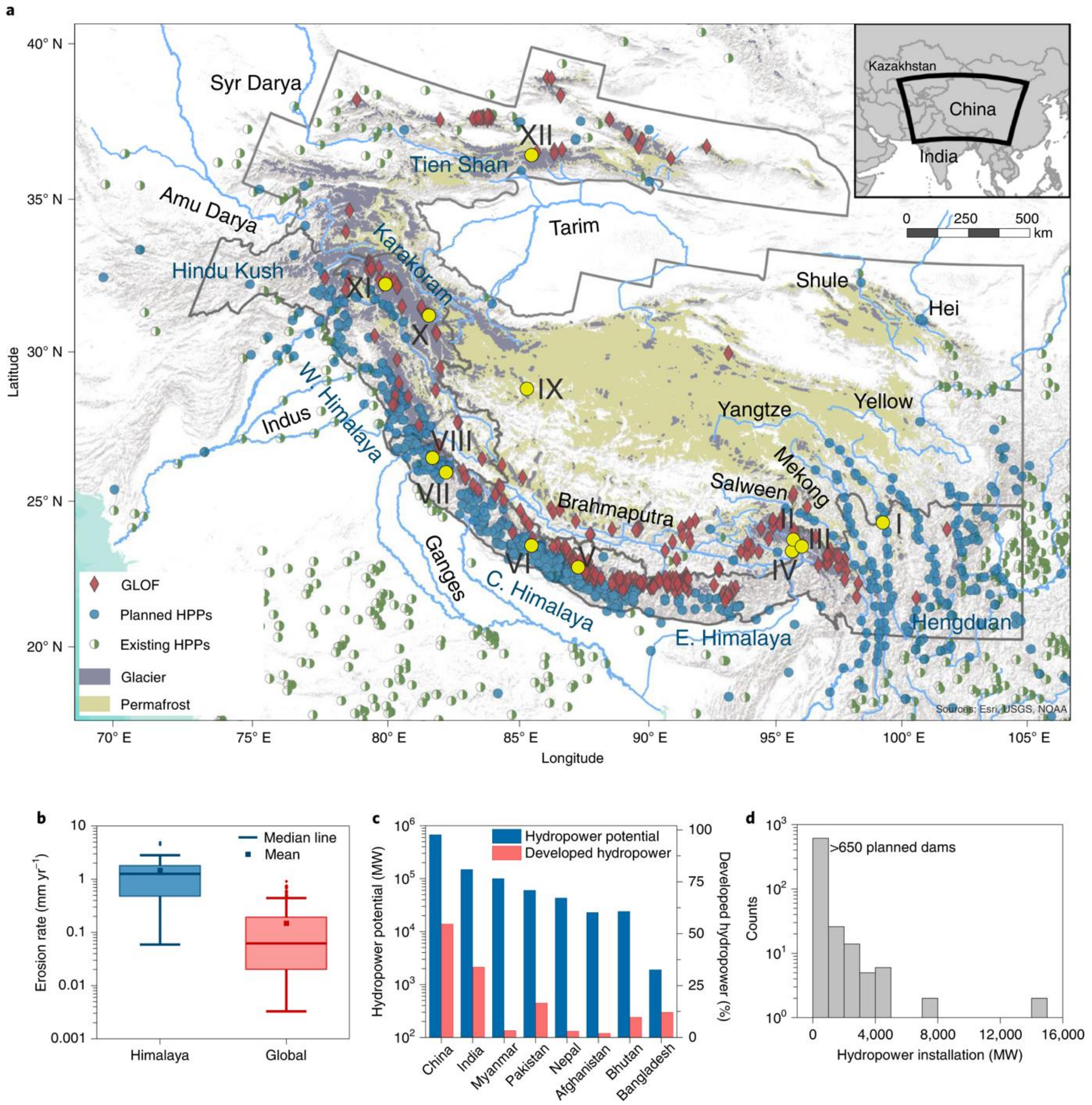

Figure 14: Glacial lake outburst floods (GLOFs), hydropower projects (HPPs) and erosion rates in High Mountain Asia. Source: Li et al. (2022). Yellow dots for (a) denote locations of key cryospheric hazards such as glacial detachments and debris flows. Erosion rates (b) based on a comparison between erosion in the Himalayas vs global (1950s-2000s). Hydropower developed vs potential (c) and hydropower installation capacity (d) based on International Hydropower Association data for 2021.

Risk management strategies rely on transboundary cooperation around information sharing, dam releases, and broader basin management, plus the diversification of energy sources with different risk profiles. More resilient energy systems will need to rely increasingly on multiple options spread across multiple grids – including different energy sources (see above) and cross-border trades. Central Asia's Interstate Coordination Water Commission (ICWC) is the main interstate mechanism for managing transboundary waters in the region. South Asia lacks similar institutions to manage transboundary waters (Scott et al., 2019). Regional power dynamics and conflicting priorities of riparian states have limited opportunities for shared governance. Several bilateral treaties fill the void, India has treaties with both Nepal and Bangladesh, and the Indus Water Treaty with Pakistan dates to 1960 (Scott et al., 2019). Nonetheless, inadequate mechanisms for dispute resolution mean that unilateral decisions to construct dams or perceived failure to uphold agreements fairly, as was the case with joint hydropower projects between India and Nepal on the Koshi River, can exacerbate mistrust between countries (Scott et al., 2019).

3.5.3 Transmission and distribution

Transmission and distribution (T&D) losses have declined across South Asia over the last two decades but remain higher than the OECD average. In Central Asia ageing infrastructure contributes to high losses (Shrestha et al., 2022; Panwar et al., 2022). In Uzbekistan, transmission losses were just over 20% (ADB, 2016), while in Kyrgyzstan average losses rise up to 17% in winter and average 2% across T&D companies operating in the country (IEA, 2022). In Sri Lanka's T&D losses declined to around 9% in 2018, and in India down to 17% (Shrestha et al., 2022). In Pakistan, high T&D losses (estimated at 17% in 2014) and challenges around cost recovery contribute to the poor financial health of electricity companies, hindering infrastructure upgrades. For electricity providers such as the Peshawar Electric Supply Company (PESCO), which covers all of Khyber Pukhtunkhwa province, losses were as high as 40% (Cheema et al., 2022). While T&D losses in Bangladesh had declined marginally to 12% by 2018, investment in transmission infrastructure has failed to keep up with the increase in generation capacity leading to inadequate high voltage transmission capacity (World Bank Group, 2022a).

Power outages have cascading impacts on businesses and households that will likely be amplified by climate change. In 2022, almost 60% of companies of all sizes operating in South Asia experienced power outages (World Bank Group, 2022b). Across the region, unreliable electricity access and power shortages lead to billions of dollars in losses for the manufacturing and services sector: USD22.7 billion in India; USD1.1 billion in Bangladesh (2016); and USD8.4 billion in Pakistan (2015) (Zhang, 2019). Data are scarce for Central Asia, but business enterprise surveys reported by Rentschler et al. (2019) indicate that firms in Afghanistan, Tajikistan, Kyrgyzstan and Uzbekistan face the largest percentage losses in sales (country-level averages) due to electricity disruption. Central Asia, and especially Uzbekistan and Kazakhstan, have also faced widespread power cuts and gas shortages because of recent cold winters, ageing infrastructure and energy export commitments (Losz and Mitrova, 2023), including in January 2023 when massive power outages hit southern Kazakhstan, eastern Uzbekistan, and most of the Kyrgyz Republic, disrupting airports and infrastructure (CAWEP, 2023). Poor/unreliable electricity access can also impact households. Using kerosene for lighting can negatively impact health outcomes and contribute to black carbon emissions, for example. In Bangladesh, India and Pakistan, long power outages are associated with a decrease in both per capita income and women's labour force productivity, suggesting that the lack of electricity is linked to an increase in the time needed for domestic work (Zhang, 2019). Electricity disruptions also force better-off households and businesses to invest in costly backup power generation (Hallegatte et al., 2019). Although comprehensive data on the contribution of natural hazards to power disruptions in each region are unavailable, networks will be increasingly exposed to climate risks (see below).

Both Central and South Asia are investing in transmission infrastructure to meet surging electricity demand but the costs are high. India is investing to upgrade high voltage distribution and smart grids in the West Bengal, with USD 270 million co-financing from the World Bank and AIIB (World Bank Group, 2023). In Nepal, investment in T&D infrastructure was a key component of ADB-financed projects to ensure security of supply and facilitate cross-border electricity trade with India (ADB 2023b; 2023c). Pakistan is adding 2,680 MVA in substation capacity and about 350 km of transmission lines to meet growing demand in Punjab, Sindh and Khyber Pakhtunkhwa provinces and restore lines damaged by flooding in 2022 (ADB, 2022). Meanwhile, Uzbekistan plans to invest in the rehabilitation and modernisation of existing transmission lines and substations to improve energy efficiency and help with the integration of renewable energy sources in the power grid (ADB, 2023d).

Extreme weather events, including heavy rainfall and intense storms, already damage and disrupt electricity networks. Electricity transmission and distribution networks span large distances, with overhead power lines often traversing exposed areas (Dodman et al, 2022). Transmission pylons are generally more susceptible to wind damage, whilst distribution lines are more likely to be affected by treefall and wind-blown debris (Karagiannis et al., 2019). After Tropical Cyclone Sidr, Bangladesh experienced its worst ever power blackout with disruption to all 26 power generation plants and transmission infrastructure, meaning that full supply of electricity was not restored for 2 or 3 days or even longer in the south of the country (Shahid, 2012). Most recently, Tropical Storm Sitrang which led to wind speeds of up to 55mph (88kph) and a storm surge of 3m, damaged around 2,000 electric poles, leaving eight million people without electricity and causing USD30 million in losses (Paul, 2022; Gallagher Re, 2023).

Power transmission can also be reduced by rising temperatures and heat extremes leading to the de-rating (lower performance) of power lines and other electrical equipment (Dodman et al, 2022). Evidence from Central and South Asia is limited, but studies in the US indicate that by the 2050s higher ambient air temperature may reduce the average summertime transmission capacity by 1.9%–5.8% relative to a 1990–2010 baseline (Bartos et al., 2016). Higher losses have been projected in other US studies, with up to 20% capacity reduction for generators, substations, and transmission lines during more intense heatwaves by 2060 (Burillo et al., 2018). In the UK, transmission losses of between 6–10% have been estimated for the 2080s for a 4°C climate scenario, with reductions of up to 27% for some components (Dawson et al., 2018). Opitz-Stapleton et al. (2022) find that while energy companies in Central Asian countries (Kyrgyzstan, Uzbekistan and Tajikistan) factor in winter extremes when designing, operating and maintaining infrastructure, they have less experience dealing with extreme heat and the potential for cascading impacts. An increase in the number of hot days with temperatures over 33°C under RCP2.6 and RCP4.5 for large parts of Uzbekistan and to a lesser extent Kyrgyzstan and Tajikistan (see Section 2.2) could therefore lead to unanticipated problems with electricity networks, especially during hot summer months when demand for cooling and irrigation pumping reach a peak – see below (Opitz-Stapleton et al., 2022).

South Asia plans to capitalise on cross-regional power sharing potential which remains underutilised and holds potential for risk mitigation. Interconnection can yield significant economic benefits for South Asia, including lower electricity costs through more efficient utilisation of renewables, price arbitrage, and efficiency gains through economies of scale. Cross-border trade can lower demand for new generation capacity by an estimated 35GW and 52GW in India and Nepal. Several forums and mechanisms raised the profile of energy cooperation, including the South Asian Association for Regional Cooperation (SAARC), South

Asian Subregional Economic Cooperation (SASEC), and Bangladesh-India-Myanmar-Sri Lanka-Thailand–Economic Co-operation (Wijayatunga and Fernando, 2013). When it comes to realised power trading in the region, India exports power to Bangladesh and Nepal and imports from Bhutan (Shrestha, 2022). While less integrated with other South Asian countries, Afghanistan and Pakistan are both members of the Central Asia Regional Economic Cooperation Program focused on facilitating regional connectivity and will benefit from the Central Asia – South Asia Transmission Interconnection Project (CASA-1000), initiated in 2008.[87] Under CASA-1000, hydropower-generated electricity from Kyrgyzstan and Tajikistan will be connected to markets in Afghanistan and Pakistan through 1,387 kilometres of high voltage transmission lines and facilitate trade of 1,300 MW of electricity.[88] Kyrgyzstan and Tajikistan can generate revenues on surplus electricity, while Afghanistan and Pakistan, alleviate power shortages and reliance on imports.

In Central Asia, recent shifts in the geopolitical environment have renewed interest in power trading. The Central Asia Power System (CAPS), a Soviet era electricity grid, interconnected the region, helping to balance seasonal variation and capitalise on different energy resource. Cooperation through the CAPS declined in the 2000s when both Turkmenistan and Tajikistan disconnected from the system (ADB, 2018). Tajikistan and Uzbekistan resumed power trade in 2018 and were planning to trade power from the contentious Roghun dam (Eurasianet, 2022). Wider power sharing across the region, beyond bilateral agreements, is contingent on substantial investment in upgrading and construction of additional transmission systems as well as scaling up power production, including capitalising on modern renewables potential across the region. Tajikistan has already modernised relay systems and built new interconnection points to re-establish connection with Uzbekistan with USD 35 million grant financing from the ADB (ADB, 2023e).

3.5.4 Energy demand

Demand for energy in Central and South Asia will rise significantly by the 2050s driven by population growth, urbanisation, rising incomes and higher temperatures. India's energy demand is set to grow by 25-35% between 2019 and 2030 depending on the shape of its economic recovery (IEA, 2021a). In Uzbekistan, electricity demand is projected to almost double between 2022 and 2030, rising from 76Twh to 138Twh, while Tajikistan projects an increase from 20 to 27GW over the same period (Tajikistan: Ministry of Energy and Water Resources; Uzbekistan: Ministry of Energy).[89] In common with most energy demand statistics, government projections are typically based on economic and demographic trends and do not account for climate change, particularly rising demand for cooling as summer temperatures rise (see below).

Rising demand for air conditioning linked to rising temperatures and heatwaves will amplify pressures on fragile systems in both Central and South Asia. Across Asia, rising

[87] CAREC members include Afghanistan (joined in 2005); Azerbaijan (2002); People's Republic of China (1997); Kazakhstan (1997); Kyrgyz Republic (1997); Mongolia (2002); Pakistan (2010); Tajikistan (1998); Turkmenistan (2010) and Uzbekistan (1997).
[88] When complete, the full CASA-1000 transmission lines will move electricity at high voltages between Kyrgyzstan and Tajikistan (the first 484 kilometres) and from Tajikistan to Afghanistan and Pakistan (the next 789 kilometres).
[89] However, demand projections for electricity are not always available across the region, e.g. for Kyrgyzstan.

summer demands will far exceed any energy savings from decreasing winter heating demands (Shaw et al, 2022). Rising household and industrial demand for cooling, and the need to cool agricultural and food products in supply chains, will likely strain electricity supplies in countries already struggling with unreliable and/or patchy services (see above). The highest peaks in electricity demand for cooling will likely occur during the 'moist' heatwaves that will increasingly affect eastern Pakistan, northern and eastern India, Sri Lanka and Bangladesh (see Section 2.2). In Pakistan, Ali et al. (2013) found that for every 1°C degree temperature rise over 30°C, electricity demand rises by roughly 110 million kWh driven by demand from cooling appliances, though this is likely an underestimate given widespread load shedding during peak hours. In India, overall energy demand is projected to rise by 15% over the period 2010-19 to 2050 because of warming-related residential air conditioning (AC) uptake alone, with daily summer demand peaks increasing by 20-30% as a result (Colelli et al, 2023); IEA (2018) project that the share of cooling demand in peak electricity load in India will rise from 10% in 2018 to around 45% in 2050 (IEA, 2018). In the city of Delhi, Sachar et al (2018) state that cooling demand *already* accounts for 40-60% of peak summer load. Data for Central Asia are scarce, but increased energy demand for current cooling during heatwaves has been estimated at 25% for Uzbekistan and Tajikistan (Peterson et al, 2021a; 2021b). Higher electricity demand to power irrigation and drainage pumps could also be expected in hotter conditions as crop water requirements increase. In Uzbekistan, irrigation and drainage pumping already accounts for 16% of national electricity generation, costing close to USD$350 million annually and accounting for 60% of the annual budget of the ministry responsible for irrigation. In Tajikistan, over 40% of irrigated agriculture relies on pumps – the highest percentage in Central Asia (Burt, 2017).

Targeted policy measures to improve cooling efficiency and building design can help manage warming-related increases in electricity demand (IEA, 2018). Improvements in the minimum energy performance of ACs offer a 'quick win' for managing cooling demands (IEA, 2018). In India, efficiency improvements could reduce the annual electricity consumption increase linked to rising temperatures by an estimated 40% (Colelli et al, 2013). More wide-ranging strategies have also been developed or planned in the region. In 2019, India became one of the first countries in the world to launch a comprehensive cooling action plan – the India Cooling Action Plan (ICAP) – to address the country's cooling needs while reducing climate impacts. In June 2022, Bangladesh published its own National Cooling Plan, and Pakistan has announced it will follow suit in 2026 (see Jha and Jain, 2022). To cope with much higher cooling demands and peak loads, countries will need grid flexibility, storage capacity,[90] and more peak power generation capacity (IEA, 2018; Barbar et al., 2023).

[90] For example, the daily pattern of solar power supply will not meet demand for cooling in the evening when ambient air temperatures are often highest in hot and humid areas (IEA (2018).

3.6 Environment

Image location: Nanga Parbat Mountain, Pakistan

<u>Summary of risks relevant to environment</u>

- The diverse ecosystems of Central and South Asia have come under intense pressure from agricultural expansion, urban encroachment, pollution, and wildlife trade. Climate change acts as an additional stressor on remaining habitats, hindering progress on SDG15: *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.*
- Species loss and extinction could accelerate across Central and South Asia due to a warming-induced shift of biome boundaries, and an upward shift in mountain treelines. Risks of species loss are highest in fragmented ecosystems where fauna/flora are unable to disperse or migrate along elevational (temperature) gradients.
- In the Tian Shan, Pamir, Karakorum, and Himalayan mountains, an upward shift in mountain treelines could increase human-wildlife conflict as shrinking alpine grasslands are contested for livestock grazing and conservation. Tajikistan, Kyrgyzstan, Kazakhstan, India, Pakistan, Nepal, and Bhutan contain many groups making their living by raising livestock in alpine zones, but endangered species such as the snow leopard require large protected areas.
- Ongoing problems of land degradation and desertification in Central Asia may be exacerbated by more intense droughts and higher levels of warming-induced evapotranspiration. The annual cost of land degradation in Central Asia is estimated at 3% of regional GDP, and more frequent/intense duststorms could result in significant soil loss and transboundary health problems. Forest dieback could also be expected in more arid and drought-prone conditions, further reducing Central Asia's forest cover - currently 1% and declining in all countries.
- Remaining wetlands are sensitive to changes in rainfall and temperature affecting inflows, direct evaporation and outflows, with evidence suggesting the wetlands of the Upper Meghna River Basin (Bangladesh and India) will be threatened by more intense monsoon rainfall and lower dry season inflows. Over 30% of natural wetlands were lost in Central and South Asia over the period 1970-2015 mostly due to draining for human use. Wetlands play a key role in storing carbon and reducing greenhouse gas emissions in addition to flood control, nutrient cycling, biodiversity, and food/fuel provision.
- There is growing interest in nature-based solutions to a range of climate mitigation and adaptation problems, including landscape restoration in Central Asia, and climate-informed design of public works programmes in India aimed at improving the productivity and resilience of natural resources. However, monitoring impacts over the long periods needed to restore landscapes is rare – a key evidence gap.

3.6.1 Context

Central and South Asia have diverse biomes that include temperate and montane grasslands, dry and moist broadleaf tropical and subtropical forests, scrub and woodlands (see Figure 15), deserts and wetlands. In the mountains of Central Asia – the Pamir and the Tien Shan (2,000-4,000m) - alpine and subalpine meadows support rich plant life, including endemic species. Meanwhile, their forests provide valuable ecosystem services, preventing erosion, and providing a source of food and timber from juniper, walnut and spruce forests (Yin et al, 2017; CEPF, 2017).

Both regions are rich in biodiversity, including global hotspots in the Hindu Kush Himalaya region and the mountains of Central Asia. India alone is home to 7-8% of all recorded species and has four biodiversity hotspots – the Himalayas, the western Ghats, the North-East and the Nicobar Islands (IUCN, n.d.). With the largest number of Ramsar sites in Asia (75), India's wetlands are also crucial to maintaining The Central Asian Flyway for migratory birds, with as many as 320 species (including 30 threatened waterbird species) found in the Thol Lake Wildlife Sanctuary (Government of India, 2022). The mountains of Central Asia (the Pamir and the Tien Shan) are home to many threatened animal species, including the snow leopard, Persian leopard and the Saiga, and 1,500 endemic plant species (CEPF, 2017).

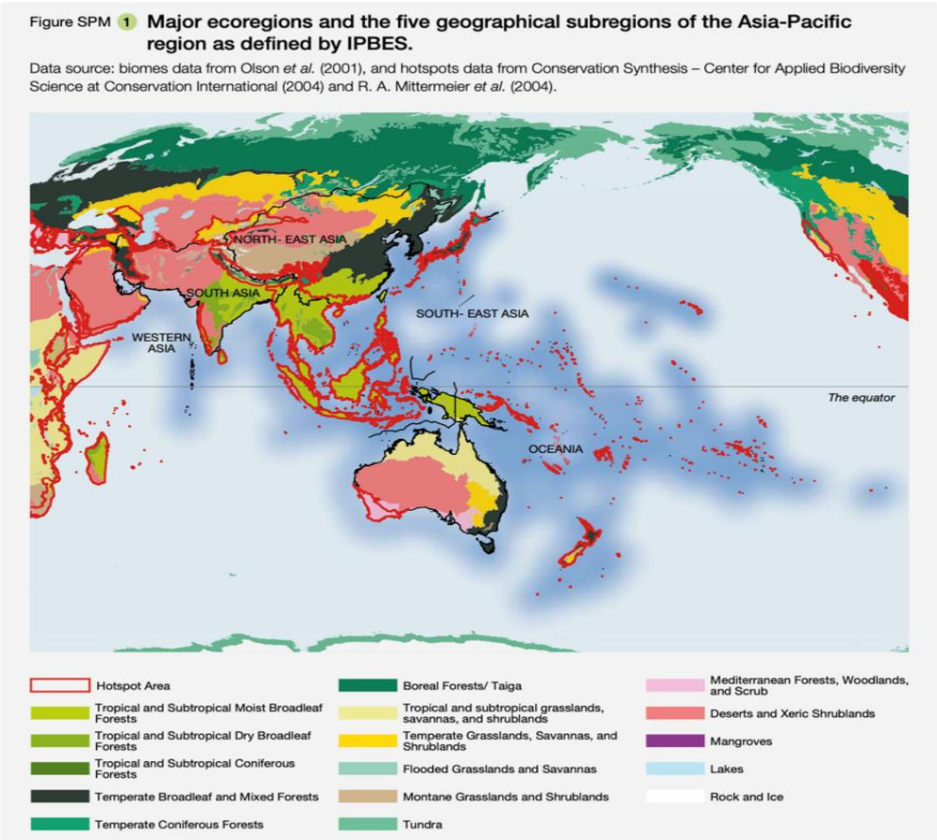

Figure 15: Major ecoregions and the five geographical subregions of the Asia-Pacific region as defined by IPBES.

Ecosystems across Central and South Asia provide valuable services that sustain local livelihoods and contribute to wider socio-economic support functions. Following the categorisation adopted for the Millenium Ecosystem Assessment (MEA, 2005), these services include *provisioning* – products obtained from ecosystems (e.g. food, fibre, fuel); *regulating* - benefits from the regulation of ecosystem processes (e.g. storm protection, erosion control, pollination); and *cultural* – the non-material benefits obtained by people (e.g. aesthetic, inspirational, spiritual). Wetlands, for example, contribute to both climate change mitigation and adaptation, and can make a significant contribution to reducing GHG emissions (Zou et al, 2022). Coastal mangroves, salt marshes and undisturbed peatlands provide carbon storage and support flood protection (see 3.7.2). Ecosystem services are discussed further in 3.6.4 below. Among the different ecosystem types, forests, alpine ecosystems, inland freshwater and wetlands, coastal systems are the most threatened (IPBES, 2018).

Across Central and South Asia, biodiversity is threatened by many different drivers of change, especially agricultural expansion and urbanisation, pollution, mining, and illegal wildlife trade (IPBES, 2018; Permesan et al, 2022). Protected area coverage is lagging across both regions, and climate change will likely alter the range of suitable habitats for many animal and plant species, reinforcing the need for transboundary cooperation to protect important habitat corridors and facilitate species movements across climate gradiants (Shaw et al, 2022). Agricultural expansion into natural habitats could also increase in response to climate-related reductions in crop yield on existing cultivated lands, exacerbating habitat loss (see Section 3.1.2). Collectively, these pressures are hampering progress on SDG15: *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.*

3.6.2 Biomes and habitats

Across Asia, and under a range of climate projections, rising temperatures are expected to contribute to a northward shift of biome boundaries and an upward shift in mountain treelines (Shaw et al, 2022; Parmesan et al, 2022). Upward shifts in elevation of bioclimatic zones, decreases in area of the highest elevation zones, and expansions of lower tropical and sub-tropical zones (Figure 15) are projected for the 2050s (Shaw et al, 2022). Projections are based largely on predictive modelling; few long-term data are available to document or verify biotic responses in either region (Parmesan et al, 2022).

The distribution of key flora including dominant tree species in Central and South Asia will be affected by higher temperatures. Higher mean temperatures have already altered plant groups in the alpine valleys of India’s northeastern Sikkim region, extending the upper ranges of almost 90% of endemic plants species (Telwala et al., 2013). Under RCP 6.0 and 8.5, suitable habitats for three of Himalayas’ tree line species – Himalayan silver fir, birch and blue pine - will shift to higher elevations and their range may expand, decreasing the areas of the highest alpine habitats (Chhetri et al., 2018). Himalayas’ lowland and highland species will likely see their distribution area increase, in contrast to those at mid-elevation, with their optimum elevation shifting by as much as 3m/year under the RCP 8.5 scenario (Maharjan et al., 2023). Targeted conservation measures will be critical in supporting tree species, particularly at higher elevations where maximum elevations are changing rapidly (Maharjan et al., 2023).

Forest cover in Central Asia has declined in all countries over the last 25 years driven mainly by agricultural expansion and overgrazing rather than climate change. Although forests cover only a small area (roughly 1%) of Central Asia, the region is home to diverse and important forest ecosystems, ranging from continuous evergreen forests in higher-rainfall upstream areas to patchy decidous forests in the more arid lowlands (Yin et al, 2017). Mountain forests play a key role in regional hydrology, regulating water flows from high mountain areas, contain a rich diversity of wild fruit and nut tree species, and serve as important carbon sinks (Yin et al, 2017). Due to its large territory, Kazakhstan is home to most of the region's forest (80% of the total), with a mix of deciduous, evergreen, and mixed forest types. Evergreen forests are more prominent in mountainous Tajikistan and Kyrgyzstan (Yin et al, 2017). Reliable country-level data on the status of Central Asia's forests is lacking, but global datasets (based on satellite imagery) highlight losses of between 0.4% (Kyrgyzstan) and 5% (Turkmenistan) over the period 2001-2023, with the largest losses in absolute terms in Kazakhstan (Global Forest Review, 2022). Forests have been cleared for agriculture in lowlands and on lower hill slopes, and overgrazing (see below) has also become a major problem following the collapse of institutions regulating rangeland access. For example, Tajikistan's limited forest cover (about 3%) is diminishing rapidly due to overexploitation and uncontrolled grazing.[91] For 70% of the population, fuelwood is the primary energy source due to an inconsistent energy supply (World Bank, 2020).

Forest dieback in semi-arid lowlands of Central Asia is likely as water stress and droughts intensify. The impact of drought on forest conditions remains poorly understood, but is known to alter leaf chemistry and increase mortality rates in trees, and is likely to alter community composition (Hughes 2017; Allen et al, 2015). Water limited and more drought-prone areas of Central Asia will likely be most vulnerable to forest dieback, although local relationships between changes in permafrost, snowpack, snow-rainfall patterns, insect outbreaks, wildfires, and seed dispersal will all shape outcomes to the 2050s (Shaw et al, 2022; Parmesan et al, 2022). Fire risks are also likely to increase, with hotter lowland areas (rangelands) likely to be most affected - see Section 2.2.2 (FAO, 2016). Although upward shifts in mountain treelines and more drought-related dieback episodes are projected, more specific forest growth and compositional changes remain difficult to predict (Parmesan et al, 2022).

In South Asia, changes in forest cover and composition will continue to be driven largely by non-climate factors, particularly agricultural expansion and, in poorer areas, the cutting of timber for fuel. Forest cover in South Asia increased by almost 6% between 1995 and 2015. Most expansion has occurred in India where afforestation and ecosystem restoration are central elements of the government's emissions reductions goals under the Green India Mission (Norton et al, 2019). However, global datasets do not distinguish between reforestation, natural regrowth of degraded forest, and harvesting/regrowth in plantations and production forests (Global Forest Review, 2022), and South Asia's increase in forest cover may derive largely from agricultural tree crops, while natural forests continue to be lost (IPBES,

[91] In 2018, Tajikistan along with five other Caucasus and Central Asian countries signed the Astana Resolution to restore about 2.7 million hectares of degraded forest landscapes. Tajikistan specifically committed to restore 48,000 ha of degraded forest landscapes from 2018-2030 (World Bank, 2020).

2018; FAO and UNEP, 2020).[92] Most countries in the region saw a decline in their forest carbon storage between 1990 and 2010, although India and Bhutan saw an increase (FAO, 2012). Continued use of wood as a cooking fuel, particularly in rural areas, is a significant driver of deforestation, affecting 30 million hectares of forest and contributing to indoor air pollution and respiratory illnesses (Sharma et al., 2016). In Bangladesh, over 70% of the population still use solid fuels for cooking, with 38-48% of all households using wood as the primary cooking fuel. Indoor air pollution accounts for over 60,000 deaths annually – see also Section 3.3 (World Bank, 2023a).

Ongoing problems of land degradation and desertification in Central Asia may be exacerbated by more intense droughts and higher levels of warming-induced evapotranspiration (Quillérou et al., 2016; Narbayep and Pavlova, 2022; Setlur et al., 2023). Roughly two thirds of Central Asia's land area consists of drylands with extreme biophysical constraints associated with arid and continental climates, making them vulnerable to both rising temperatures (and greater aridity, more intense droughts) projected to the 2050s, and direct anthropogenic pressures from land conversion, logging, and overgrazing (FAO, 2016; Quillérou et al., 2016). Land degradation is already a major problem, particularly in border areas where low land productivity, high poverty, and unemployment coincide, and in areas of intensive irrigation where high summer temperatures and poor drainage have caused soil and water salinisation in roughly 50% of irrigated lands[93] (see 3.1.2).

Land degradation trends and symptoms vary across Central Asian landscapes but impacts are widespread. The annual cost of land degradation in the region due to land use and cover change between 2001 and 2009 has been estimated at roughly USD6 billion, with most caused by rangeland degradation (USD4.6 billion), followed by desertification (USD0.8 billion), deforestation (USD0.3 billion), and the abandonment of croplands (USD0.1 billion) caused by soil salinisation (Mirzabaev et al, 2016). These costs exclude impacts from lower soil and land productivity within the same land use, but still account for between 3% and 11% of country GDP (Mirzabaev et al, 2016).[94] In Kyrgyzstan, around 30% of rangeland is estimated to be degraded; in Turkmenistan around 70% of rangeland pasture is degraded (Quillérou et al., 2016). Observed trends vary across the region with increasing desertification in western areas such as the Ustyurt Plateau (transboundary plateau and desert shared by Kazakhstan, Uzbekistan and Turkmenistan), and reversed desertification in parts of eastern Central Asia (e.g. Tien Shan mountains, southern Kazakhstan) where higher rainfall and desertion of rangelands contributed to the trend (Jiang et al., 2019). Deserts have also expanded in the north of the region, shifting by over 100 km (Hu and Han, 2022).

Increasing aridity in Central Asian lowlands could result in more duststorms and soil loss. In 2021, a summer heatwave in Kazakhstan dried up vegetation and soils to a depth of

[92] Remaining areas of natural forest are concentrated in the Himalayan region from northern Pakistan and Himalayan areas of NW India through Nepal and Bhutan to Arunachal Pradesh (in India), and in other higher elevation areas of northeastern India and southeastern Bangladesh, central and eastern regions of India, the mountainous Western Ghats of India from western Maharashtra to southern Kerala and Tamil Nadu, and in Sri Lanka (Ramakrishnan et al, 2012).
[93] Restrictions on the movement of pastoralists between seasonal pastures in different countries (e.g. from the mountains of Tajikistan to the plains of Uzbekistan) can result in overgrazing and land degradation along borders (Quillérou et al., 2016).
[94] Costs of land degradation as a share of GDP: Kazakhstan 3%; Kyrgyzstan 11%; Tajikistan 10%; Turkmenistan 4%; and Uzbekistan 3% (Mirzabaev et al, 2016).

50cm leading to a winter duststom extending into Uzbekistan and the Fergana Valley, with particulate levels far exceeding WHO-defined safe standards (Nishonov et al, 2021). Summer heatwaves are expected to increase in intensity, potentially increasing the frequency/intensity of duststroms. The shrinkage of the Aral Sea following upstream water diversion for irrigation led to the formation of Aralkum desert. With an area of approximately 60,000 km^2 and high salt concentrations, the desert contributes to sand and dust storms in surrounding areas – see also Sections 3.2 and 3.7 (Amrakhanov et al., 2021). Further shrinkage of the sea could exacerbate duststorms as meltwater flows in upstream catchments decline after the 2050s. In the Karakalpakstan region of Uzbekistan, afforestation with shrub and trees could help reduce the estimated USD44 million lost annually in foregone ecosystem services and health and agriculture impacts as a result of sand and dust storms from the Aralkum desert (Akramkhanov et al., 2021).

The health and integrity of wetlands are affected by many different factors, including higher temperatures and more intense droughts and heavy rainfall events. However, the main pressures come from drainage for agriculture, urban expansion, pollution and upstream water diversions. Central and South Asia have experienced overall declines in wetland area, even though some sites have likely gained in area between 1980-2014 (see Figure 16). The overall decline is reflected in the failure to meet relevant Aichi targets (Convention on Wetlands, 2021). While the proportion of human-made wetlands has expanded, natural wetlands have declined by over 30% between 1970 and 2015. Central Asian countries (few country-specific details available) and India are among the key regional hotspots where over 50% of wetlands were lost by 2020, with India alone accounting for 6.5% of global wetland losses (Fluet-Chouinard et al., 2023). However, there is large variability in wetland coverage trends between 2000 and 2018 (Tesch and Thevs, 2020). For instance, in Kazakhstan's Ili River Delta, wetland territories supporting important bird areas decreased substantially between 2010 and 2015 due to the construction of the Kapchagai hydroelectric station (RSIS, 2012) but then increased over the following three years (Tesch and Thevs, 2020).

More intense droughts and higher levels of evapotranspiration are the main climate-related threats to wetlands in the Upper Meghna River basin and south, central and eastern India (see Figure 16). In south, central and eastern parts of India, which experience droughts every 4-5 years and where the probability of intense droughts is higher, wetlands are vulnerable to the drying of surface and groundwater. Changes to their hydrological balance, and higher groundwater extraction during periods of low rainfall, have contributed to their deterioration (Roy et al., 2022). In the transboundary Upper Meghna River Basin shared by Bangladesh and India, which supports rich wetland ecosystems, dry season (October-May) flows are projected to decline by up to 60% while monsoonal streamflows (June-September) are projected to increase by around 12% by 2040 and 42% by 2080 under RCP 4.5 (Rahman, 2017). Rising temperatures are already leading to water scarcity in dry seasons on major rivers like the Meghna, which form part of the basin and contribute to the haors (wetlands) in northeast Bangladesh, with observed higher temperatures leading to water scarcity in dry seasons (IUCN, 2021). The wetlands, already threatened by overuse, play an important ecosystem role in sustaining fish populations and fish-dependent livelihoods.

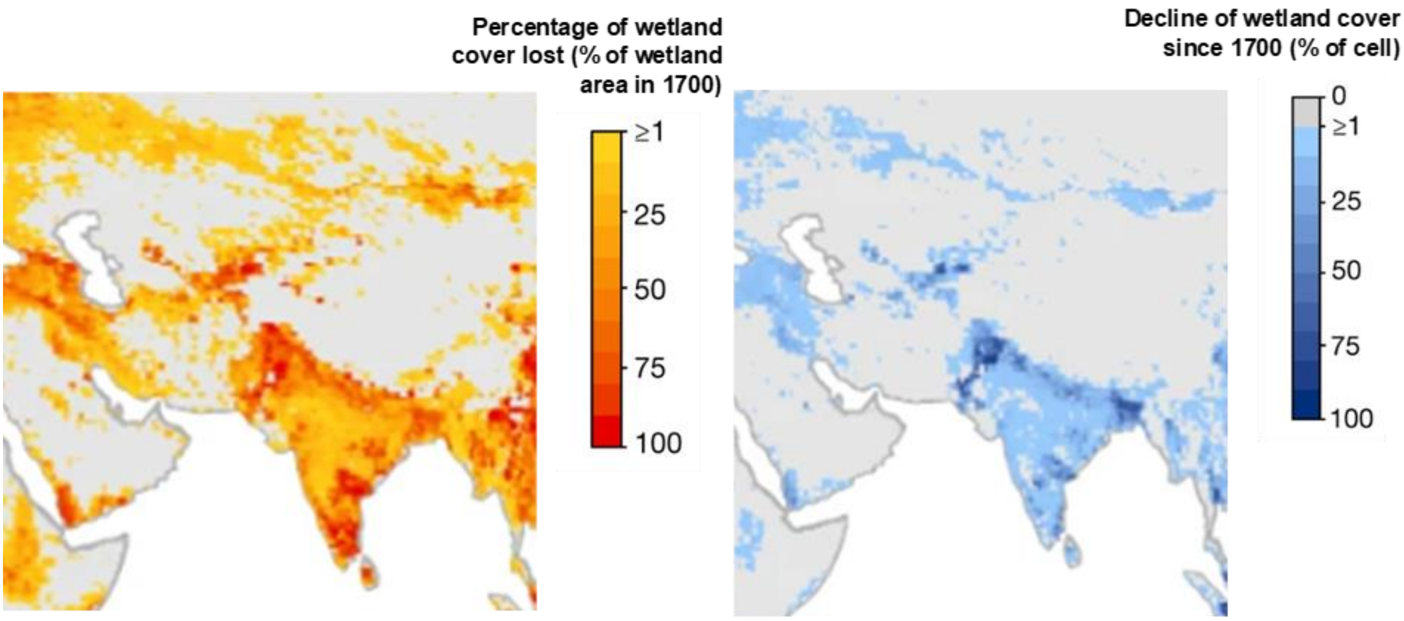

Figure 16: left) percentage of wetland cover lost (% of wetland area in 1700), and right) decline of wetland cover since 1700 (% of cell). Source Fluet-Chouinard, et a., 2023.

3.6.3 Biodiversity and species loss

Climate change is likely to cause or exacerbate biodiversity and habitat loss in many parts of Asia, but local evidence based on long-term data is lacking (Shaw et al, 2022). Changes in temperature and rainfall will likely affect species distribution, species interactions, population sizes, and the timing of reproduction or migration, but relationships are complex. It is largely unknown how broad-scale climate variables interact with local-scale factors to shape species response, including site-specific changes in land use (Hughes, 2017; Shaw et al, 2022). However, species losses are likely to be greater in ecosystems that have become fragmented.

Ecosystems that are fragmented, either naturally or as a result of habitat destruction, are likely to be most at risk from climate-related losses. This is because species unable to survive changes in climate may become regionally extict if they are unable to disperse or migrate, for example by moving along elevational (temperature) gradients which allow them to 'track climate change' (Hughes, 2017; Shaw, 2022). Reduced competitive pressures from incomers in fragmented landscapes could *potentially* aid survivial, but lack of obervational data on the impacts of climate change on isolated fragments means that evidence-based projections are difficult to make (Hughes, 2017).

Ecosystems and endemic species are under threat from land conversion, wildlife trade, pollution, the spread of invasive species, higher temperatures, and changing hydrological conditions (IPBES, 2018). Central Asia includes one of the world's biodiversity hotspots – the Central Asian mountains (Tian Shan, Pamir). South Asia includes three hotspots - Himalayas, the tropical Indo-Burma area, and the Western Ghats mountain range in western peninsular India. While there has been an increase in forest cover across some parts of the Asia-Pacific region, biodiversity continues to decline with 25% of the region's endemic species 'threatened' (IPBES, 2018; see above on deforestation). Continued habitat loss as a result of agriculture conversion and population pressures will likely continue across the continent (Farhadinia et al., 2022). Wildlife trade for markets in traditional medicine and pets also threatens species across the region (IPBES, 2018). In India, many of the country's 1394 threatened species, including rhinoceros, tigers, and elephants, are in decline because of habitat loss and poaching (Rana and Kumar, 2023). Climate change is thought to have caused habitat loss for amphibians and the extinction of some endemic species in Sri Lanka (Kottawa-Arachchi and Wijeratne, 2017).

Across both regions, higher mean temperatures and changing precipitation will affect the range, ecological interactions and behaviour of key fauna (Salas et al., 2018; IPBES, 2018). Suitable habitats of the Marco Polo sheep (argali) in the Pamirs in the east of Tajikistan, already classified as a 'near-threatened' species and under pressure from wildlife hunting, will expand at higher elevations due to warmer temperatures, but shrink at lower elevations due to less rainfall under both RCP 4.5 and 8.5 (Salas et al., 2018). The habitat for Marco Polo sheep, that play an important ecosystem role as grazers and prey for larger animals like snow leopards, will also be affected by terrain ruggedness (a measure of the overall variablity of terrain elevation within an area). Precipitation in driest and coldest seasons along with higher mean temperatures and humidity determine the habitats of the endangered Kashmir musk deer, important for determining ecosystem health. The range of Kashmir musk deer will likely expand from central Nepal and east/northeast Afghanistan to parts of India, Nepal and China, but shrink in Kashmir and along the Pakistan-Afghanistan border under all four RCPs – RCP2.6, RCP4.5, RCP6, and RCP8.5 (Singh et al., 2020). Between 10-30% of snow leopard habitats in the Himalayas (an importance species for tourism in Nepal and north India) could be lost because of shifting (upward) treelines and consequent shrinking of alpine zones under the four RCPs, leaving them unable to compete with other large predators and exposing them to retaliatory killings from livestock grazing (Forrest et al., 2012; Kazmi et al., 2022). Results indicate that about 30% of snow leopard habitat in the Himalaya may be lost due to a

Human-wildlife conflict in alpine zones may increase as land available or suitable for livestock grazing in mountain grasslands is squeezed. Kazakhstan, Kyrgyzstan, Tajikistan, India, Pakistan, Nepal, and Bhutan contain many groups making their living by raising livestock extensively on upland pastures, often migrating seasonally between high-altitude alpine meadows and the plains (Kerven et al, 2012; Singh and Kerven, 2023). However, restrictions on pastoral mobilities and loss of access to critical pastures has increased pressure on more limited areas, with resource-sharing by livestock and wildlife often seen as conflicting with conservation efforts (Singh and Kerven, 2023). Upward shifts in montane forest treelines (see above) could also 'squeeze' mountain pasture areas as temperatures increase, and increase pressure on or in conservation areas for snow leopard (see above) and endemic alpine plant species (Forrest et al., 2012; Kazmi et al., 2022). Alpine areas are also important for medicinal and aromatic plant collection (Forrest et al, 2012). In Himachal Pradesh, the northernmost state of India, Srivasava (2022) argues that instead of helping pastoralists deal with the impacts of climate change, the government has instead used a 'climate change narrative' to legitimise attempts to settle them in the western Himalayas.

Many Asian countries have struggled to achieve Aichi biodiversity targets for protected areas, however securing species habitats in the future will require even higher ambitions and adopting transboundary ecosystem approaches. While some South Asian countries were on track to achieve Aichi Target 11 for designating 17% of land to protected areas by 2020, the region will nonetheless struggle to meet the 30% target by 2030 (Farhidinia et al., 2022).[95] In contrast, Central Asia – lagging on the same Aichi 2020 targets - will likely achieve the 2030 target (Farhidinia et al., 2022). However, protected areas may still fail to fully reflect diverse ecosystems and may need to expand, particularly in hotspot areas such as the Tian Shan, Pamir, and Himalayan (FAO and UNEP, 2020). Weak monitoring and enforcement of control measures in protected areas is also an issue. In Tajikistan, for example, land degradation within protected areas is an ongoing problem because they lack management plans, proper boundary mapping, and monitoring of resource access and use (World Bank 2020). As the range of key biomes and habitats change with climate, protected area boundaries may need to shift (Forrest et al., 2012; Salas et al., 2018; Hoffman et al., 2019). Integrating transboundary approaches and regional cooperation in the high mountains and across border hotspots (areas rich in biodiversity) in Asia, home to 82% of global border hotspots, will be critical to supporting ecosystems and threatened species (Xu et al., 2019; Farhadinia et al., 2022).

3.6.4 Ecosystem services

Ecosystem services support large populations across South and Central Asia but services have been under-valued by markets. Across Asia-Pacific the value of services of terrestrial ecosystems is estimated at USD 14 trillion (Kubiszewski et al., 2016). In the Hindu Kush Himalaya, ecosystem services support around 240 million people and benefit almost two billion people living in its basins (Xu et al., 2019). In Bhutan alone, the value of ecosystem services – including their contribution toward climate mitigation via carbon sequestration in forest cover and ecotourism – is reckoned to exceed country GDP: USD15.5 billion annually compared with USD3.5 billion for GDP (Xu et al., 2019). The value of ecosystem services across Hindu Kush Himalaya remains poorly understood compared with other sectors such as water and hydropower (Xu et al., 2019). The value of services provided by wetlands, for instance, are now more widely recognised, but empirical assessments are lacking (Convention on Wetlands, 2021).

South Asia has great potential to incorporate Nature-based Solutions (NbS) to restore and protect ecosystems, while this approach has gained political traction, barriers remain to realising the region's full potential (Fernandes et al., 2022). The IUCN defines NbS as "Actions to protect, manage and restore natural or modified ecosystems, which address societal challenges, effectively and adaptively, providing human well-being and biodiversity benefits".[96] While there are limited policies and legal mechanisms to integrate NbS in countries such as India, Bangladesh and Nepal, existing frameworks can assist with their

[95] Aichi Target 11 of the Convention on Biodiversity: By 2020, at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes. See: https://www.cbd.int/aichi-targets/target/11

[96] NbS incorporates a range of different approaches including: 1. Ecosystem-restoration approaches (e.g., ecological restoration, ecological engineering and forest- landscape restoration) 2. Issue-specific ecosystem-related approaches (e.g., ecosystem-based adaptation, ecosystem- based mitigation, and ecosystem-based disaster risk reduction) 3. Infrastructure-related approaches (e.g., natural infrastructure and green infrastructure approaches) 4. Ecosystem-based management approaches (e.g., integrated coastal zone management and integrated water resources management) 5. Ecosystem-protection approaches (e.g., area-based conservation approaches, including protected-area management).

mainstreaming. Across the three countries, different NbS approaches have been applied in both rural and urban contexts. Under the Greening Lumbini Initiative in Nepal, wetlands were restored, higher nesting grounds were created for sarus cranes, classified as vulnerable species, and drought and flood resistant native varieties of rice were reintroduced (see Fernandes et al., 2022 for further examples).

In Central Asia a number of programmes are being implemented to raise awareness of ecosystem services and implement NbS. Applying land restoration solutions in Uzbekistan's Karakalpakstan region can both provide additional benefits worth around USD 39 million a year and prevent degradation of ecosystem services (Akramkhanov et al., 2021). Under the umbrella of the World Bank's RESILAND CA+ programme with support by UK PACT, IUCN and Uzbekistan's Ministry of Ecology, Environmental Protection and Climate Change have convened a regional dialogue on the regulatory, financial, and implementation challenges for mainstreaming NbS across the region (IUCN, 2023). Under the RESILAND CA+ programme, the World Bank has committed almost USD200M in Kyrgyzstan and Uzbekistan to finance land restoration (World Bank, 2023b; 2023c). In Tajikistan, the programme also aims to reverse land degradatioin through a mix of afforestation, natural regeneration, forest protection, joint forest management, pasture protection, and other landscape management interventions (World Bank, 2020).

Employment-based public works programmes are seeking to additionally address climate adaptation and mitigation goals in some South Asian countries through NbS-aligned interventions (Davies et al, 2013; Costella et al, 2021; Norton et al, 2020). Public works or public employment programmes (largely rural) aim to meet immediate consumption/income needs (coping capacity), and strengthen livelihoods over the longer term (adaptation and resilience). Since rural livelihoods are typically dependent on the natural resource base, public works often focus on land, soil and water management, with the objective of creating a productive safety net - breaking the link between repeated cycles of deprivation and humanitarian assistance (Costella et al, 2021). One of the largest programmes globally is the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), which included around 120 million active workers and generated upwards of 2.5 billion person days of work in 2018.[97] A large part of the labour supported by the programme is directed at environmental objectives: soil and water conservation, groundwater recharge, tree planting, and sustainable land management (Norton et al, 2022).The Indian government is now seeking to integrate explicit adaptation and mitigation objectives though climate vulnerability mapping, climate-informed design of natural resource interventions, and the expansion of employment during drought periods (Costella et al, 2021; Norton, 2022). Monitoring the impacts of nature-based interventions over the long periods needed to restore landscapes remains rare. Similarly, the longer-term impacts of natural resource-orientated public works programmes are usually assumed rather than systematically assessed (Costella et al, 2021).

Wetlands play a key role in storing carbon and reducing greenhouse emissions in addition to the other regulating and provisioning services they provide. Wetland greenhouse gas budgets are highly sensitive to changes in wetland area, and wetland

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[97] Other public works programmes in South Asia include the Employment Generation Programme for the Poorest (Bangladesh), the Kamali Employment Programme (Nepal), and the Community Physical Infrastructure programme in Pakistan (Norton et al, 2022).

restoration – specifically rewetting – can be a very effective NbS for reducing GHGs. A global study by Zou et al (2022) indicates a volume equivalent to 10% of anthropogenic CO_2 emissions could be reduced through wetland restoration. This is higher than potential GHG reductions from the rehabilitation of other types of ecosystem, for example forest re-growth or afforestation (Zou et al, 2022).

Permafrost zones also store greenhouse gasses and thawing in the high mountains could release large quantities of GHG and impact vegetation growth and composition (Parmesan et al, 2022). However, relationships between rising temperatures, thawing, vegetation change, and the timing/ magnitude of gas release are poorly understood, and regional data are limited. Global evidence suggests that increased ecosystem carbon losses could potentially cause large temperature increases in the future (Parmesan et al, 2022).

3.7 Blue economy and the marine environment

Image location: Sri Lanka

Summary of risks relevant to blue economy and the marine environment

- Central Asia's inland seas and South Asia's coastal and marine ecosystems are threatened by compounding problems of habitat destruction, over-exploitation of aquatic/coastal resources, and climate change. Coastal and marine habitats play a key role in supporting livelihoods, local economies, and food security, and combined risks will hamper progress towards SDG14: *Conserve and sustainably use oceans, seas and marine resources for sustainable development.*
- Reduced meltwater (river) inflows to the North Aral Sea in Central Asia from the 2050s onwards, combined with higher temperatures and more intense droughts, will likely contribute to the sea's longer-term shrinkage, with negative impacts on remaining fish stocks and ecosystems. Higher inflows from 2005 onwards have led to a partial recovery in water levels following decades of decline caused by upstream river diversions, but the rebound effect will likely be temporary.
- The Caspian Sea in Central Asia is the largest inland lake in the world and supports the livelihoods of millions of people in the sea's five littoral states, but water levels are projected to drop by 8-14m by 2100 because of higher rates of warming-induced evaporation. Sea shrinkage could cause major ecosystem disruption, cut off exisiting ports and trade routes, and create tensions over fishing zones and oil and gas claims.
- Ecosystems are threatened by rising sea temperatures and marine heatwaves (corals), ocean acidification (corals), and sea level rise, cyclones, and storm surges (corals, mangroves, sea grass meadows and salt marshes). South Asia's coastal ecosystems include the world's largest mangrove forest (the Sundarbans, Bay of Bengal), coral reefs (India, Sri Lanka, Maldives), and important sea grass beds and salt marshes, all providing key provisioning, regulating, and cultural services. The Sundarbans mangrove forest provides direct and indirect benefits to around 3.5 million coastal people, with a total asset value to Bangladesh estimated at USD10 billion, including cyclone and flood protection.
- Tourism industries relying heavily on coastal zones and coral reefs for tourism (Maldives, Sri Lanka) will be negatively affected by rising sea levels and coral loss. Sri Lanka's tourism sector accounted for roughly 6% of GDP and 1 in 11 jobs in 2021, and most of the tourism economy is located on exposed coastlines.
- Fish catch potential is projected to decline in the Arabian Sea, Bay of Bengal, and East Indian Ocean due to climate-driven changes in ocean conditions and coastal-oceanic food webs. Climate risks will disproportionately affect poorer, artisanal fishers restricted to near-coast waters, less able to adapt to shifting fish distributions and more exposed to climate extremes.
- Despite the importance of fish to livelihoods and food security, especially in Maldives, Bangladesh, Sri Lanka, and India, links between climate change and fish productivity/distribution remain poorly understood – a key evidence gap.

3.7.1 Context

Marine and coastal environments play a significant role in supporting livelihoods, economies, food security, and ecosystems in both Central and South Asia. The South Asia coastline, extending for around 12,000km, supports some of the most extensive and diverse marine ecosystems in the world (SACEP, 2019). India, Pakistan, Sri Lanka, Bangladesh, and Maldives have coastlines hosting 400 million people (UNISDR/UNDP, 2012) with major ports, fishing industries, and tourism economies, although the composition and importance of the blue economy[98] varies between countries. Central Asia encloses the Caspian Sea, surrounded by Iran, Azerbaijan, Kazakhstan, Turkmenistan, and the Russian Federation, and also the Aral Sea lying between Kazakhstan to its north and Uzbekistan to its south. Both are continental water bodies cut off from the ocean that contain (largely) salty water. Inland and coastal-ocean environments in both regions are affected by climate and non-climate pressures, undermining SDG 14: to *conserve and sustainably use the oceans, seas and marine resources for sustainable development* (United Nations, 2015).

South Asia's coastal and marine environment is threatened by pollution, the loss of coastal ecosystems to agriculture and urban expansion, and over-fishing. The Ocean Health Index[99] of all countries in the region, except Bangladesh, was below the global average figure of 69 in 2022 (Ocean Health Index, 2022). Key climate-related pressures include sea level rise, exacerbating the impacts of more intense cyclones, storm surges and flooding; and rising sea temperatures, marine heatwaves and ocean acidification affecting coastal and marine flora and fauna, including mangrove forests, coral reefs, and fisheries (see Section 2.1 for physical trends). The causes and consequences of sea level rise and coastal flooding are discussed further in Sections 3.1, 3.2 and 3.5, with key headlines summarised in Focus Box 7 below.

The Aral Sea in Central Asia was once the fourth largest inland lake in the world, but upstream irrigation diversions on the Amu Darya and Syr Darya rivers since the early 1960s have led to shrinkage and salinisation (see also Section 3.2). Between 1960 and 2018, the sea's surface area shrank by 60,156 km^2, or roughly 88% (Yang et al, 2020). As it receded, the sea also split into a number of residual basins: the North Aral Sea; the South Aral Sea; and more recently the division of the South Aral Sea into eastern and western sections (Yang et al, 2020; Ma et al, 2024). The exposed seabed has created the Aralkum Desert, contributing to damaging dust storms (see Sections 3.3 and 3.6). Since 2005, increased inflows have led to a modest expansion of the North Aral Sea, although the recovery may only be temporary (see below).

The Caspian Sea, in contrast, has retained its status as the largest inland lake in the world, supporting unique ecosystems and the livelihoods of millions of people in the sea's five littoral states (Prange et al, 2020). However, climate-impact projections suggest lake water levels will continue their recent decline to 2050 and beyond, with far-reaching ecological, economic and

[98] The blue economy can be described as the sustainable use of ocean resources to improve livelihoods and employment and support economic growth (World Bank, 2017).
[99]The Ocean Health Index is a measure of the state of the world's oceans, providing an independently verified assessment of ocean health based on the sustainable provisioning of benefits and services people expect from healthy oceans, such as food, cultural and social services, and jobs. A high score describes a healthy ocean sustainably delivering a range of benefits. The score is an average of 10 goals representing ecological, social and economic benefits. See: https://oceanhealthindex.org/

geo-political consequences (Prange et al, 2020; Koriche et al, 2021; Samant and Prange, 2023).

Focus Box 7: Coastal flood risks in South Asia – key headlines

South Asia is one of the most flood-exposed regions of the world in terms of *absolute* exposure (numbers of people exposed to coastal and river floods) and *relative* exposure (proportion of the population exposed to such floods) (Rentschler and Salhab, 2020). Roughly 370 million people in South Asia are currently exposed to significant flood risk– some 20% of the region's population. Absolute numbers are highest in India (225 million people), Pakistan (72 million) and Bangladesh (52 million); relative exposure is highest in Bangladesh (32%) (Rentschler and Salhab, 2020).

By the end of the century, and without effective adaptation measures, coastal flooding will likely affect 5-18 million people in India, depending on the emission scenario (World Bank, 2021a). Around 14% of India's population live in coastal districts where long-term average sea-level rise is estimated at 1.7mm/year (World Bank, 2021a; MoEFCC, 2021). The eastern coast is particularly exposed as major river deltas allow storm surge water to flow further inland (Rao et al., 2020a; 2020b).

Around 46% of Bangladesh's population live in areas that are within 10m of current sea level (Roy et al., 2022), and more than 80% of the country's coastal population may be exposed to low-level flooding (>0.1m) by 2100 under SSP5-RCP8.5 (Mitchell et al., 2022). The poorest households are already disproportionately threatened in most (69%) coastal subdistricts (Adshead et al, 2014). The low-lying Ganges-Brahmaputra-Meghna delta shared by India and Bangladesh is home to around 500 million people exposed to faster-than-global average sea-level rise (Becker et al., 2020 – see also Focus Box 3, Section 3.1). Higher sea levels may exacerbate coastal flooding caused by more intense cyclones and storm surges and increase the risk of soil salinisation and saline water intrusion into freshwater aquifers (Mycoo et al., 2022; Barbour et al, 2022). However, recent analysis of delta dynamics focussing on sediment supply and deposition suggests that accelerated sediment flows to the delta (caused by more intense monsoon rains) could compensate for sea level rise and ensure continued sustainability of the delta system if sediment supply is not interrupted by upstream dam building and river diversion (Raff et al, 2023).

In Maldives, more than 50% of the population may be exposed to coastal inundation by the 2100s under RCP4.5 due to sea-level rise and storm surges. Much of the country's tourism infrastructure, fisheries infrastructure, harbours, settlements, and its four international airports are located within 100m of the coastline (World Bank and ADB, 2021a). Sea-level rise and storm surges will also lead to continued coastal erosion and beech loss. Across South Asia as a whole, sandy shorelines could retreat by up to 350m (Ranasinghe et al., 2021).

Sri Lanka is less exposed than Maldives to sea level rise because of its hillier terrain, but the combined effects of sea level rise and storm surges are more significant, with potentially 400,000 to 500,000 people living in flood plains exposed to heightened storm surges by the 2060s (World Bank and ADB, 2021b).

3.7.2 Biodiversity and ecosystem services

Coral reefs

Rising sea temperatures around southern India, Sri Lanka and the Maldives are approaching the upper tolerance limits for most coral species. Projected warming trends suggest that southern India, Sri Lanka and the Maldives will face increasingly stressed coral environments by mid-to-late century due to rising sea surface temperatures and more frequent and intense marine heatwaves (Fordyce et al, 2019; SACEP, 2019 - see also Section 2.1). Warmer sea surface temperatures and marine heatwaves can stunt reef growth, cause coral bleaching, and lead to coral death (van Woesik et al., 2022). Bleached corals can recover, but are more susceptible to disease in a bleached state. New reefs can also form after mass mortality events, but re-growth can take several decades (World Bank and ADB, 2021a). Ocean acidification can also compromise coral growth (Lam et al, 2019) but research on changing acidity levels and their impact on marine life is lacking (Focus Box 8). Reef health is also affected by more direct human influences such as coral mining, reef entrance blasting, dredging, solid waste and sewage disposal, all of which have affected coral health in Maldives (World Bank and ADB, 2021a). Conditions in the Bay of Bengal are too turbid for extensive reef development.

Mass coral bleaching events have increased over the last 20 years particularly in warmer waters where reef species are close to their thermal tolerance limits (Fordyce et al., 2019). Rising summer sea surface temperatures are increasing the frequency and the intensity of marine heatwaves, especially in the southern Indian Ocean (Cheng et al., 2023; IPCC, 2021). The Maldives contains coral atolls developed from the natural growth of extensive coral reef habitats that support significant reef biodiversity. A marine heatwave linked to an El Niño event destroyed significant coral cover in 1998, with up to 90% mortality (UNISDR/UNDP, 2012). The Chagos Islands in the Indian Ocean host the largest atoll in the world, the Great Chagos Bank. Long-term coral reef monitoring started in the 1970s with two major coral bleaching events recorded in 1998 and 2015-2016 (Koldeway et al., 2021).

Focus Box 8: Ocean acidification

Oceans are becoming more acidic (lower pH) as they absorb excess amounts of atmospheric CO_2 released from human activities. Ocean acidification interacts with pre-existing stressors such as pollution, sedimentation, overfishing, rising sea surface temperatures, and habitat destruction (Lam et al., 2019). The consequences of more acidic conditions on marine life are the subject of intense research efforts, but reported effects include changes in cellular biology, physiology, population dynamics, and ecosystem function (Hansson and Gattuso, 2011).

There is still considerable uncertainty over the likely impacts on many ecosystems, organisms and species, and their ability to tolerate and/or adapt to more acidic conditions (Doney et al., 2020). For example, emerging evidence suggests the physiology of some fish species can adapt to a lower pH in their blood, while marine invertebrates with calcium carbonate skeletons such as corals, zooplankton, and shellfish are likely to grow more slowly (Esbaugh, 2017; Lam et al., 2019). Further uncertainty remains over how these effects will interact in complex ecosystem dynamics, for example in pelagic or coral reef food webs, where the nutrition of commercially important fish relies on the productivity of zooplankton or corals (Doney et al., 2020).

Coral reefs help protect coastlines, drive tourism, provide nurseries for fish and support shallow water artisanal fishers, therefore the health of coral ecosystems is important. In the Indian Ocean, the services provided by coral reefs contributed around USD 2 billion to the region's GDP in 2017 (Lam et al., 2019). In the Maldives, tourism linked to coral reefs contributed roughly 26% to national GDP in 2019 (Maldives Tourism Ministry, 2021). Coral reefs also help dissipate wave energy, especially during storms, protecting coastlines from erosion and flooding (Ferrario et al, 2014; Burke and Spalding, 2022). In Maldives, coral reefs are estimated to prevent around USD 3.6 billion of flood-related damage over 10-year periods based on 2019 prices, equivalent to 55% of GDP (Amores et al., 2021; Burke and Spalding, 2022). While coral reefs are less extensive in India, their flood protection value over a decade has been estimated at USD 3.3 billion in 2019 prices (Burke and Spalding, 2022).

Mangroves

Mangroves provide coastal protection and other ecosystem services in South Asia but large areas of primary forest have been lost. Rates of decline have slowed since the mid-1990s (Macintosh and Ashton, 2002; Giri et al, 2015; Leal and Spalding, 2022). Mangroves help protect coasts through wave attenuation, shoreline stabilistion and shelter from high winds. They also provide an important source of timber, livestock forage and food, sequester and store significant amounts of carbon,[100] and provide important habitats for fish and invertebrates (Giri et al, 2015; Rahman et al, 2021). For example, around 82% of fishers in Bangladesh fish in and around mangroves (Leal and Spalding, 2022). Large areas have been deforested, however, with estimated losses of 85% in India, 75% in Pakistan, and 73% in Bangladesh between the 1960s and 1996 (Macintosh and Ashton, 2002). Rates of decline in South Asia have since slowed, with a net loss of around 3% since 1996, albeit with significant local variation (Leal and Spalding, 2022). Conversion to agriculture or aquaculture is the most common driver of change (Macintosh and Ashton, 2002; UNISDR/UNDP, 2012; Leal and Spading, 2022). In Sri Lanka, 40-50% of mangrove habitat was cleared for aquaculture development between the 1980s and 2010s (FAO, 2018). River modification, particularly the construction of dams and diversion of water for irrigation, has also negatively affected the hydrology, sedimentation, and salinity of mangrove forests (SACEP, 2017).

Mangroves are potentially vulnerable to rising sea levels and more intense cyclones and storm surges, but much depends on site-specific relationships affecting relative sea level rise (Ward et al., 2016; Woodroffe et al., 2016; Kazi et al, 2022). Rising sea levels can increase the frequency, depth, and duration of inundation experienced by mangroves, making them vulnerable to drowning or coastal squeeze – the loss of inter-tidal habitat (Woodroffe et al., 2016). Mangrove vulnerability varies spatially as relative sea level rise is a function of local coastal subsidence and climate-driven sea level rise, as well as mangrove sediment accretion and wider (catchment-delta) sediment dynamics. Many studies conclude that mangrove sediment accretion can keep pace with sea level rise as long as sufficient sediments continue flowing to coastal areas (Woodroffe et al., 2016), although that depends on upstream river diversions and daming (Raff et al, 2023 – see Focus Box 7).

The status of the Sundarbans mangrove forest, a protected UNESCO World Heritage Site located in the Ganges-Brahmaputra delta, highlights the effects of intense cyclones on forest integrity but also the role mangroves play in protecting coasts (Kazi et al, 2022). The Sundarbans mangrove forest, the largest in the world at roughly 10,000km^2, is a global biodiversity hotspot supporting 350 plant species, 300 bird species, and 250 fish species, and is the main habitat for the Bengal Tiger (SACEP, 2019; Raff et al, 2023). The forest also provides direct and indirect benefits to aound 3.5 million coastal people, with a total asset value to Bangladesh estimated at USD10 billion, including cyclone and flood protection

[100] Tropical mangrove forests have a higher carbon density than tropical rainforest and sequester carbon faster than any other terrestrial ecosystem (Donato et al, 2011).

functions (Kazi et al, 2022).[101] Over the last three decades the Sundarbans region has experienced over 20 major cyclones causing significant damage. Cyclone Sidr (in 2007) destroyed 10-45% of Sundaraban mangroves, with many areas yet to fully recover (Kazi et al, 2022). This highlights the long-lasting damage more intense cyclones and storm surges could potentially cause in future, and the need for proactive restoration as well as natural regeneration and mangrove protection (Payo et al., 2016; Samanta et al., 2021; Kazi et al, 2022).

Seagrasses

Seagrass survival in India, Bangladesh, Sri Lanka and Maldives is threatened by rising sea levels, warmer waters, and ocean acidification, potentially diminishing habitats for vital fish species and depleting carbon storage. Sea grasses form an important part of coastal marine ecosystems in India, Pakistan, Bangladesh, Sri Lanka and the Maldives (Patro et al. 2017; FAO, 2018) and provide a number of important ecosystem services. For example, sea grass meadows provide nurseries and breeding grounds for fish and other organisms, help stabilise sediments and prevent erosion, support coral reefs by trapping heavy metals and nutrients, provide forage and food for marine turtles and dugongs, and sequester carbon (Patro et al., 2017). However, rising sea levels can inundate seagrass meadows and restrict their growth, and warmer sea temperatures can lead to seagrass mortality (FAO, 2018). Tropical cyclones have also been associated with damage to seagrass habitats around the Andaman Islands, so more intense cyclone events (see Focus Box 9) may also pose a threat (Patro et al., 2017). Nonetheless, the main threats to seagrasses will continue to come from pollution, eutrophication, dredging, and destructive fishing techniques such as bottom trawling.

Despite their ecological importance, research on seagrass services and climate sensitivities is limited. Some 15 species of seagrass are reported in South Asia; all are present in India, eight in Sri Lanka, five in Bangladesh and two in the Maldives (Patro et al., 2017). Based on a limited-survey and using then-current carbon prices, one study found that carbon sequestration services of seagrasses in India ranged between USD 1.02 million and USD 3.65 million per year (Ganguly et al., 2018). However, wider assessments of carbon sequestration and other services provided by seagrasses in South Asia (and other global regions) remain scarce.

Salt marshes

Ecosystem services from South Asian salt marshes are likely to decline in the future due sea level rise, threatening to squeeze marshes against developed inland areas There is limited research and data available on salt marshes in South Asia and their conservation status (Patro et al. 2017). In Sri Lanka, however, UNISDR/UNDP (2012) report that upto 50% of salt marshes were lost over one decade, mainly because of drainage and agricultural-urban encroachment. Salt marshes comprise roughly 24,000 ha of the coastal marine ecosystem in India (14 species), Bangladesh (five species), Sri Lanka (five species), Pakistan (five species). They provide breeding grounds for economically important organisms as well as protecting coasts (from erosion, storm surges) and sequestering carbon (Patro et

[101] In Bangladesh, a 100m wide strip of mangrove forest can reduce storm surge velocity by over 90%. During Cyclone Sidr in 2007, the protection value of the Sundarbans was estimated at USD 1025 per household (Dasgupta et al, 2019; Kazi et al, 2022).

al. 2017; FitzGerald and Hughes, 2019). Further research to better undertand the impacts of rising sea levels on salt marshes in the region is needed.

3.7.3 Fisheries

Fish catch is projected to decline in the tropics, including the Arabian Sea, Bay of Bengal and East Indian Ocean, because of climate-driven changes in ocean conditions and the coastal-oceanic food webs that affect fish productivity and distribution (FAO, 2018). India and Bangladesh are particularly at risk, with projected declines in fish catch potential of almost 20% and 10% by 2050, respectively (based on the SRES scenario A1B) (Barange et al., 2014). Reductions in fish catches from climate change imply negative effects for the livelihoods of fishers, those engaged in fish supply chains and trade, and for nutrition and food security more broadly (see below). However, links between climate variables and the capacity of aquatic envionments to produce fish remain poorly understood, with changes in both the physical and chemical properties of seawater, including temperature, salinity, currents, vertical stratification and oxygen concentration, all potentially affecting fish productivity and distribution. As a result, regional projections are uncertain (FAO, 2018).

Stocks of commercially important fish and invertebrates are vulnerable to changes in ocean temperatures, marine heatwaves, and ocean acidification (FAO, 2018). Changes in temperature and acidity affect fish physiology (FAO, 2007) and changes in temperature and ocean currents can affect the distribution of fish stocks and habitats (FAO, 2018). South Asian seas are projected to warm by 1.2-2.4°C by 2050 (Ranasinghe et al., 2021) with the Persian Gulf and Caspian Sea showing greater levels of warming than the Bay of Bengal, Arabian Sea and Gulf of Persia. Consequently, marine species are likely to experience average and maximum temperatures above, and pH and oxygen below, the levels to which they are adapted (Kay et al., 2023). Those species which cannot adapt physiologically will need to change their distributions to survive, with implications for both artisanal fishers and commercial operators/fleets (see below). Indirect climate effects on fish stocks arise from damage to or destruction of fish nursery habitats such as mangroves, coral reefs and sea grass meadows (see above), plus impacts on ocean circulation, thermal stratification and nutrient content/distribution that influence broader oceanic food webs (FAO, 2018).

Fish stocks in South Asia are already under pressure from over-fishing and damage/disruption to fish habitats (FAO, 2018; FAO, 2022). Roughly 34% of eastern Indian Ocean fish stocks are overfished - exploited beyond their sustainable limits (FAO, 2022). Challenges with keeping fish catches within sustainable limits are compounded by illegal, unreported, and unregulated fishing activities (FAO, 2018), including the use of destructive fishing techniques such as bottom trawling. Other pressures on fish stocks include marine pollution and the loss of nursery habitats to aquaculture and agriculture. This baseline of environmental degradation and unsustainable fishing exacerbates vulnerability to climate impacts.

Coastal and inland fisheries are important contributors to livelihoods, local economies and nutrition, so climate-related impacts on fish stocks and distribution could have local to regional impacts. In Maldives and Sri Lanka, where production is concentrated in marine waters, fisheries account for around 20% of domestic employment (Ministry of Environment, 2020), over 280,000 jobs (FAO, 2021), and roughly USD144 million and USD 339 million in exports, respectively (FAO, 2023). In Bangladesh fishing contributes up to 4%

of GDP (Fernandes, 2018), around 7-8% of employment (FAO, 2018), and over 11% of annual export revenue (SACEP, 2019; FAO, 2018), with the majority of production from inland aquaculture. Likewise, most of India's production is from inland waters with exports of USD 7.5 billion in 2021, and fisheries employed an estimated 8.7 million fishers and 5.5 million fish farmers in 2019 (FAO, 2021). Fish also accounts for 60% of all animal protein consumed in Bangladesh and the Maldives, and over 50% in Sri Lanka (FAO, 2021). Although 70% of India's fish is produced in inland waters, it produces more fish from marine waters – 4.3 million tonnes in 2021 – than all other nations in the region combined (FAO, 2023) and is the second largest fisheries producer in the world. Bangladesh's marine waters yield 900,000 tonnes, just 20% of its total fisheries production (FAO, 2023). Maldivian and Sri Lankan fisheries are concentrated in marine waters, with 100% and 78% of production respectively. In Pakistan, production is split evenly between marine and inland waters (FAO, 2023). Aquaculture is significant only in Bangladesh and India, where it accounts for about 25% of marine production (FAO, 2023).

The fisheries sector is changing, affecting the distribution of risks between different fishing types and groups of people. The organisation of the fishing sector varies across the region. Over 80% of Pakistani fishing vessels are industrial ships over 12m in length, while over 95% of Sri Lankan and Bangladeshi vessels are under 12m in length, many of which do not have engines (see Table 4) (FAO, 2018). Industrial fleets tend to operate in formal businesses and supply chains and are generally clustered in major ports such as Chittagong (Bangladesh) and Karachi (Pakistan) (FAO, 2018). In India and Bangladesh, the number of unpowered vessels has fallen by 70%, while the number of powered vessels has doubled and increased tenfold, respectively (FAO, 2021). This reflects growing investment in the sector, but also highlights growing income inequality between artisanal fishers remaining in unpowered, smaller boats and commercialised fishing using larger, powered vessels. Sri Lanka is the only country where the number of unpowered vessels has continued to rise, from almost 20,000 in 2000 to over 27,000 in 2019 (FAO, 2021).

Table 4: Size and composition of fishing fleets of key nations. Source: FAO (2018).

	Number of vessels	Non-powered (<12m)	Powered (<12m)	Powered (>12m)
Bangladesh	67,917	51%	48%	1%
India	193,587	26%	37%	37%
Pakistan	16,901	3%	15%	82%
Sri Lanka	50,667	39%	56%	5%

Climate risks will disproportionately affect poorer, artisanal fishers in South Asia (FAO, 2018). Industrial fleets are generally concentrated in port facilities which may be increasingly exposed to tropical cyclones, storm surges and sea level rise but offer some measure of protection against climate risks (see also Section 3.4 and Focus Box 9). The greater range of industrial vessels also allows them to 'follow the fish', and commercial operators are better able to access finance and invest in new gear and equipment. In contrast, artisanal fishers generally lack access to sheltering ports leaving them more exposed to cyclones and severe weather, are less able to move to new fishing grounds, and have more limited access to finance (FAO, 2018). As a result, artisanal fishers are vulnerable to deepening poverty if catches fail. Within the general category of artisanal fishers, those in unpowered vessels are generally poorer and more vulnerable than those in powered vessels of less than 12m (Table 4). Artisanal fishers in unpowered vessels – generally among the poorest people in a given area – are therefore the most vulnerable to climate impacts (FAO, 2018).

Focus Box 9: Tropical cyclones and the fishing industry

South Asia, and particularly the Bay of Bengal, is prone to dangerous tropical cyclones. Tropical cyclones are associated with storm surges – rapid coastal floods – that often cause more damage and loss of life than high wind speeds (Seo and Bakkensen, 2017; Mitchell et al, 2022). The concentration of human population and economic activities in coastal areas means that such extreme events damage coastal infrastructure and cause fatalities as well as impact marine ecosystems. For example, in 2007, Cyclone Sidr and an associated storm surge killed 4,000 people and caused USD 1.7 billion of damage in Bangladesh, with 54,000 shrimp farms and hatcheries destroyed (Kais and Islam, 2018; 2019; Alam and Dominey-Howes, 2014). However, long term investment in adaptation and disaster mitigation has greatly increased Bangladesh’s resilience to such events, with cyclone-related mortality declining 100-fold since the 1970s (Haque et al., 2011; Takagi et al., 2022; Sammonds et al., 2021 – see also Section 3.4). In 1970, for example, Cyclone Bhola resulted in 200,000 - 500,000 fatalities in Bangladesh (Alam and Dominey-Howes, 2014).

The frequency of cyclones has not significantly increased since the 1970s, but intense cyclones (Category 4 and 5) have become more common (Vinke et al., 2016). In the North Indian Ocean, a modelling study suggests an increase in storm surge height along the Indian coast of 20-30% depending on the future warming scenario (Rao et al., 2020a; 2020b). The intensity of historical tropical cyclones has been amplified by marine heat waves in the northern Indian Ocean (Rathore et al., 2022).

Tropical cyclonic storms are likely to become more intense (higher wind speeds, heavier rains) to the 2050s, but are unlikely to increase in frequency (IPCC, 2021 - see Section 2).

Central Asia fisheries

Continued shrinking of the Aral Sea caused by upstream diversions and declining meltwater contributions to catchment rivers will likely reduce remaining fish catch potential. Commercial fish capture from the Aral Sea disappeared temporarily in 1983 because of the sea’s dramatic shrinkage and salinisation (see Sections 2 and 3.2), but fish stocks have since recovered somewhat with non-native species adapted to high salinity and, in the Norh Aral Sea, the return of freshwater fish. In Uzbekistan, however, per capita fish consumption declined by a factor of 10 between the 1980s and 2000s. Increased inflows from the Syr Darya and Amu Darya rivers due to snow and glacier melt has slowed the shrinkage of the North Aral Sea since 2005, but the projected reduction in meltwater flows after their 2050 peak, plus the likely continuation of upstream diversions, will likely accelerate the sea’s longer-term decline (Wang et al., 2020; Narbayep and Pavlova, 2022). Aquaculture production within the many reservoirs of the Aral Sea basin has potential for growth, and aquaculture already provides the main source of fish in Uzbekistan (Alieva et al., 2023), but rising temperatures, water scarcity and concerns over pollution from fish farms may limit expansion.

Water levels in the Caspian Sea may continue to fall because of decling inflows, higher rates of warming-induced evaporation and unsustainable withdrawals, threatening fisheries and ecosystems. Water levels in the Caspian Sea have fluctuated over the last century, but have fallen by roughly 10cm/year since 2006 (Yao et al., 2023; Samant and Prange, 2023). Projections indicate that water levels will continue to fall, with a 8-14m reduction by the end of the century depending on emission scenario, driven by higher rates of warming induced evaporation in some catchment areas and higher rates of evaporation from the lake surface itself (Focus Box 10). Falling water levels will mean that shallower 'shelf' areas will emerge from under the sea surface, depriving the sea of some of its key shallow-water habitats that provide spawning grounds and food sources for fish, as well as habitats for migrating birds and endemic seal (Prange et al, 2020). The Caspian Sea is a major source of fisheries production for Kazakhstan, alongside the North Aral Sea (Timirkhanov et al., 2010). As the sea shrinks, however, the fishing (and other) claims of the five littoral states may need to be reallocated (Prange et al, 2020).

Focus Box 10: Climate change and the Caspian Sea

The Caspian Sea is the largest inland lake in the world, with an area of around 390,000km^2 – roughly equivalent to the land area of Japan. The sea's catchment area is 10 times larger than its surface area, with most of the catchment (80%) in the northern Volga basin. The sea is bounded by Kazakhstan to the northeast, Russia to the northwest, Azerbaijan to the southwest, Iran to the south, and Turkmenistan to the southeast.

The Caspian Sea has experienced large variations in water levels over the last century, but more recent monitoring indicates that levels have been falling since 2006 because of reduced inflows (upstream river diversions), direct water withdrawals, and higher rates of sea and catchment evaporation. Sea levels are projected to fall by 8-14m by the end of the century, driven largely by higher rates of warming-induced evaporation from the sea surface.

Falling water levels will expose many shallower areas of the sea that currently provide important aquatic habitats for fish, migrating birds and endemic seal. The loss of shallow shelf areas and coastal wetlands will also mean that river pollutants and nutrients will directly impact the central basin with no prior filtration. These impacts will likely lead to major ecosystem disruption, threatening the unique Caspian biota that have evolved over millions of years. Economic and geopolitical ramifications could also be significant with shipping potentially disrupted and ports made obsolete. The five littoral states could also be faced with the challenge of having to re-negotiate maritime zones of jurisdiction linked to water withdrawals, planned desalination plants, fishing zones, and oil and gas claims.

Sources: Koriche et al (2021); Prange et al (2020); Samant and Prange (2023).

3.7.4 Tourism

The Maldives and Sri Lanka rely heavily on coastal zones and coral reefs for tourism, so sea level rise and coral loss are major economic threats. The Maldives is highly dependent on tourism, which contributed roughly 26% of national GDP in 2019 (Maldives

Tourism Ministry, 2021) and over one-third of government revenue, with multiplier effects throughout the economy (World Bank and ADB, 2021a). The country's beeches and coral reefs attract much of this revenue but are threatened by sea level rise, coastal erosion and coral loss (Hosterman and Smith, 2015; World Bank and ADB, 2021a – see above and Focus Box 7). Climate impact modelling based on four different climate scenarios to 2100 project revenue losses to tourism of 27 - 31% by 2100 (Hosterman and Smith, 2015). Higher temperatures could also making competing tourist destinations at higher latitides more attractive. Sri Lanka's tourism sector accounted for roughly 6% of GDP and 1 in 11 jobs in 2021 (World Travel and Tourism Council, 2022), and since most of the tourism economy is located on the coast, climate-related impacts could be significant. Research studies are lacking, although the government is already investing heavily in beech protection (World Bank and ADB, 2021b).

Image location: Kyrgyzstan

4 References

Foreword

Eskelinen, T. (2011) Absolute Poverty, In: Chatterjee, D. (eds) Encyclopaedia of Global Justice, Springer, Dordrecht, https://doi.org/10.1007/978-1-4020-9160-5_178

Country Profiles

IFRC (2021) Climate Change Impacts on Health and Livelihoods: Maldives Assessment, Climate Centre, https://www.climatecentre.org/wp-content/uploads/Climate-change-impacts-on-health-and-livelihoods-MALDIVES-assessment_April-2021_.pdf

Ministry of Environment and Energy (2016) Second National Communication of Maldives to the United Nations Framework Convention on Climate Change, https://unfccc.int/sites/default/files/resource/SNC%20PDF_Resubmission.pdf

UNDP (2013) Country Report Climate Risk Management in Maldives: Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES).

Section 1 – Introduction

Richardson, K., Lewis, K., Osborne, R., Doherty, A., Mayhew, L. and Burgin, L. (2022) Climate in context: An interdisciplinary approach for climate risk analysis and communication, *Met Office Hadley Centre*.

SEDACMaps, Population, Landscape, and Climate Estimates, Accessed February 2024, Available https://www.flickr.com/photos/54545503@N04/albums/72157626167057008/

WorldPop (2018) www.worldpop.org – School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Departement de Geographie, Universite de Namur) and Center for International Earth Science Information Network (CIESIN), Columbia University (2018). Global High Resolution Population Denominators Project – Funded by The Bill and Melinda Gates Foundation. Accessed from https://worldpop.arcgis.com/arcgis/rest/services/WorldPop_Total_Population_1km/ImageServer, which was acquired from https://www.worldpop.org/doi/10.5258/SOTON/WP00647 on 15 Sep, 2021.

Yao, T., Bolch, T., Chen, D. et al. (2022) The imbalance of the Asian water tower. Nat Rev Earth Environ 3, 618–632 https://doi.org/10.1038/s43017-022-00299-4

Section 2 – Current and future climate in the Central and South Asia region

ADB (2021) *Asian Development Outlook 2021 Update: Transforming Agriculture in Asia*. Asian Development Bank, September 2021. https://www.adb.org/outlook/editions/september-2021/theme-chapter

Aggarwal, P.K., Joshi, P.K., Ingram, J.S.I. and Gupta, R.K. (2004) Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environmental Science & Policy* 7 (2004) 487-498.

Ahmed, M.K., Alam, M.S., Yousuf, A.H.M. *et al.* A long-term trend in precipitation of different spatial regions of Bangladesh and its teleconnections with El Niño/Southern Oscillation and Indian Ocean Dipole. *Theor Appl Climatol* **129**, 473–486 (2017). https://doi.org/10.1007/s00704-016-1765-2

Alahacoon, N. and Edirisinghe, M. (2021) 'Spatial Variability of Rainfall Trends in Sri Lanka from 1989 to 2019 as an Indication of Climate Change', *ISPRS International Journal of Geo-Information*, 10(2), p. 84. Available at: https://doi.org/10.3390/ijgi10020084.

Alifu, H., Hirabayashi, Y., Imada, Y. and Shiogama, H. (2022) Enhancement of river flooding due to global warming, *Scientific Reports*, 12: 20687, https://doi.org/10.1038/s41598-022-25182-6

Almazroui, M., Saeed, S., Saeed, F., Islam, M. and Ismail, M. (2020) Projections of Precipitation and Temperature over the South Asian Countries in CMIP6, *Earth Systems and Environment*, 4: 297-320, https://doi.org/10.1007/s41748-020-00157-7

Akter, S. (2021) *Gender Inequality and Food Insecurity in the Asian Food System During the COVID-19 Pandemic.* Background paper for ADB. DOI: https://doi.org/10.16997/srjed.19

Ashfaq, M., Cavazos, T., Reboita, M., Torres-Alavez, J., Im, E-S., Olusegun, C., Alves, L., Key, K., Adeniyi, M., Tall, M., Sylla, M., Mehmood, S., Zafar, Q., Das, S., Diallo, I., Coppola, E. and Giorgi, F. (2020) Robust late twenty-first century shift in the regional monsoons in RegCM-CORDEX simulations, *Climate Dynamics*, 57: 1463-1488, https://doi.org/10.1007/s00382-020-05306-2

Barooah, P., Alvi, M., Ringler, C. and Pathak, V. (2023) Gender, agriculture policies, and climate-smart agriculture in India. *Agricultural Systems* 212 (2023) 103751. DOI: https://doi.org/10.1016/j.agsy.2023.103751

Becker, M., Papa, F., Karpytchev, M. and Chum, C. (2020) Water level changes, subsidence, and sea-level rise in the Ganges-Brahmaputra-Meghna delta, *Earth, Atmospheric, and Planetary Sciences*, 117(4): 1867-1876, https://doi.org/10.1073/pnas.1912921117

Begum, A., R., R. Lempert, E. Ali, T.A. Benjaminsen, T. Bernauer, W. Cramer, X. Cui, K. Mach, G. Nagy, N.C. Stenseth, R. Sukumar, and P. Wester (2022) Point of Departure and Key Concepts. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 121-196, doi:10.1017/9781009325844.003

Bhavithra, R.S. and Sannasiraj, S.A. (2022) ‘Climate change projection of wave climate due to Vardah cyclone in the Bay of Bengal’, *Dynamics of Atmospheres and Oceans*, 97, p. 101279. Available at: https://doi.org/10.1016/j.dynatmoce.2021.101279.

Chatterjee, A., Anil, G. and Shenoy, L. (2022) Marine heatwaves in the Arabian Sea, *Ocean Science*, 18: 639-657, https://doi.org/10.5194/os-18-639-2022

Chen, Y., Li, Z., Fang, G., Bian, W. (2018) Water and Ecological Security at the Heart of China’s Silk Road Economic Belt, in: Yang, X., Jiang, S. (Eds.), Challenges Towards Ecological Sustainability in China. Springer International Publishing, Cham, pp. 281–306. https://doi.org/10.1007/978-3-030-03484-9_12

Cho, C., Wang, S-Y., Yoon, J-H. and Gillies, R. (2016) Anthropogenic footprint of climate change in the June 2013 northern Indian flood, *Climate Dynamics*, 46: 797-805, https://doi.org/10.1007/s00382-015-2613-2

CRED-EM-DAT (2023) Em-dat: international disaster database. *Centre for Research on the Epidemiology of Disasters, Universidad Católic a de Lovaina, Bruselas*. https://www.emdat.be/

Cruz, M. and Alexander, M. (2019) The 10% Wind Speed Rule of Thumb for Estimating a Wildfire’s Forward Rate of Spread in Forests and Shrublands, *Annals of Forest Science*, 76(44), https://doi.org/10.1007/s13595-019-0829-8

Devendra, C. and Thomas, D. (2002) Crop–animal interactions in mixed farming systems in Asia, *Agricultural Systems*, 71(1–2), pp. 27–40. Available at: https://doi.org/10.1016/S0308-521X(01)00034-8.

Dhanda, S., Yadav, A., Yadav D.B. and Chauhan, B.S. (2022). Emerging Issues and Potential Opportunities in the Rice-Wheat Cropping System of North-Western India. *Front. Plant Sci*. 13.832683. doi: 10.3389/fpls.2022.832683

Didovets, I. *et al.* (2021) ‘Central Asian rivers under climate change: Impacts assessment in eight representative catchments’, *Journal of Hydrology: Regional Studies*, 34, p. 100779. Available at: https://doi.org/10.1016/j.ejrh.2021.100779.

Douville, H., Raghavan, K., Renwick, J., Allan, R., Arias, P., Barlow, M., Cerezo-Mota, R., Cherchi, A., Gan, T., Gergis, J., Jiang, D., Khan, A., Pokam Mba, W., Rosenfeld, D., Tierney, J. and Zolina, O. (2021) Water Cycle Changes. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1055–1210, doi:10.1017/9781009157896.010.

Fahad, A.A. *et al.* (2023) ‘The Role of Tropical Easterly Jet on the Bay of Bengal’s Tropical Cyclones: Observed Climatology and Future Projection’, *Journal of Climate*, 36(17), pp. 5825–5840. Available at: https://doi.org/10.1175/JCLI-D-22-0804.1.

Fallah, B., Russo, E., Menz, C., Hoffmann, P., Didovets, I. and Hattermann, F. (2023) Anthropogenic influence on extreme temperature and precipitation in Central Asia, *Scientific Reports*, 13: 6854, https://doi.org/10.1038/s41598-023-33921-6

Fan, L-J., Yan, Z-W., Chen, D. and Li, Z. (2022) Assessment of Central Asian heat extremes by statistical downscaling: Validation and future projection for 2015-2100, *Advances in Climate Change Research*, 13(1): 14-27, https://doi.org/10.1016/j.accre.2021.09.007

Fang, C., Haywood, J., Liang, J., Johnson, B., Chen, Y., Zhu, B. (2023) Impacts of reducing scattering and absorbing aerosols on the temporal extent and intensity of South Asian summer monsoon and East Asian summer monsoon, *Atmospheric Chemistry and Physics*, 23(14): 8341-8368, https://doi.org/10.5194/acp-23-8341-2023

Fox-Kemper, B., Hewitt, H., Xiao, C., Aðalgeirsdóttir, G., Drijfhout, S., Edwards, T., Golledge, N., Hemer, M., Kopp, R., Krinner, G., Mix, A., Notz, D., Nowicki, S., Nurhati, I., Ruiz, L., Sallée, J.-B., Slangen, A. and Yu, Y. (2021) Ocean, Cryosphere and Sea Level Change. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi:10.1017/9781009157896.011.

Gan, R., Luo, Y., Zuo, Q. and Sun, L. (2015) Effects of projected climate change on the glacier and runoff generation in the Naryn River Basin, Central Asia, *Journal of Hydrology*, 523: 240-251, https://doi.org/10.1016/j.jhydrol.2015.01.057

Gutiérrez, J., Jones, R., Narisma, G., Alves, L., Amjad, M., Gorodetskaya, I., Grose, M., Klutse, N., Krakovska, S., Li, J., Martínez-Castro, D., Mearns, L., Mernild, S., Ngo-Duc, T., van den Hurk, B. and Yoon, J.-H. (2021a) Atlas. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/.

Gutiérrez, J., Jones, R., Narisma, G., Alves, L., Amjad, M., Gorodetskaya, I., Grose, M., Klutse, N., Krakovska, S., Li, J., Martínez-Castro, D., Mearns, L., Mernild, S., Ngo-Duc, T., van den Hurk, B. and Yoon, J.-H. (2021b) Atlas. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA, pp. 1927–2058, doi:10.1017/9781009157896.021.

Haque, U., Hashizume, M., Kolivras, K.N., Overgaard, H.J., Das, B. and Yamamoto, T. (2012) Reduced death rates from cyclones in Bangladesh: what more needs to be done? Bulletin of the World Health Organization, 90(2), pp.150–156. doi: https://doi.org/10.2471/blt.11.088302.

Hansen, J., Hellin, J., Rosenstock, T., Fisher, E., Cairns, J., Stirling, C., Lamanna, C., van Etten, J., Rose, A. and Campbell, B. (2019) Climate risk management and rural poverty reduction. Agricultural Systems, 172: 28-46

He, H., Hamdi, R., Luo, G., Cai, P., Zhang, M., Shi, H., Li, C., Termonia, P., Maeyer, P. and Kurban, A. (2022) Numerical study on the climatic effect of the Aral Sea, *Atmospheric Research*, 268: 105977, https://doi.org/10.1016/j.atmosres.2021.105977

Hirabayashi, Y., Mahendran, R., Koirala, S. *et al.* (2013) Global flood risk under climate change. *Nature Clim Change* **3**, 816–821. https://doi.org/10.1038/nclimate1911

Hirabayashi, Y., Alifu, H., Yamazaki, D., Imada, Y., Shiogama, H. and Kimura, Y. (2021) Anthropogenic climate change has changed frequency of past flood during 2010-2013, *Progress in Earth and Planetary Science*, 8(36), https://doi.org/10.1186/s40645-021-00431-w

Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., Jackson, M., Kääb, A., Kang, S., Kutuzov, S., Milner, Al., Molau, U., Morin, S., Orlove, B. and Steltzer, H. (2019) High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [Pörtner, H.-O., Roberts, D., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B. and Weyer, N. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 131-202. https://doi.org/10.1017/9781009157964.004.

Hu, Z. *et al.* (2016) 'Evaluation of reanalysis, spatially interpolated and satellite remotely sensed precipitation data sets in central Asia', *Journal of Geophysical Research: Atmospheres*, 121(10), pp. 5648–5663. Available at: https://doi.org/10.1002/2016JD024781.

Hua, L., Zhao, T. and Zhong, L. (2022) Future changes in drought over Central Asia under CMIP6 forcing scenarios, *Journal of Hydrology: Regional Studies*, 43, https://doi.org/10.1016/j.ejrh.2022.101191

IEA (2023) *A Vision for Clean Cooking Access for All*, IEA, Paris https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all, Licence: CC BY 4.0

IHME-GBD (2019) *Global Burden of Disease (GBD) Study 2019*. Institute for Health Metrics and Evaluation/The Lancet. See: https://www.healthdata.org/research-analysis/gbd

Im, E-S., Pal, J. and Eltahir, E. (2017) Deadly heat waves projected in the densely populated agricultural regions of South Asia, *Science Advances*, 3(8), DOI: 10.1126/sciadv.1603322

IPCC (2021a) Regional Fact Sheet – Asia. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Asia.pdf

IPCC (2021b) Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

Jiang, J. and Zhou, T. (2021) Human-Induced Rainfall Reduction in Drought-Prone Northern Central Asia, *Geophysical Research Letters*, 48(7): e2020GL092156, https://doi.org/10.1029/2020GL092156

Jiang, J. and Zhou, T. (2023) Agricultural drought over water-scarce Central Asia aggravated by internal climate variability, *Nature Geoscience*, 16: 154-161, https://doi.org/10.1038/s41561-022-01111-0

Kam, J., Knutson, T., Zeng, F. and Wittenberg, A. (2016) Multimodel Assessment of Anthropogenic Influence on Record Global and Regional Warmth During 2015, *American Meteorological Society*, S4-S8, https://doi.org/10.1175/BAMS-D-16-0138.1

Katzenberger, A. *et al.* (2021) 'Robust increase of Indian monsoon rainfall and its variability under future warming in CMIP6 models', *Earth System Dynamics*, 12(2), pp. 367–386. Available at: https://doi.org/10.5194/esd-12-367-2021.

Khanal, S., Lutz, A., Kraaijenbrink, P., van den Hurk, B., Yao, T. and Immerzeel, W. (2021) Variable 21st Century Climate Change Response for Rivers in High Mountain Asia at Seasonal to Decadal Time Scales, *Water Resources Research*, 57(5), https://doi.org/10.1029/2020WR029266

Kim, S., Eghdamirad, S., Sharma, A. and Kim, J. (2020) Quantification of Uncertainty in Projections of Extreme Daily Precipitation, *Earth and Space Science*, 7(8): e2019EA001052, https://doi.org/10.1029/2019EA001052

Knutson, T., Camargo, S., Chan, J., Emanuel, K., Ho, C-H., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K. and Wu, L. (2020) Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming, *American Meteorological Society*, E303-E322, https://doi.org/10.1175/BAMS-D-18-0194.1

Kumar, S., Chakraborty, A., Chandrakar, R., Kumar, A., Sadhukhan, B. and Chowdhury, R. (2023) Analysis of marine heatwaves over the Bay of Bengal during 1982-2021, *Scientific Reports*, 13: 14235, https://doi.org/10.1038/s41598-023-39884-y

Latif, M., Syed, F. and Hannachi, A. (2017) Rainfall trends in the South Asian summer monsoon and its related large-scale dynamics with focus over Pakistan, *Climate Dynamics*, 48: 3565-3581, https://doi.org/10.1007/s00382-016-3284-3

Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou, 2021: Future Global Climate: Scenario-Based Projections and Near Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi:10.1017/9781009157896.006

Li, Y., Chen, Y., Wang, F., He, Y. and Li, Z. (2020) Evaluation and projection of snowfall changes in High Mountain Asia based on NASA's NEX-GDDP high-resolution daily downscaled dataset, *Environmental Research Letters*, 15, DOI 10.1088/1748-9326/aba926

Lumbruso, D., Brown, E. and Ranger, N. (2016) Stakeholders' perceptions of the overall effectiveness of early warning systems and risk assessments for weather-related hazards in Africa, the Caribbean and South Asia. *Nat Hazards* 84, 2121–2144 (2016). https://doi.org/10.1007/s11069-016-2537-0

Madkaiker, K., Valsala, V., Sreeush, M., Mallissery, A., Chakraborty, K. and Deshpande, A. (2023) Understanding the Seasonality, Trends, and Controlling Factors of Indian Ocean Acidification Over Distinctive Bio-Provinces, *Journal of Geophysical Research: Biogeosciences*, 128(1), https://doi.org/10.1029/2022JG006926

Met Office (2024) Climate Zones, accessed 9th May 2024, available https://www.metoffice.gov.uk/weather/climate/climate-explained/climate-zones#:~:text=Tundra%20climate,grasses%2C%20and%20other%20small%20plants.

Ministry of Environment and Energy (2016) Second National Communication of Maldives to the United Nations Framework Convention on Climate Change, https://unfccc.int/sites/default/files/resource/SNC%20PDF_Resubmission.pdf

Mitchell, D. *et al.* (2022) 'Increased population exposure to Amphan-scale cyclones under future climates', *Climate Resilience and Sustainability*, 1(2), p. e36. Available at: https://doi.org/10.1002/cli2.36.

Mondal, S., Huang, J., Wang, Y., Su, B., Kundzewicz, Z., Jiang, S., Zhai, J., Chen, Z., Jing, C. and Jiang, T. (2022) Changes in extreme precipitation across South Asia for each 0.5 °C of warming from 1.5 °C to 3.0 °C above pre-industrial levels, *Atmospheric Research*, 266, https://doi.org/10.1016/j.atmosres.2021.105961

Nair, H., Budhavant, K., Manoj, M., Andersson, A., Satheesh, S., Ramanathan, V. and Gustafsson, Ö. (2023) Aerosol demasking enhances climate warming over South Asia, *Climate and Atmospheric Science*, 6(39), https://doi.org/10.1038/s41612-023-00367-6

Nanditha, J., van der Wiel, K., Bhatia, U., Stone, D., Selton, F. and Mishra, V. (2020) A seven-fold rise in the probability of exceeding the observed hottest summer in India in a 2 °C warmer world, *Environmental Research Letters*, 15(4), DOI 10.1088/1748-9326/ab7555

Narbayep, M. and Pavlova, V. (2022) The Aral Sea, Central Asian Countries and Climate Change in the 21st Century, ESCAP, https://www.unescap.org/sites/default/d8files/event-documents/ESCAP-2022-WP-Aral-Sea-central-Asian-countries-climate-change.pdf

Naveendrakumar, G., Vithanage, M., Kwon, H.-H., Chandrasekara, S.S.K., Iqbal, M.C.M., Pathmarajah, S., Fernando, W.C.D.K. and Obeysekera, J. (2019) South Asian perspective on temperature and rainfall extremes: A review, Atmospheric Research 225, 110–120, https://doi.org/10.1016/j.atmosres.2019.03.021

Oppenheimer, M., Glavovic, B., Hinkel, J., van de Wal, R., Magnan, A., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B. and Sebesvari, Z. (2019) Sea-level rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [Pörtner, H-O., Roberts, D., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegria, A., Nicolai, M., Okem, A., Petzold, J., Rama, B. and Weyer, N. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321-445. https://doi.org/10.1017/9781009157964.006

Ozturk, T. (2023) ‘Projected Future Changes in Extreme Climate Indices over Central Asia Using RegCM4.3.5’, *Atmosphere*, 14(6), p. 939. Available at: https://doi.org/10.3390/atmos14060939.

Palash, W. *et al.* (2023) ‘Climate Change Impacts on the Hydrology of the Brahmaputra River Basin’, *Climate*, 11(1), p. 18. Available at: https://doi.org/10.3390/cli11010018.

Pan, Y., Yang, J., Chen, D., Zhu, T., Bao, Q. and Mahmoudi, P. (2023) Skilful seasonal prediction of summer wildfires over Central Asia, *Global and Planetary Change*, 221, https://doi.org/10.1016/j.gloplacha.2023.104043

Philip, S., Sparrow, S., Kew, S., van der Wiel, K., Wanders, N., Singh, R., Hassan, A., Mohammed, K., Javid, H., Haustein, K., Otto, F., Hirpa, F., Rimi, R., Islam, A., Wallom, D. and van Oldenborgh, G. (2019) Attributing the 2017 Bangladesh floods from meteorological and hydrological perspectives, *Hydrology and Earth System Sciences*, 23(3): 1409-1429, https://doi.org/10.5194/hess-23-1409-2019

PLN, M. and Kolukula, S.S. (2023) ‘Future projections of storm surges and associated coastal inundation along the east coast of India’, *Journal of Water and Climate Change*, 14(5), pp. 1413–1432. Available at: https://doi.org/10.2166/wcc.2023.358.

Prange, M., Wilke, T. and Wesselingh, F. (2020) The other side of sea level change, *Communications Earth & Environment*, 1 (69), https://doi.org/10.1038/s43247-020-00075-6

Rao, A., Upadhaya, P., Pandey, S. and Poulose, J. (2020a) Simulation of extreme water levels in response to tropical cyclones along the Indian coast: a climate change perspective, *Natural Hazards*, 100: 151-172, https://doi.org/10.1007/s11069-019-03804-z

Rao, A., Upadhaya, P., Ali, H., Pandey, S. and Warrier, V. (2020b) Coastal inundation due to tropical cyclones along the east coast of India: an influence of climate change impact, *Natural Hazards*, 101: 39-57, https://doi.org/10.1007/s11069-020-03861-9

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul (2021) Climate Change Information for Regional Impact and for Risk Assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1767–1926, doi:10.1017/9781009157896.014 https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter12.pdf

Rathore, S., Goyal, R., Jangir, B., Ummenhofer, C., Feng, M. and Mishra, M. (2022) Interactions Between a Marine Heatwave and Tropical Cyclone Amphan in the Bay of Bengal in 2020, *Frontiers in Climate*, 4, https://doi.org/10.3389/fclim.2022.861477

Rimi, R., Haustein, K., Barbour, E. and Allen, M. (2018) Risks of Pre-monsoon Extreme Rainfall Events of Bangladesh: Is Anthropogenic Climate Change Playing a Role?, *American Meteorological Society*, S61-S65, https://doi.org/10.1175/BAMS-D-18-0152.1

Roxy, M.K. *et al.* (2020) Indian Ocean Warming, in R. Krishnan et al. (eds) *Assessment of Climate Change over the Indian Region*. Singapore: Springer Singapore, pp. 191–206. Available at: https://doi.org/10.1007/978-981-15-4327-2_10.

Sachs, J., McArthur, J.W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M. and McCord, G. (2004). Ending Africa's poverty trap. Brookings papers on economic activity 2004(1): 117-240 .

Saha, P., Mahanta, R. & Goswami, B.N. Present and future of the South Asian summer monsoon's rainy season over Northeast India. *npj Clim Atmos Sci* **6**, 170 (2023). https://doi.org/10.1038/s41612-023-00485-1

Sanjay, J., Krishnan, R., Shrestha, A., Rajbhandari, R. and Ren, G-Y. (2017) Downscaled climate change projections for the Hindu Kush Himalayan region using CORDEX South Asia regional climate models, *Advances in Climate Change Research*, 8(3): 185-198, https://doi.org/10.1016/j.accre.2017.08.003

Saranya, J., Roxy, M., Dasgupta, P. and Anand, A. (2022) Gensis and Trends in Marine Heatwaves Over the Tropical Indian Ocean and Their Interaction With the Indian Summer Monsoon, *Journal of Geophysical Research: Oceans*, 127(2): e2021JC017427, https://doi.org/10.1029/2021JC017427

Schipper, L. and Pelling, M. (2006). Disaster risk, climate change and international development: scope for, and challenges to, integration. Disasters 30(1): 19-38

Seneviratne, S., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S., Wehner, M. and Zhou, B. (2021) Weather and Climate Extreme Events in a Changing Climate. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi:10.1017/9781009157896.013.

Shaw, R., Luo, Y., Cheong, T., Abdul Halim, S., Chaturvedi, S., Hashizume, M., Insarov, G., Ishikawa, Y., Jafari, M., Kitoh, A., Pulhin, J., Singh, C., Vasant, K., and Zhang, Z. (2022) Asia. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O., Roberts, D., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457-1579, doi:10.1017/9781009325844.012.

Singh, D., Horton, D., Tsiang, M., Haugen, M., Ashfaq, M., Mei, R., Rastogi, D., Johnson, C., Charland, A., Rajaratnam, B. and Diffenbaugh, N. (2014) Severe Precipitation in Northern India in June 2013: Causes, Historical Context, and Changes in Probability, *Bulletin of the American Meteorological Society*, 95(9): S58-61, Sun, Q., Miao, C., Hanel, M., Borthwick, A., Duan, Q., Ji, D. and Li, H. (2019) Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming, *Environmental International*, 128: 125-136, https://doi.org/10.1016/j.envint.2019.04.025

Taylor, C., Robinson, T.R., Dunning, S., Rachel Carr, J. and Westoby, M. (2023) Glacial lake outburst floods threaten millions globally. Nat Commun 14, 487. https://doi.org/10.1038/s41467-023-36033-x

Ullah, I., Ma, X., Asfaw, T., Yin, J., Iyakaremye, V., Saleem, F., Xing, Y., Azam, K. and Syed, S. (2022) Projected Changes in Increased Drought Risks Over South Asia Under a Warmer Climate, *Earth's Future*, 10(10), https://doi.org/10.1029/2022EF002830

UNDP (2013) Country Report Climate Risk Management in Maldives: Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES).

Vadrevu, K., Lasko, K., Giglio, L., Schroeder, W., Biswas, S. and Justice, C. (2019) Trends in Vegetation fires in South and Southeast Asian Countries, *Scientific Reports*, 9: 7422, https://doi.org/10.1038/s41598-019-43940-x

Wang, H., Wu, Q. and Hong, J. (2022) Climate control of tropical cyclone rapid intensification frequency in the northern Indian Ocean, *Environment Research Communications*, 4, DOI 10.1088/2515-7620/aca646

Wang, S.-Y. *et al.* (2015) 'The Deadly Himalayan Snowstorm of October 2014: Synoptic Conditions and Associated Trends', *Bulletin of the American Meteorological Society*, 96(12), pp. S89–S94. Available at: https://doi.org/10.1175/BAMS-D-15-00113.1.

Wang, X., Chen, Y., Li, Z., Fang, G., Wang, F. and Liu, H. (2020) The impact of climate change and human activities on the Aral Sea Basin over the past 50 years, *Atmospheric Research*, 245, https://doi.org/10.1016/j.atmosres.2020.105125

Wehner, M., Stone, D., Krishnan, H., AchutaRao, K. and Castillo, F. (2016) The Deadly Combination of Heat and Humidity in India and Pakistan in Summer 2015, *American Meteorological Society*, S81-S86, https://doi.org/10.1175/BAMS-D-16-0145.1

Wisner, B., Blaikie, P., Cannon, T. and Davis, I. (2003) At Risk: natural hazards, people's vulnerability and disasters (2nd Ed.) New York, NY, Routledge, 464 pp.

World Bank (2020) Demographic Trends and Urbanisation. Washington D.C.: World Bank. https://documents1.worldbank.org/curated/en/260581617988607640/pdf/Demographic-Trends-and-Urbanization.pdf

World Bank (2022a) Bangladesh Country Climate and Development Report. CCDR Series. Washington, D.C.: World Bank Group. http://hdl.handle.net/10986/38181

World Bank (2022b) DataBank – World Development Indicators, Accessed July 2023, https://databank.worldbank.org/source/world-development-indicators

World Meteorological Organization (WMO) (2024) State of the Climate in Asia 2023, https://library.wmo.int/viewer/68890/download?file=1350_State-of-the-Climate-in-Asia-2023.pdf&type=pdf&navigator=1

Yao, F., Livneh, B., Rajagopalan, B., Wang, J., Crétaux, J-F., Wada, Y. and Berge-Nguyen, M. (2023) Satellites reveal widespread decline in global lake water storage, *Science*, 380(6646): 743-749, DOI: 10.1126/science.abo2812

Yao, J. *et al.* (2021) 'Intensification of extreme precipitation in arid Central Asia', *Journal of Hydrology*, 598, p. 125760. Available at: https://doi.org/10.1016/j.jhydrol.2020.125760.

Yao, T., Bolch, T., Chen, D., Gao, J., Immerzeel, W., Piao, S., Su, F., Thompson, L., Wada, Y., Wang, L., Wang, T., Wu, G., Xu, B., Yang, W., Zhang, G. and Zhao, P. (2022) The imbalance of the Asian water tower, *Nature Reviews Earth & Environment*, 3: 618-623, https://doi.org/10.1038/s43017-022-00299-4

Yu, S., Yan, Z., Freychet, N. and Li, Z. (2019) Trends in summer heatwaves in central Asia from 1917 to 2016: Association with large-scale atmospheric circulation patterns, *International Journal of Climatology*, 40(1): 115-127, https://doi.org/10.1002/joc.6197

Zachariah, M., Arulalan, T., AchutaRao, K., Saeed, F., Jha, R., Dhasmana, M. K., Mondal, A., Bonnet, R., Vautard, R., Philip, S., Kew, S., Vahlberg, M., Singh, R., Arrighi, J., Heinrich, D., Thalheimer, L., Marghidan, C. P., Kapoor, A., van Aalst, M., Raju, E., Li, S., Sun, J., Vecchi, G., Yang, W., Hauser, M., Schumacher, D. L., Seneviratne, S. I., Harrington, L. J. and Otto, F. E. L. (2022) Climate change made devastating early heat in India and Pakistan 30 times more likely, World Weather Attribution, https://www.worldweatherattribution.org/wp-content/uploads/India_Pak-Heatwave-scientific-report.pdf

Zhang, M., Chen, Y., Shen, Y. and Li, B. (2019) Tracking climate change in Central Asia through temperature and precipitation extremes, Journal of Geographical Sciences, 29, 3–28, https://doi.org/10.1007/s11442-019-1581-6

Zhao, Y. and Zhang, H. (2016) 'Impacts of SST Warming in tropical Indian Ocean on CMIP5 model-projected summer rainfall changes over Central Asia', *Climate Dynamics*, 46(9–10), pp. 3223–3238. Available at: https://doi.org/10.1007/s00382-015-2765-0.

Zong, X., Tian, X. and Yin, Y. (2020) Impacts of Climate Change on Wildfires in Central Asia, *Forests*, 11(8): 802, DOI:10.3390/f11080802

Zou, S., Abuduwaili, J., Duan, W., Ding, J., Maeyer, P., Voorde, T. and Ma, L. (2021) Attribution of changes in the trend and temporal non-uniformity of extreme precipitation events in Central Asia, *Scientific Reports*, 11: 15032, https://doi.org/10.1038/s41598-021-94486-w

Section 3.1 – Agriculture and food security

ADB (2021) *Asian Development Outlook 2021 Update: Transforming Agriculture in Asia*. Asian Development Bank, September 2021. https://www.adb.org/outlook/editions/september-2021/theme-chapter

Aggarwal, P.K., Joshi, P.K., Ingram, J.S.I. and Gupta, R.K. (2004) Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environmental Science & Policy* 7 (2004) 487-498.

Aidan, I. et al. (2020) Impact of Climate Change on Agriculture in Kazakhstan. *Silk Road: A Journal of Eurasian Development* 2(1): 66–88. DOI: https://doi.org/10.16997/srjed.19

Akter, S. (2021) *Gender Inequality and Food Insecurity in the Asian Food System During the COVID-19 Pandemic.* Background paper for ADB. DOI: https://doi.org/10.16997/srjed.19

Allison, E.H., Perry, A.L., Badjeck, M-C., Adger, W.N., Brown, K., Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L. & Dulvy, N.K. (2009) Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10(2): 173–196.

Barooah, P., Alvi, M., Ringler, C. and Pathak, V. (2023) Gender, agriculture policies, and climate-smart agriculture in India. *Agricultural Systems* 212 (2023) 103751. DOI: https://doi.org/10.1016/j.agsy.2023.103751

Bastagli, F. and Lowe, A. (2021) *Social protection response to Covid-19 and beyond: Emerging evidence and learning for future crises*. ODI Working Paper 614, ODI, London. https://odi.org/en/publications/social-protection-response-to-covid-19-and-beyond-emerging-evidence-and-learning-for-future-crises/

Bezner Kerr, R., T. Hasegawa, R. Lasco, I. Bhatt, D. Deryng, A. Farrell, H. Gurney-Smith, H. Ju, S. Lluch-Cota, F. Meza, G. Nelson, H. Neufeldt, and P. Thornton (2022) Food, Fibre, and Other Ecosystem Products. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 713–906, doi:10.1017/9781009325844.007.

Bhatt, R., Hossain, A. and Singh, P. (2019) Scientific interventions to improve land and water productivity for climate-smart agriculture in South Asia, Agronomic Crops, 499-558, https://doi.org/10.1007/978-981-32-9783-8_24

Biemans, H., Siderius, C., Lutz, A.F. et al. (2019). Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nat Sustain* 2, 594–601 (2019). https://doi.org/10.1038/s41893-019-0305-3

Cai, Y., Jayatilleke S. Bandara, David Newth (2016). A framework for integrated assessment of food production economics in South Asia under climate change. *Environmental Modelling & Software*, Volume 75, pp 459-497. https://doi.org/10.1016/j.envsoft.2015.10.024.

Chakraborti, R., Davis, K.F., DeFries, R. et al (2023). Crop switching for water sustainability in India's food bowl yields co-benefits for food security and farmers' profits. *Nat Water* 1, 864–878 (2023). https://doi.org/10.1038/s44221-023-00135-z

Chhay, P., Rahut, D.B., Tashi, S. and Chamberlin, J. (2023) *Does Wild Food Contribute to Food Security? Evidence from Rural Bhutan*. ADBI Working Paper 1367. Tokyo: Asian Development Bank Institute. Available: https://doi.org/10.56506/SYQK7435.

CIAT/World Bank (2017) *Climate-Smart Agriculture in Bangladesh*. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); World Bank. Washington, D.C. 28 p. For all Asian country profiles, see: https://ccafs.cgiar.org/resources/publications/csa-country-profiles

CIAT/World Bank (2018) *Climate-Smart Agriculture in the Kyrgyz Republic*. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); World Bank, Washington, D.C. 28 p.

CIAT/World Bank/CCAFS and LI-BIRD (2017) *Climate-Smart Agriculture in Nepal*. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); The World Bank; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); Local Initiatives for Biodiversity Research and Development (LI-BIRD). Washington, D.C. 26 p.

Darby, S.E., Appeaning Addo, K., Hazra, S., Rahman, M.M., Nicholls, R.J. (2020) Fluvial Sediment Supply and Relative Sea-Level Rise. In: Nicholls, R., Adger, W., Hutton, C., Hanson, S. (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-23517-8_5

Dash, S. (2017). Contribution of Livestock Sector to Indian Economy. *PARIPEX – Indian Journal of Research*, Volume 6, Issue 1, January 2017. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.worldwidejournals.com/paripex/recent_issues_pdf/2017/January/contribution-of-livestock-sector-to-indian-economy_January_2017_1682756615_1515929.pdf

Deutsch, C.A., et al. (2018) Increase in crop losses to insect pests in a warming climate. *Science*, 361(6405), 916–919, doi:10.1126/science.aat3466.

Devendra, C. and Thomas, D. (2002) Smallholder farming systems in Asia. *Agricultural Syststems* 71 (2002), 17-25. https://doi.org/10.1016/S0308-521X(01)00033-6

Dhanda, S., Yadav, A., Yadav D.B. and Chauhan, B.S. (2022). Emerging Issues and Potential Opportunities in the Rice-Wheat Cropping System of North-Western India. *Front. Plant Sci*. 13.832683. doi: 10.3389/fpls.2022.832683

FAO (2015). *Climate change and food security: risks and responses*. Food and Agriculture Organisation of the United Nations, 2015. Rome.

FAO (2019) Data From FAOSTAT: https://www.fao.org/faostat/en/#home

FAO (2020) Data for 2020 from FAO AQUASTAT accessed July 2023. https://www.fao.org/aquastat/en/overview/

FAO (2023a) *Fishery and Aquaculture Statistics. Global aquaculture production 1950-2021 (FishStatJ).* In: FAO Fisheries and Aquaculture Division [online]. Rome. Updated 2023. www.fao.org/fishery/en/statistics/software/fishstatj

FAO (2023b) *The Impact of Disasters on Agriculture and Food Security 2023 – Avoiding and reducing losses through investment in resilience*. Rome. https://doi.org/10.4060/cc7900en

FAO (2023c) The State of Food Security and Nutrition in the World 2023, Urbanization, agrifood systems transformation and healthy diets across the rural-urban continuum, FAO, IFAD, UNICEF, WFP, WHO, https://www.fao.org/documents/card/en?details=cc3017en

FAO, UNICEF, WFP and WHO (2023) *Asia and the Pacific – Regional Overview of Food Security and Nutrition 2022. Urban food security and nutrition*. Bangkok, FAO. https://doi.org/10.4060/cc3990en

Rituparna Hajra, Tuhin Ghosh (2018) Agricultural productivity, household poverty and migration in the Indian Sundarban Delta. *Elementa: Science of the Anthropocene* 1 January 2018; 6 3. doi: https://doi.org/10.1525/elementa.196

Hallegatte, Stephane; Bangalore, Mook; Bonzanigo, Laura; Fay, Marianne; Kane, Tamaro; Narloch, Ulf; Rozenberg, Julie; Treguer, David; Vogt-Schilb, Adrien (2016) *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Climate Change and Development. Washington, DC: World Bank. http://hdl.handle.net/10986/22787

Hallegatte,Stephane; Vogt-Schilb, Adrien Camille; Bangalore, Mook; Rozenberg, Julie (2017) *Unbreakable : building the resilience of the poor in the face of natural disasters.* Climate Change and Development Washington, D.C: World Bank Group. http://documents.worldbank.org/curated/en/512241480487839624/Unbreakable-building-the-resilience-of-the-poor-in-the-face-of-natural-disasters

Hamidov, A., Helming, K. & Balla, D (2016) Impact of agricultural land use in Central Asia: a review. *Agron. Sustain. Dev.* 36, 6 (2016). https://doi.org/10.1007/s13593-015-0337-7

ILO (2019) *Working on a warmer planet: The impact of heat stress on labour productivity and decent work*. International Labour Office – Geneva, ILO, 2019. ISBN 978-92-2-132967-1 (print) ISBN 978-92-2-132968-8

Islam MA, MI Shariful and MA Wahab (2016) Impacts of climate change on shrimp farming in the South-West coastal region of Bangladesh. *Res. Agric. Livest. Fish*., 3 (1): 227-239

Jafino, Bramka Arga; Walsh, Brian; Rozenberg, Julie; Hallegatte, Stephane (2020) *Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030*. Policy Research Working Paper 9417. World Bank, Washington, DC. http://hdl.handle.net/10986/34555

Kais, S.M. and M.S. Islam (2018) Impacts of and resilience to climate change at the bottom of the shrimp commodity chain in Bangladesh: A preliminary investigation. *Aquaculture*, 493, 406–415, doi:10.1016/j. aquaculture.2017.05.024.

Lei, J., Chen, L. & Li, H. (2017) Using ensemble forecasting to examine how climate change promotes worldwide invasion of the golden apple snail (Pomacea canaliculata). *Environ Monit Assess* 189, 404 (2017). https://doi.org/10.1007/s10661-017-6124-y

Li, S., Wang, Q. and Chun, J.A. (2017) Impact assessment of climate change on rice productivity in the Indochinese Peninsula using a regional-scale crop model. *International Journal of Climatology* https://rmets.onlinelibrary.wiley.com/doi/ epdf/10.1002/joc.5072

Lutz, A.F., Immerzeel, W.W., Siderius, C. et al. (2022) South Asian agriculture increasingly dependent on meltwater and groundwater. *Nat. Clim. Chang*. 12, 566–573 (2022). https://doi.org/10.1038/s41558-022-01355-z

Menegat, S., Ledo, A. & Tirado, R. (2022) Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Sci Rep* 12, 14490 (2022). https://doi.org/10.1038/s41598-022-18773-w

Mirzabaev, A., Jann Goedecke, Olena Dubovyk, Utkur Djanibekov, Quang Bao Le and Aden Aw-Hassan (2016) The Economics of Land Degradation in Central Asia. Chapter10 in *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*. Edited by Mirzabaev, A. et al. ISBN : 978-3-319-19167-6

Noack,Frederik; Wunder,Sven; Angelsen,Arild; Börner,Jan (2015) *Responses to weather and climate: a cross-section analysis of rural incomes*. Policy Research Working Paper WPS 7478 Washington, D.C. World Bank Group. http://documents.worldbank.org/curated/en/684571467991989362/Responses-to-weather-and-climate-a-cross-section-analysis-of-rural-incomes

Perry, C.J., Allen, R., Droogers, P., Lillic, A. and Grafton, R.Q. (2023). *Water Consumption, Measurements and Sustainable Water Use*. Technical Report for the Global Commission on the Economics of Water, February 2023. See https://watercommission.org/

Qamer, F.M., Abbas, S., Ahmad, B. et al. (2023) A framework for multi-sensor satellite data to evaluate crop production losses: the case study of 2022 Pakistan floods. *Sci Rep* 13, 4240 (2023). https://doi.org/10.1038/s41598-023-30347-y

Quillérou, E., Thomas, R.J., Guchgeldiyev, O. , Ettling, S., Etter, H., & Stewart, N. (2016*) Economics of Land Degradation (ELD) Initiative: Broadening options for improved economic sustainability in Central Asia. Synthesis report*. Report for the ELD Initiative from the Dryland Systems Program of CGIAR c/o ICARDA, Amman, Jordan. Available from www.eld-initiative.org

Raff, J.L., Goodbred, S.L., Pickering, J.L. et al. (2023) Sediment delivery to sustain the Ganges-Brahmaputra delta under climate change and anthropogenic impacts. *Nat Commun* 14, 2429 (2023). https://doi.org/10.1038/s41467-023-38057-9

Rahman, M.M. et al. (2020) Ganges-Brahmaputra-Meghna Delta, Bangladesh and India: A Transnational Mega-Delta. In: Nicholls, R., Adger, W., Hutton, C., Hanson, S. (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-23517-8_2

ReliefWeb (2024) *ReliefWeb Response – Pakistan*. https://reliefweb.int/country/pak. See also Carbon Brief Cropped for food prices: https://www.carbonbrief.org/cropped-7-september-2022-pakistan-floods-chinas-food-security-100-days-to-cop15/

Reyer, C., Otto, I.M., Adams, S. et al. (2017) Climate change impacts in Central Asia and their implications for development. *Reg Environ Change* 17, 1639–1650 (2017). https://doi.org/10.1007/s10113-015-0893-z

Robinson, S. (2020) *Livestock in Central Asia: From rural subsistence to engine of growth?* Discussion Paper 193, Leibniz Institute of Agricultural Development and Transition Economies (IAMO). https://www.iamo.de/en/research/research-projects/details/anicanet/

Rodella, Aude-Sophie, Esha Zaveri, and François Bertone (2023) *The Hidden Wealth of Nations: The Economics of Groundwater in Times of Climate Change*. Washington, DC: World Bank. License: Creative Commons Attribution CC BY 3.0 IGO

Safra de Campos, R. et al. (2020) Where People Live and Move in Deltas. In: Nicholls, R., Adger, W., Hutton, C., Hanson, S. (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-23517-8_7

Scoones, I. (ed.), (2023) *Pastoralism, Uncertainty and Development*, Rugby, UK: Practical Action Publishing http://doi.org/10.3362/9781788532457

Sekhar, C.S.C. (2018) *Climate change and rice economy in Asia: Implications for trade policy*. Rome, FAO. 62 pp. Licence: CC BY-NC-SA 3.0 IGO.

Shah,, T. (2009) Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environ. Res. Lett*. 4 doi:10.1088/1748-9326/4/3/035005

Shaw, R., Y. Luo, T.S. Cheong, S. Abdul Halim, S. Chaturvedi, M. Hashizume, G.E. Insarov, Y. Ishikawa, M. Jafari, A. Kitoh, J. Pulhin, C. Singh, K. Vasant, and Z. Zhang (2022) Asia. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457–1579, doi:10.1017/9781009325844.012.

Singh, R., Kerven, C. (2023) Pastoralism in South Asia: Contemporary stresses and adaptations of Himalayan pastoralists. *Pastoralism* 13, 21 (2023). https://doi.org/10.1186/s13570-023-00283-7

Smolenaars, W., Muhammad Khalid Jamil, Sanita Dhaubanjar, Arthur F. Lutz, Walter Immerzeel, Fulco Ludwig and Hester Biemans (2023) Exploring the potential of agricultural system change as an integrated adaptation strategy for water and food security in the Indus basin. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-023-03245-6

Sutton, William R., Jitendra P. Srivastava, and James E. Neumann (2013a) *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*. Directions in Development. Washington, DC: World Bank. doi:10.1596/978-0-8213-9768-8. License: Creative Commons Attribution CC BY 3.0

Sutton, William R., Jitendra P. Srivastava, James E. Neumann, Peter Droogers, and Brent B. Boehlert. (2013b) *Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options*. World Bank Study. Washington, DC: World Bank. doi:10.1596/978-1-4648-0000-9. License: Creative Commons Attribution CC BY 3.0

Suzuki, A. (2021) *Rising Importance of Aquaculture in Asia: Current Status, Issues, and Recommendations*. Background Paper for ADB. DOI: https://doi.org/10.16997/srjed.19

Thomas, T.S., Akramov, K., Robertson, R.D., Nazareth, V. and Ilyasov, J. (2021). *Climate Change, Agriculture and Potential Crop Yields in Central Asia*. IFPRI Discussion Paper 02081, December 2021. International Food Policy Research Institute. https://doi.org/10.2499/p15738coll2.134920

Thornton, P., Mensah, C. and Enahoro, D. (2022) *Modelling the effects of climate change on livestock: Towards Identifying the priorities*. ILRI Discussion Paper 45. Nairobi, Kenya: ILRI.

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

UN-HABITAT (2020) Slum population as a proportion of urban population. Data for 2020 from World Bank World Development Indicators accessed July 2023. https://databank.worldbank.org/source/world-development-indicators

UN World Population Prospects (2022) Data for 2022 from World Bank World Development Indicators, accessed July 2023. https://databank.worldbank.org/source/world-development-indicators

Wassmann, R.. S. V. K. Jagadish, K. Sumfleth, H. Pathak, G. Howell, A. Ismail, R. Serraj, E. Redona, R. K. Singh, and S.Heuer (2009) Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation. *Advances in Agronomy*, 2009, Vol. 102, Elsevier INC, DOI:10.1016/S0065-2113(09)01003-7.

Wiggins, S. (2022) *Impacts of War on Food Prices and Food Security in Potentially Vulnerable Countries*. ODI Policy Brief, April 2022.

Woetzel, J., Pinner, D., Samandara, H., Gupta, R., Engel, H., Krishnan, M. and Powis, C (2020) *Will India get too hot to work?* Case study, November 2020. McKinsey Global Institute. https://www.mckinsey.com/capabilities/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts

World Bank (2022a) Bangladesh Country Climate and Development Report. CCDR Series. Washington, D.C.: World Bank Group. http://hdl.handle.net/10986/38181

World Bank (2022b) *Climate and Development Report: Kazakhstan*. World Bank Group, November 2022. See https://openknowledge.worldbank.org/entities/publication/dabff214-772e-50b4-89d9-a172e99accc3

World Bank (2022c) *Coping with Shocks: Migration and the Road to Resilience*. South Asia Economic Focus (October), World Bank, Washington, DC. Doi: 10.1596/978-1-4648-1920-9.

World Bank (2022d) *Pakistan Country Climate and Development Report*. World Bank, Washington, DC. http://hdl.handle.net/10986/38277

World Food Summit (1996) Report of the World Food Summit, November Rome Italy, Food and Agriculture Organization of the United Nations, https://www.fao.org/3/w3548e/w3548e00.htm

Yuan, S., Linquist, B.A., Wilson, L.T. et al. (2021) Sustainable intensification for a larger global rice bowl. *Nat Commun* 12, 7163 (2021). https://doi.org/10.1038/s41467-021-27424-z

Yuan, S., Stuart, A.M., Laborte, A.G. et al (2022) Southeast Asia must narrow down the yield gap to continue to be a major rice bowl. *Nat Food* 3, 217–226 (2022). https://doi.org/10.1038/s43016-022-00477-z

Section 3.2 – Water and water-dependent services

Aggarwal, P.K. Joshi, J.S.I. Ingram, R.K. Gupta (2004) Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environmental Science & Policy*, Volume 7, Issue 6, 2004, Pages 487-498, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2004.07.006

Alderman, K., Turner, L.R. and Tong, S. (2012) Floods and human health: a systematic review. *Environ. Int*. 47:37-47.

Anchita *et al.* (2021) Health Impact of Drying Aral Sea: One Health and Socio-Economical Approach, *Water*, 13(22), p. 3196. Available at: https://doi.org/10.3390/w13223196

Armstrong, R.L., Rittger, K., Brodzik, M.J. et al. (2019) Runoff from glacier ice and seasonal snow in High Asia: separating melt water sources in river flow. *Reg Environ Change* 19, 1249–1261 (2019). https://doi.org/10.1007/s10113-018-1429-0

Baig, Sohaib, and ul Hasson, S. (2024) Flood Inundation and Streamflow Changes in the Kabul River Basin under Climate Change, *Sustainability* 16, no. 1: 116. https://doi.org/10.3390/su16010116

Balasubramanya, S. et al (2024) Risks from solar-powered groundwater irrigation. *Science* 383, 256-258 (2024). DOI:10.1126/science.adi9497

Barandun, M., Joel Fiddes, Martin Scherler, Tamara Mathys, Tomas Saks, Dmitry Petrakov, Martin Hoelzle (2020) The state and future of the cryosphere in Central Asia, *Water Security*, Volume 11, 2020, 100072, ISSN 2468-3124, https://doi.org/10.1016/j.wasec.2020.100072.

Bekturganov, Zakir, Kamshat Tussupova, Ronny Berndtsson, Nagima Sharapatova, Kapar Aryngazin, and Maral Zhanasova (2016) Water Related Health Problems in Central Asia—A Review, *Water* 8, no. 6: 219. https://doi.org/10.3390/w8060219

Biemans, H., Siderius, C., Lutz, A.F. et al. (2019) Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nat Sustain* 2, 594–601 (2019). https://doi.org/10.1038/s41893-019-0305-3

Calow, R.C., Mason, N., Mosello, B. and Ludi, E. (2017) *Linking risk with response: options for climate resilient WASH*. Technical Brief for the GWP-UNICEF Strategic Framework for WASH Climate Resilience. https://www.gwp.org/en/WashClimateResilience/

Calow, R.C., MacDonald, A.M. and Le Seve, M. (2018) The Environmental Dimensions of Universal Access to Safe Water. Chapter 6 in: *Equality in Water and Sanitation Services*, edited by Tom Slaymaker and Oliver Cummings. Earthscan Water, Routledge. https://doi.org/10.4324/9781315471532

Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. et al Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, and S. Supratid (2022) Water. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551–712, doi:10.1017/9781009325844.006.

CAWEP (2023). *Central Asia Water and Enegy Programme, Annual Report 2022 and 2023*. World Bank, Washington DC.

Conrad, C., Usman, M., Morper-Busch, L and Schonbrodt-Stitt, S. (2020) Remote sensing-based assessments of land use, soil and vegetation status, crop production and water use in irrigation systems of the Aral Sea Basin. A review. *Water Security* 11 (2020) 100078. https://doi.org/10.1016/j.watec.2020.100078

Cui, T., Li, Y., Yang, L., Nan, Y., Li, K., Tudaji, M., ... and Tian, F. (2023) Non-monotonic changes in Asian Water Towers' streamflow at increasing warming levels. *Nature Communications*, *14*(1), 1176. https://doi.org/10.1038/s41467-023-36804-6

De Stefano, Lucia, Duncan, James, Shlomi, Dinar, Stahl, Kerstin, Strzepek, Kenneth, Wolf, Aaron T. (2010) *Mapping the Resilience of International River Basins to Future Climate Change-Induced Water Variability*. World Bank's Water Sector Board Discussion Paper Series, Paper No. 15, March 2010. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://documents1.worldbank.org/curated/en/251101468136811144/pdf/560510NWP0Box31oundary1screen1final.pdf

Davies, M. and Matthews, N. (2021) 'Water futures along China's Belt and Road Initiative in Central Asia', International Journal of Water Resources Development, 37(6), pp. 955–975. Available at: https://doi.org/10.1080/07900627.2020.1856049.

Drenkhan, F. *et al.* (2023) 'Hydrology, water resources availability and management in the Andes under climate change and human impacts', *Journal of Hydrology: Regional Studies*, 49, p. 101519. Available at: https://doi.org/10.1016/j.ejrh.2023.101519.

EPRS (2018) Water in Central Asia: An increasingly scarce resource. Briefing, European Parliamentary Research Serice, September 2018. https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2018)625181

FAO (2023) The State of Food Security and Nutrition in the World 2023, Urbanization, agrifood systems transformation and healthy diets across the rural-urban continuum, FAO, IFAD, UNICEF, WFP, WHO, https://www.fao.org/documents/card/en?details=cc3017en

Gan, R., Luo, Y., Zuo, Q. and Sun, L. (2015) Effects of projected climate change on the glacier and runoff generation in the Naryn River Basin, Central Asia, *Journal of Hydrology*, 523: 240-251, https://doi.org/10.1016/j.jhydrol.2015.01.057

Giordano, M. (2009) Global Groundwater? Issues and Solutions. *Annu. Rev. Environ. Resour*. 2009. 34:7.1–7.26. https://doi.org/10.1146/annurev.environ.030308.100251

Gleeson, T. *et al.* (2012) 'Towards Sustainable Groundwater Use: Setting Long-Term Goals, Backcasting, and Managing Adaptively', *Groundwater*, 50(1), pp. 19–26. Available at: https://doi.org/10.1111/j.1745-6584.2011.00825.x.

Gafurov, A., Yapiyev, V., Ahmed, A., Sagin, J., Haghighi, A. T., Murtazin, E., Akylbekova, A. and Klove, B. (2019) Chapter 3: Groundwater Resources in the Aral Sea Basin, https://oulurepo.oulu.fi/bitstream/handle/10024/28246/nbnfi-fe202001283693.pdf?sequence=1

Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., Jackson, M., Kääb, A., Kang, S., Kutuzov, S., Milner, Al., Molau, U., Morin, S., Orlove, B. and Steltzer, H. (2019) High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [Pörtner, H.-O., Roberts, D., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B. and Weyer, N. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 131-202. https://doi.org/10.1017/9781009157964.004.

Howard, G., Calow, R.C., MacDonald, A.M. and Bartram, J. (2016) Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annual Review of Environment and Resources*. 2016. 41:8.1-8.24.

Hua, L., Zhao, T. and Zhong, L. (2022) Future changes in drought over Central Asia under CMIP6 forcing scenarios, *Journal of Hydrology: Regional Studies*, 43, https://doi.org/10.1016/j.ejrh.2022.101191

Immerzeel, W.W., Lutz, A.F., Andrade, M. et al. Importance and vulnerability of the world's water towers. *Nature* 577, 364–369 (2020) https://doi.org/10.1038/s41586-019-1822-y

Ilkhamov, A. (2023*) Implications for Uzbekistan's Water Supply of Qosh Tepa Canal Construction in Afghanistan*. Central Asia Due Diligence (CADD), 14 November 2023. https://cenasiaduediligence.uk/implications-for-uzbekistans-water-supply-of-qosh-tepa-canal-construction-in-afghanistan/

Ibraimov, B. and Ali, F. (2023). '*A lot of work for diplomats' in Central Asia as the Taliban build huge canal'*. Opinion piece for The Third Pole, May 18, 2023. https://www.thethirdpole.net/en/

IPCC (2021) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.

Khanal, S., Lutz, A., Kraaijenbrink, P., van den Hurk, B., Yao, T. and Immerzeel, W. (2021) Variable 21st Century Climate Change Response for Rivers in High Mountain Asia at Seasonal to Decadal Time Scales, *Water Resources Research*, 57(5), https://doi.org/10.1029/2020WR029266

Li, D., Lu, X., Walling, D. E., Zhang, T., Steiner, J. F., Wasson, R. J., and Bolch, T. (2022) High Mountain Asia hydropower systems threatened by climate-driven landscape instability. *Nature Geoscience*, *15*(7), 520-530. https://doi.org/10.1038/s41561-022-00953-y

Lutz, A.F., Immerzeel, W.W., Siderius, C. et al. (2022) South Asian agriculture increasingly dependent on meltwater and groundwater. *Nat. Clim. Chang*. 12, 566–573 (2022). https://doi.org/10.1038/s41558-022-01355-z

Ma, X. *et al.* (2024) 'Evaporation from the hypersaline Aral Sea in Central Asia', *Science of The Total Environment*, 908, p. 168412. Available at: https://doi.org/10.1016/j.scitotenv.2023.168412.

MacAllister, D.J., Krishan, G., Basharat, M. et al. (2022) A century of groundwater accumulation in Pakistan and northwest India. *Nat. Geosci*. 15, 390–396 https://doi.org/10.1038/s41561-022-00926-1

MacDonald AM, Bonsor HC, Taylor R, Shamsudduha M, Burgess WG, Ahmed KM, Mukherjee A, Zahid A, Lapworth D, Gopal K, Rao MS, Moench M, Bricker SH, Yadav SK, Satyal Y, Smith L, Dixit A, Bell R, van Steenbergen F, Basharat M, Gohar MS, Tucker J, Calow RC and Maurice L. (2015) *Groundwater resources in the Indo-Gangetic Basin: resilience to climate change and abstraction*. British Geological Survey Open Report, OR/15/047, 63pp.

MacDonald, A., Bonsor, H., Ahmed, K. et al. (2016) Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. *Nature Geosci* 9, 762–766 https://doi.org/10.1038/ngeo2791

Milman, A., Bunclark, L., Conway, D. and Adger, W.N. (2013) Assessment of institutional capacity to adapt to climate change in transboundary river basins. *Climatic Change*. DOI 10.1007/s10584-013-0917-y

Mukherjee, A., Bhanja, S.N., Rodell, M., Wada, Y., Malakar, P., Saha, D. and McDonald, A.M. (2023) *ACS ES&T Water* 2023 3 (3), 626-628. DOI: 10.1021/acsestwater.3c00052

Peña-Ramos, J. A., López-Bedmar, R. J., Sastre, F. J. and Martínez-Martínez, A. (2022) Water Conflicts in Sub-Saharan Africa, Front. Environ. Sci., Sec. Water and Wastewater Management, 10, https://doi.org/10.3389/fenvs.2022.863903

Philipsborn, R., Ahmed, S.M., Brosi, B.J. and Levy, K. (2016) Climatic Drivers of Diarrheagenic Escherichia coli Incidence: A Systematic Review and Meta-analysis. *J Infect Dis*. 2016 Jul 1;214(1):6-15. doi: 10.1093/infdis/jiw081. Epub 2016 Feb 29. PMID: 26931446; PMCID: PMC4907410.

Porkka, M., Matti Kummu, Stefan Siebert & Martina Flörke (2012) The Role of Virtual Water Flows in Physical Water Scarcity: The Case of Central Asia. *International Journal of Water Resources Development*, 28:3, 453-474. http://dx.doi.org/10.1080/07900627.2012.684310

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M.C., Gordon, B., Hunter, P.R., Medicott, K. and Johnston, R. (2019) Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low-and middle-income countries. International Journal of Hygiene and Environmental Health. https://doi.org/10.1016/j.ijeh.2019.05.004

Rodell, M., Velicogna, I. & Famiglietti, J. (2009) Satellite-based estimates of groundwater depletion in India. *Nature* 460, 999–1002 https://doi.org/10.1038/nature08238

Rodella, A.D., Zaveri, E. and Bertone, F. (2023) *The Hidden Wealth of Nations: The Economics of Groundwater in Times of Climate Change*. Executive Summary. World Bank, Washington, DC. https://www.worldbank.org/en/topic/water/publication/the-hidden-wealth-of-nations-groundwater-in-times-of-climate-change

Scanlon, B.R., Fakhreddine, S., Rateb, A. et al. (2023) Global water resources and the role of groundwater in a resilient water future. *Nat Rev Earth Environ* 4, 87–101 https://doi.org/10.1038/s43017-022-00378-6

Shah, M.A.A. *et al.* (2016) 'Equity in a tertiary canal of the Indus Basin Irrigation System (IBIS)', *Agricultural Water Management*, 178, pp. 201–214. Available at: https://doi.org/10.1016/j.agwat.2016.09.018.

Shah, M., Jonathan Lautze and Asadullah Meelad (2023) *Afghanistan–Pakistan Shared Waters: State of the Basins*. CAB International 2023. https://doi.org/10.1079/9781800622371.0000

Shah,, T. (2009) Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environ. Res. Lett*. 4 doi:10.1088/1748-9326/4/3/035005

Shaw, R., Luo, Y., Cheong, T., Abdul Halim, S., Chaturvedi, S., Hashizume, M., Insarov, G., Ishikawa, Y., Jafari, M., Kitoh, A., Pulhin, J., Singh, C., Vasant, K., and Zhang, Z. (2022) Asia. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O., Roberts, D., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457-1579, doi:10.1017/9781009325844.012.

Taylor, C., Robinson, T.R., Dunning, S., Rachel Carr, J. and Westoby, M. (2023) Glacial lake outburst floods threaten millions globally. Nat Commun 14, 487. https://doi.org/10.1038/s41467-023-36033-x

UNICEF and GWP (2022) WASH Climate Resilient Development, Strategic Framework, 2022 Edition, Global Water Partnership, UNICEF, https://www.gwp.org/globalassets/global/about-gwp/publications/unicef-gwp/gwp_unicef_strategic_framework-2022-edition.pdf

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

World Bank (2023) Country Climate and Development Report: Uzbekistan, November 2023, https://documents1.worldbank.org/curated/en/099111423124532881/pdf/P1790680f452f10ba0a34c06922a1df0003.pdf

World Bank/CAWEP (2020) Central Asia Water and Energy Program, CAWEP Annual Report 2020, https://documents1.worldbank.org/curated/en/762821637173388611/pdf/Central-Asia-Water-and-Energy-Program-Annual-Report-2020.pdf

World Bank/ADB (2021) *Climate Risk Country Profile: Tajikistan*. The World Bank Group and the Asian Development Bank. https://climateknowledgeportal.worldbank.org/country-profiles

Yao, T., Bolch, T., Chen, D. et al. (2022) The imbalance of the Asian water tower. *Nat Rev Earth Environ* 3, 618–632 https://doi.org/10.1038/s43017-022-00299-4

Zeitoun, M. and Warner, J. (2006). Hydro-Hegemony- a Framework for Analysis of Trans-Boundary Water Conflicts. *Water Policy*, 8(5). DOI: 10.2166/wp.2006.054

Zhou, X., Shumin Han, Huilong Li, Dandan Ren, Zhuping Sheng, Yonghui Yang (2021). Virtual Water Flows in Internal and External Agricultural Product Trade in Central Asia*. Journal of the American Water Resources Association*, https://doi.org/10.1111/1752-1688.12959

Section 3.3 – Health

A. Akramkhanov, S. Strohmeier, Y.A. Yigezu, M. Haddad, T. Smeets, G. Sterk, C. Zucca, A. Zakhadullaev, P. Agostini, E.S. Golub, N. Akhmedkhodjaeva, C.S. Erencin, (2021) *The Value of Landscape Restoration in Uzbekistan to Reduce Sand and Dust Storms from the Aral Seabed*. © World Bank."

Alderman, K., Turner, L.R. and Tong, S. (2012) Floods and human health: a systematic review. *Environ. Int*. 47:37-47.

Carlton, E.J., Woster, A.P., DeWitt, P., Goldstein, R.S., Levy, K. (2016) 'A systematic review and meta-analysis of ambient temperature and diarrhoeal diseases' *Int J Epidemiol* 45(1): 117-30

Cissé, G., R. McLeman, H. Adams, P. Aldunce, K. Bowen, D. Campbell-Lendrum, S. Clayton, K.L. Ebi, J. Hess, C. Huang, Q. Liu, G. McGregor, J. Semenza, and M.C. Tirado (2022) Health, Wellbeing, and the Changing Structure of Communities. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1041–1170, doi:10.1017/9781009325844.009.

Dhimal, M., Ahrens, B., & Kuch, U. (2015) Climate Change and Spatiotemporal Distributions of Vector-Borne Diseases in Nepal – A Systematic Synthesis of Literature. *PLOS ONE*, 10(6), 1–31. URL: https://journals.plos.org/plosone/article?id=10.1371/journal. pone.0129869

Dhiman, R.C. and Sarkar, S. (2017) El Nino Southern Oscillation as an early warning tool for malaria outbreaks in India. *Malar.J.*, 16(1), 122 doi: 10.1186/s12936-017-1779-y.

Di Napoli, C., McGushin, A., Romanello, M. et al. (2022) Tracking the impacts of climate change on human health via indicators: lessons from the Lancet Countdown. *BMC Public Health* 22, 663 (2022). https://doi.org/10.1186/s12889-022-13055-6

FAO, IFAD, UNICEF, WFP and WHO (2022) *The State of Food Security and Nutrition in the World 2022: Repurposing food and agricultural policies to make healthy diets more affordable*. Rome, FAO. https://doi.org/10.4060/cc0639en

Forsythe, L. (2023) *Gender and acute food insecurity: Importance of meaningfully engaging women in acute food insecurity prevention and response*. UK AID/WOW Guidance Note July 2023. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://assets.publishing.service.gov.uk/media/65b23090160765001118f8a6/WOW_Helpdesk_Query_79_Gender_and_acute_food_insecurity.pdf

Grembi, J., Anna T. Nguyen, Marie Riviere et al (2022) Influence of climatic and environmental risk factors on child diarrhoea and enteropathogen infection and predictions under climate change in rural Bangladesh. *medRxiv* 2022.09.26.22280367; doi: https://doi.org/10.1101/2022.09.26.22280367

Hallegatte,Stephane; Vogt-Schilb, Adrien Camille; Bangalore, Mook; Rozenberg, Julie (2017) *Unbreakable : building the resilience of the poor in the face of natural disasters.* Climate

Change and Development Washington, D.C: World Bank Group. http://documents.worldbank.org/curated/en/512241480487839624/Unbreakable-building-the-resilience-of-the-poor-in-the-face-of-natural-disasters

Hashizume, M., Yoonhee Kim, Chris Fook Sheng Ng, Yeonseung Chung, Lina Madaniyazi, Michelle L. Bell, Yue Leon Guo, Haidong Kan, Yasushi Honda, Seung-Muk Yi, Ho Kim, and Yuji Nishiwaki (2020) Health Effects of Asian Dust: A Systematic Review and Meta-Analysis. *Environmental Health Perspectives*, Volume 128, Issue 6. https://doi.org/10.1289/EHP5312

He, Y., Rentschler, J., Avner, P., Gao, J., Yue, X., and Radke, J. (2022) Mobility and Resilience: A Global Assessment of Flood Impacts on Road Transportation Networks. World Bank Policy Research Working Paper 10049. Washington DC: World Bank. http://hdl.handle.net/10986/37452

Howard, G., Calow, R.C., MacDonald, A.M. and Bartram, J. (2016) Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annual Review of Environment and Resources*. 2016. 41:8.1-8.24.

IHME-GBD (2019) *Global Burden of Disease (GBD) Study 2019*. Institute for Health Metrics and Evaluation/The Lancet. See: https://www.healthdata.org/research-analysis/gbd

Im, E. S., Pal, J. S., & Eltahir, E. A. B. (2017) Deadly heat waves projected in the densely populated agricultural regions of South Asia. *Science Advances*, 3(8), 1–8. URL: https://advances.sciencemag.org/content/3/8/e1603322

International Finance Corporation (IFC) (2017) *Climate Investment Opportunities in South Asia*. © Washington, DC. http://hdl.handle.net/10986/29205

Irfan, H. (2024) Air pollution and cardiovascular health in South Asia: A comprehensive review. *Current Problems in Cardiology*, Volume 49, Issue 2, 2024. https://doi.org/10.1016/j.cpcardiol.2023.102199.

Jafino, Bramka Arga; Walsh, Brian; Rozenberg, Julie; Hallegatte, Stephane (2020) *Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030*. Policy Research Working Paper 9417. World Bank, Washington, DC. http://hdl.handle.net/10986/34555

Jha, A. and Jain, M. (2022) *South Asia needs equitable cooling as heat waves worsen*. World Bank blog, 27 October 2022. https://blogs.worldbank.org/en/endpovertyinsouthasia/south-asia-needs-equitable-cooling-heatwaves-worsen

Jones, B., Tebaldi, C., O'Neill, B.C. et al. (2018) Avoiding population exposure to heat-related extremes: demographic change vs climate change. *Climatic Change* 146, 423–437 (2018). https://doi.org/10.1007/s10584-017-2133-7

Kim, Ella Jisun; Henry, Grace; Jain, Monica (2023) *Urban Heat in South Asia: Integrating People and Place in Adapting to Rising Temperatures.* © World Bank, Washington DC. http://hdl.handle.net/10986/39749

Khormi, H. M. and Kumar, L. (2016) Future malaria spatial pattern based on the potential global warming impact in South and Southeast Asia, *Geospatial Health*, 11(3), https://doi.org/10.4081/gh.2016.416 https://doi.org/10.4081/gh.2016.416 (2016) Future malaria spatial pattern based on the potential global warming impact in South and Southeast Asia, *Geospatial Health*, 11(3), https://doi.org/10.4081/gh.2016.416

Lancet Global Health (LGH) (2022) Assessing performance of the Healthcare Access and Quality Index, overall and by select age groups, for 204 countries and territories, 1990-2019: a systematic analysis from the Global Burden of Disease Study 2019. *Lancet Global Health* 2022; 10:e1715-43. DOI: https://doi.org/10.1016/S2214-109X(22)00429-6

Lieber, M., Peter Chin-Hong, Knox Kelly, Madhavi Dandu & Sheri D. Weiser (2022) A systematic review and meta-analysis assessing the impact of droughts, flooding, and climate variability on malnutrition, *Global Public Health*, 17:1, 68-82, DOI: 10.1080/17441692.2020.1860247

Lwin, K. S., Aurelio Tobias, Paul Lester Chua et al (2023) Effects of Desert Dust and Sandstorms on Human Health: A Scoping Review. *GeoHealth*, Vol 7, Issue 3. https://doi.org/10.1029/2022GH000728

NASA (2022) *NASA's ECOSTRESS Detects Heat Islands in Extreme India Heat Wave*. NASA Global Climate Change Feature, https://climate.nasa.gov/news/3176/nasas-ecostress-detects-heat-islands-in-extreme-indian-heat-wave/

Nguyen, A., Jessica A. Grembi, Marie Riviere et al (2022) Influence of climate and environment on the efficacy of water, sanitation, and handwashing interventions on diarrheal disease in rural Bangladesh: a re-analysis of a randomized control trial. *medRxiv* 2022.09.25.22280229; doi: https://doi.org/10.1101/2022.09.25.22280229

Nijhawan A, Howard G. (2022) Associations between climate variables and water quality in low- and middle-income countries: A scoping review. *Water Res*. Feb 15;210:117996. doi: 10.1016/j.watres.2021.117996. Epub 2021 Dec 21. PMID: 34959067.

Nishonov, B.E., Kholmatjanov, B.M., Labzovskii, L.D. et al. (2023) Study of the strongest dust storm occurred in Uzbekistan in November 2021. *Sci Rep* 13, 20042 (2023). https://doi.org/10.1038/s41598-023-42256-1

Patankar, A. (2015) *The Exposure, Vulnerability, and Ability to Respond of Poor Households to Recurrent Floods in Mumbai*. Policy Research Working Paper 7481, World Bank, Washington, DC. https://doi.org/10.1596/1813-9450-7481

Phalkey, R.K., Aranda-Jan, C., Marx, S., Hofle, B. and Sauerborn, R. (2015) Systematic review of current efforts to quantify the impacts of climate change on undernutrition. *PNAS* E4522-E4529. www.pnas.org/cgi/doi/10.1073/pnas.1409769112

Philipsborn, R., Ahmed, S.M., Brosi, B.J. and Levy, K. (2016) Climatic Drivers of Diarrheagenic Escherichia coli Incidence: A Systematic Review and Meta-analysis. *J Infect Dis*. 2016 Jul 1;214(1):6-15. doi: 10.1093/infdis/jiw081. Epub 2016 Feb 29. PMID: 26931446; PMCID: PMC4907410.

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M.C., Gordon, B., Hunter, P.R., Medicott, K. and Johnston, R. (2019) Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low-and middle-income countries. *International Journal of Hygiene and Environmental Health*. https://doi.org/10.1016/j.ijeh.2019.05.004

Quillérou, E., Thomas, R.J., Guchgeldiyev, O. , Ettling, S., Etter, H., & Stewart, N. (2016) *Economics of Land Degradation (ELD) Initiative: Broadening options for improved economic sustainability in Central Asia*. Synthesis report. Report for the ELD Initiative from the Dryland Systems Program of CGIAR c/o ICARDA, Amman, Jordan. Available from: www.eld-initiative.org

Rekha, S., Nalini, S.J., Bhuvana, S., Kanmani, S., Hirst, J.E. and Venugopal, V. (2014) Heat stress and adverse pregnancy outcome: Prospective cohort study. *BJOG*. 2024 Apr;131(5):612-622. doi: 10.1111/1471-0528.17680. Epub 2023 Oct 9. PMID: 37814395.

Sarkar, S., Gangare, V., Singh, P. and Dhiman, R.C. (2019) Shift in Potential Malaria Transmission Areas in India, Using the Fuzzy-Based Climate Suitability Malaria Transmission (FCSMT) Model under Changing Climatic Conditions. *International Journal of Environmental Research and Public Health* 2019, 16, 3474; doi: 10.3390/ijerph16183474

SCF (2023) *Dengue outbreaks threaten children across Asia as extreme weather spurs mosquitos*. News and Press Release, SCF, 23 July 2023. See: https://reliefweb.int/report/world/dengue-outbreaks-threaten-children-across-asia-extreme-weather-spurs-mosquitos

SDC (2022) *Chilling Prospects: Tracking Sustainable Cooling for All*. See: https://www.seforall.org/our-work/research-analysis/chilling-prospects-series

Shaw, R., Y. Luo, T.S. Cheong, S. Abdul Halim, S. Chaturvedi, M. Hashizume, G.E. Insarov, Y. Ishikawa, M. Jafari, A. Kitoh, J. Pulhin, C. Singh, K. Vasant, and Z. Zhang (2022): Asia. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457–1579, doi:10.1017/9781009325844.012.

Sherburne-Benz,Lynne D.; Haque,Trina S.; Tandon,Ajay; Coudouel,Aline; Fasih,Tazeen; Andersen,Christopher Thomas; Majoka,Zaineb; Alam,Muneeza Mehmood; Vargas,Martha P.; Cain,Jewelwayne Salcedo; Hasan,Rifat Afifa; Johnson,Kelly Suzanne; Agarwal,Vivek; Narain,Urvashi; Govindaraj,Ramesh; Mittal,Pallavi Anand; Saleem,Furqan Ahmad; Joseph,George; Debebe,Zelalem Yilma; Hasan,Amer; Darvas,Peter; Crystal,Sybille (2021) Unleashing the South Asian Century Through Human Capital for All (English). Washington, D.C. World Bank Group. http://documents.worldbank.org/curated/en/885781616013381140/Unleashing-the-South-Asian-Century-Through-Human-Capital-for-All

Shi, W., Qinghua Sun, Peng Du, Song Tang, Chen Chen, Zhiying Sun, Jiaonan Wang, Tiantian Li, and Xiaoming Shi (2020) Modification Effects of Temperature on the Ozone–Mortality Relationship: A Nationwide Multicounty Study in China. *Environmental Science & Technology* 2020 54 (5), 2859-2868. DOI: 10.1021/acs.est.9b05978

Silva, R.A., West, J.J., Lamarque, J.F. et al (2017) Future global mortality from changes in air pollution attributable to climate change. *Nat Clim Chang*. 2017 Sep;7(9):647-651. doi: 10.1038/nclimate3354. Epub 2017 Jul 31. PMID: 30245745; PMCID: PMC6150471.

Tasgaonkar, P., Zade, D., Ehsan, S., Gorti, G., Mamnun, N., Siderius, C. and Singh, T. (2022) Indoor heat measurement data from low-income households in rural and urban South Asia. *Sci Data* 9, 285. https://doi.org/10.1038/s41597-022-01314-5

Turgali, D., Kopeyeva, A., Dikhanbayeva, D. and Rojas-Solórzano, L. (2021) 'Potential impact of global warming on wind power production in Central Asia', *Environmental Progress & Sustainable Energy*, 40(4), p. e13626. Available at: https://doi.org/10.1002/ep.13626.

Rocque RJ, Beaudoin C, Ndjaboue R, Cameron L, Poirier-Bergeron L, Poulin-Rheault RA, Fallon C, Tricco AC, Witteman HO. (2021) Health effects of climate change: an overview of systematic reviews. *BMJ Open*. 2021 Jun 9;11(6):e046333. doi: 10.1136/bmjopen-2020-046333. PMID: 34108165; PMCID: PMC8191619.

UNICEF/WHO/World Bank Group (2023) *Levels and trends in child malnutrition*, 2023 edition. https://data.unicef.org/resources/jme-report-2023/

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

Vecellio, D. J., S. Tony Wolf, Rachel M. Cottle, and W. Larry Kenney (2022) Evaluating the 35°C wet-bulb temperature adaptability threshold for young, healthy subjects. *J Appl Physiol* 132: 340–345, 2022. doi:10.1152/japplphysiol.00738.2021

Wali, N., Agho, K and Renzaho, A.M.N. (2019) Past drivers of and priorities for child undernutrition in South Asia: a mixed methods systematic review protocol. *Systematic Reviews*, 8, 189 (2019). https://doi.org/10.1186/s13643-019-1112-7

Wehner, Michael, Dáithí Stone, Hari Krishnan, Krishna Achutarao, and Federico Castillo (2016) The Deadly Combination of Heat and Humidity in India and Pakistan in Summer 2015. *Bulletin of the American Meteorological Society* 97 (12): S81–86. https://doi.org/10.1175/BAMS-D-16-0145.1.

WFP and FAO (2023) *Hunger Hotspots. FAO-WFP early warnings on acute food insecurity, June 2023 to November 2023 outlook*. Rome. https://doi.org/10.4060/cc6206en

WHO (2014) *Quantitative Risk Assessment of the effects of Climate Change on Selected Causes of Death, 2030s and 2050s.* Geneva: World Health Organisation.

WHO (2017) *Diarrhoeal disease: key facts*. World Health Organisation Fact Sheet, May 2017. Geneva: World Health Organisation. https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease

WHO (2021) *WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide*. Geneva: World Health Organisation, 2021. https://www.who.int/publications/i/item/9789240034228

WHO (2022a) *Roadmap for health and well-being in Central Asia* (2022–2025). Copenhagen: WHO Regional Office for Europe; 2022. Licence: CC BY-NC-SA 3.0 IGO.

WHO (2022b) World Malaria Report 2022. Geneva: World Health Organisation.

WHO (2023) WHO Newsroom: "It was just the perfect storm for malaria" – Pakistan responds to surge in cases following the 2022 floods. Newsroom feature 18 April 2023.

Woetzel, J., Pinner, D., Samandara, H., Gupta, R., Engel, H., Krishnan, M. and Powis, C (2020) *Will India get too hot to work?* Case study, November 2020. McKinsey Global Institute. https://www.mckinsey.com/capabilities/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts

World Bank Group (2017) *Glass Half Full: Poverty Diagnostic of Water Supply, Sanitation, and Hygiene Conditions in Tajikistan*. World Bank, Washington, DC. http://hdl.handle.net/10986/27830

World Bank (2018) *Promising Progress: A Diagnostic of Water Supply, Sanitation, Hygiene, and Poverty in Bangladesh*. WASH Poverty Diagnostic, World Bank, Washington, DC. http://hdl.handle.net/10986/29450. http://hdl.handle.net/10986/29450

World Bank (2021) Striving for Clean Air, Air Pollution and Public Health in South Asia, South Asia Development Matters, World Bank Group, https://openknowledge.worldbank.org/server/api/core/bitstreams/fa89a482-f616-4da0-914f-40dac1a88bdc/content

World Bank (2021) Striving for Clean Air, Air Pollution and Public Health in South Asia, South Asia Development Matters, World Bank Group, https://openknowledge.worldbank.org/server/api/core/bitstreams/fa89a482-f616-4da0-914f-40dac1a88bdc/content

World Bank (2022c) *Afghanistan Welfare Monitoring Survey (AWMS) 2022, Round 2*. See: https://www.worldbank.org/en/news/press-release/2022/11/22/world-bank-survey-living-conditions-remain-dire-for-the-afghan-people

World Bank (2023a) *Striving for Clean Air: Air Pollution and Public Health in South Asia*. South Asia Development Matters. Washington, DC: World Bank. doi:10.1596/978-1-4648-1831-8

World Bank (2023b) *Building Back a Greener Bangladesh: Country Environmental Analysis*. Washington DC, The World Bank Group. https://www.worldbank.org/en/region/sar/publication/bangladesh-country-environment-analysis-2023

Zachariah, M., Arulalan T, Krishna Achuta Rao et al (2022) *Climate Change made devastating early heat in India and Pakistan 30 times more likely*. Research report for World Weather Attribution. See: https://public.wmo.int/en/media/news/climate-change-made-heatwaves-india-and-pakistan-30-times-more-likely

Section 3.4 – Infrastructure and Settlements

Alam, E. (2023) Factors of cyclone disaster deaths in coastal Bangladesh. *Heliyon*, Volume 9, Issue 7, 2023. https://doi.org/10.1016/j.heliyon.2023.e18417.

Amores, A., Marcos, M., Pedreros, R., Le Cozannet, G., Lecacheux, S., Rohmer, J., ... and Khaleel, Z. (2021) Coastal flooding in the Maldives induced by mean sea-level rise and wind-waves: from global to local coastal modelling. *Frontiers in Marine Science*, *8*, 665672. https://doi.org/10.3389/fmars.2021.665672

Boas, I., Farbotko, C., Adams, H. et al (2019) Climate migration myths. *Nat. Clim. Chang*. 9, 901–903 (2019). https://doi.org/10.1038/s41558-019-0633-3

Clement, V., Rigaud, K. K., De Sherbinin, A., Jones, B., Adamo, S., Schewe, J., and Shabahat, E. (2021) *Groundswell part 2: Acting on internal climate migration*. World Bank.

CoI (2011). *Population Census 2011, India*. Census Organisation of India. https://www.census2011.co.in/

CRED-EM-DAT (2023) Em-dat: international disaster database. *Centre for Research on the Epidemiology of Disasters, Universidad Católic a de Lovaina, Bruselas*. https://www.emdat.be/

Dawson, R. J. (2015) Handling interdependencies in climate change risk assessment. *Climate*, *3*(4), 1079-1096. https://doi.org/10.3390/cli3041079

Dawson, R. J., Thompson, D., Johns, D., Wood, R., Darch, G., Chapman, L., ... and Hall, J. W. (2018) A systems framework for national assessment of climate risks to infrastructure. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2121), 20170298. https://doi.org/10.1098/rsta.2017.0298

Dodman, D., B. Hayward, M. Pelling, V. Castan Broto, W. Chow, E. Chu, R. Dawson, L. Khirfan, T. McPhearson, A. Prakash, Y. Zheng, and G. Ziervogel (2022) Cities, Settlements and Key Infrastructure. In: *Climate Change (2022). Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907–1040, doi:10.1017/9781009325844.008.

FAO, UNICEF, WFP and WHO (2023) *Asia and the Pacific – Regional Overview of Food Security and Nutrition 2022. Urban food security and nutrition*. Bangkok, FAO. https://doi.org/10.4060/cc3990en

Fiddian-Qasmiyeh, E; (2019) Looking Forward: Disasters at 40. *Disasters*, 43 (S1) S36-S60. 10.1111/disa.12327.

Geisler, C., and B. Currens (2017) Impediments to inland resettlement under conditions of accelerated sea level rise. *Land Use Policy* 66:322–30. doi: 10.1016/j.landusepol.2017.03.029.

Gemenne, F. (2011) Why the numbers don't add up: A review of estimates and predictions of people displaced by environmental changes. *Global Environmental Change*, Volume 21, Supplement 1, Pages S41-S49. https://doi.org/10.1016/j.gloenvcha.2011.09.005.

GoK (2018) Post Disaster Needs Assessment: Kerala Floods 2018. Government of the state of Kerala, India.

GoN (2017) Nepal Floods 2017: Post Floods Recovery Needs Assessment. Government of Nepal.

GoO (2019) Post Disaster Needs Assessment: Cyclone Fani 2019. Government of the state of Odisha, India.

GoP (2022) Post Disaster Needs Assessment: Pakistan Floods 2022. Government of Pakistan.

GoSL (2017) Post Disaster Needs Assessment: Sri Lank Floods 2017. Government of Sri Lanka.

Gray, C.L. and Mueller, V. (2012) Natural disasters and population mobility in Bangladesh. *PNAS*, Vol 109, No.6. https://doi.org/10.1073/pnas.1115944109

Hallegatte, S. (2016) *Shock waves: managing the impacts of climate change on poverty*. World Bank Publications.

Hallegatte, S., Rentschler, J. and Rozenberg, J. (2019) Lifelines: The Resilient Infrastructure Opportunity. Sustainable Infrastructure Series. Washington DC: World Bank. https://openknowledge.worldbank.org/handle/10986/31805

Hallegatte, S., Vogt-Schilb, A., Bangalore, M., and Rozenberg, J. (2017) Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters. Climate Change and Development. Washington, DC: World Bank.

Haque U, Hashizume M, Kolivras K, Overgaard H, Das B, Yamamoto T (2011) *Reduced death rates from cyclones in Bangladesh: what more needs to be done?* Bulletin of the World Health Organization. http://www.who.int/bulletin/volumes/90/2/11-088302/en/

Haquea, S.S., Yanez-Pagansb, M., Arias-Granada, Y. and Joseph, G. (2022) Water and sanitation in Dhaka slums: access, quality, and informality in service provision. *Water International*, https://doi.org/10.1080/02508060.2020.1786878

He, Y., Rentschler, J., Avner, P., Gao, J., Yue, X., and Radke, J. (2022) Mobility and Resilience: A Global Assessment of Flood Impacts on Road Transportation Networks. World Bank Policy Research Working Paper 10049. Washington DC: World Bank. http://hdl.handle.net/10986/37452

Hulme, M., O'Neil, S.J. and Dessai, S. (2011) Is weather event attribution necessary for adaptation funding? *Science*, 334, 764-765. https://doi.org/10.1126/science.1211740

IFRC (2021) Bangladesh: Cyclone Amphan Final Report. International Federation of Red Cross And Red Crescent Societies. https://reliefweb.int/report/bangladesh/bangladesh-cyclone-amphan-final-report-n-mdrbd024

International Finance Corporation (IFC) (2017) *Climate Investment Opportunities in South Asia*. © Washington, DC. http://hdl.handle.net/10986/29205

Kim, Ella Jisun; Henry, Grace; Jain, Monica (2023) *Urban Heat in South Asia: Integrating People and Place in Adapting to Rising Temperatures.* © World Bank, Washington DC. http://hdl.handle.net/10986/39749

Koks, E.E., Rozenberg, J., Zorn, C. et al. A global multi-hazard risk analysis of road and railway infrastructure assets. *Nat Commun* 10, 2677 (2019). https://doi.org/10.1038/s41467-019-10442-3

Kulp, S. A., and Strauss, B. H. (2019) New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature communications*, *10*(1), 1-12. https://doi.org/10.1038/s41467-019-12808-z

Lahsen, M. and Ribot, J. (2021). Politics of attributing extreme events and disasters to climate change. *WIREs Climate Change*, Vol 13, Issue 1. https://doi.org/10.1002/wcc.750

Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou, 2021: Future Global Climate: Scenario-Based Projections and Near Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi:10.1017/9781009157896.006

Li, D., Lu, X., Walling, D. E., Zhang, T., Steiner, J. F., Wasson, R. J., ... and Bolch, T. (2022). High Mountain Asia hydropower systems threatened by climate-driven landscape instability. *Nature Geoscience*, *15*(7), 520-530. https://doi.org/10.1038/s41561-022-00953-y

Lumbruso, D., Brown, E. and Ranger, N. (2016) Stakeholders' perceptions of the overall effectiveness of early warning systems and risk assessments for weather-related hazards in Africa, the Caribbean and South Asia. *Nat Hazards* 84, 2121–2144 (2016). https://doi.org/10.1007/s11069-016-2537-0

Manzo, D., Zee, G., and Uddin, S. (2021) Facing dire sea level rise threat, Maldives turns to climate change solutions to survive. ABC news. Accessed on 10 July 2023. https://abcnews.go.com/International/facing-dire-sea-level-rise-threat-maldives-turns/story?id=80929487

Mondal, D., and Banerjee, A. (2021) Exploring peri-urban dynamism in India: Evidence from Kolkata Metropolis. *Journal of Urban Management*, *10*(4), 382-392. https://doi.org/10.1016/j.jum.2021.06.004

Nagchaoudhary, S., and Paul, R. (2020) Cyclone Amphan loss estimated at USD13 billion in India, may rise in Bangladesh. Reuters. Accessed on 11 July 2023. https://www.reuters.com/article/us-asia-storm-india-idUSKBN22Z0HE

Nayna Schwerdtle P, Stockemer J, Bowen KJ, Sauerborn R, McMichael C, Danquah I. (2020) A Meta-Synthesis of Policy Recommendations Regarding Human Mobility in the Context of Climate Change. *Int J Environ Res Public Health*. 2020 Dec 14;17(24):9342. doi: 10.3390/ijerph17249342. PMID: 33327439; PMCID: PMC7764877.

OECD (2018) Climate Resilient Infrastructure. OECD Environment POLICY Paper No. 14. Paris: OECD.

Otto, F. E., Zachariah, M., Saeed, F., Siddiqi, A., Kamil, S., Mushtaq, H., and Clarke, B. (2023) Climate change increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan. *Environmental Research: Climate*, *2*(2), 025001. https://www.worldweatherattribution.org/wp-content/uploads/Pakistan-floods-scientific-report.pdf

Panwar, V., and Sen, S. (2019) Economic impact of natural disasters: An empirical re-examination. *Margin: The Journal of Applied Economic Research*, *13*(1), 109-139. https://doi.org/10.1177/0973801018800087

Patankar, A. (2015) *The Exposure, Vulnerability, and Ability to Respond of Poor Households to Recurrent Floods in Mumbai*. Policy Research Working Paper 7481, World Bank, Washington, DC. https://doi.org/10.1596/1813-9450-7481

Raff, J.L., Goodbred, S.L., Pickering, J.L. et al. (2023) Sediment delivery to sustain the Ganges-Brahmaputra delta under climate change and anthropogenic impacts. *Nat Commun* 14, 2429 (2023). https://doi.org/10.1038/s41467-023-38057-9

Rahman, M.M. et al. (2020) Ganges-Brahmaputra-Meghna Delta, Bangladesh and India: A Transnational Mega-Delta. In: Nicholls, R., Adger, W., Hutton, C., Hanson, S. (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-23517-8_2

Rentschler, J. and Salhab, M. (2020) *People in Harm's Way: Flood Exposure and Poverty in 189 Countries.* World Bank Group Policy Research Working Paper 9447, October 2020. https://openknowledge.worldbank.org/entities/publication/04ad161e-7144-5984-8b85-91710f2900b4

Reyer, C., Otto, I.M., Adams, S. et al. (2017) Climate change impacts in Central Asia and their implications for development. *Reg Environ Change* 17, 1639–1650 (2017). https://doi.org/10.1007/s10113-015-0893-z

Rigaud, K., Kanta, Alex de Sherbinin, Bryan Jones, Jonas Bergmann, Viviane Clement, Kayly Ober, Jacob Schewe, Susana Adamo, Brent McCusker, Silke Heuser, and Amelia Midgley. (2018) *Groundswell: Preparing for Internal Climate Migration*. Washington, DC: The World Bank.

Rollins, A. M., Wheeler, M., and Frazier, T. (2022) A Marshall Plan for the 21st century: Addressing climate change in the Asia-Pacific through diplomacy, development, and defence. *Journal of Emergency Management*, *20*(8). https://doi.org/10.5055/jem.0684

Ross, I., Scott, R. and Joseph, R. (2016) *Faecal Sludge Management: Diagnostics for Service Delivery in Urban Areas. Case study in Dhaka, Bangladesh*. World Bank Group, Washington DC. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/461321468338637425/fecal-sludge-management-diagnostics-for-service-delivery-in-urban-areas-tools-and-guidelines

Safra de Campos, R. et al. (2020) Where People Live and Move in Deltas. In: Nicholls, R., Adger, W., Hutton, C., Hanson, S. (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-23517-8_7

Sandhu, H. S., and Raja, S. (2019) *No Broken Link: The Vulnerability of Telecommunication Infrastructure to Natural Hazards*. Washington D.C.: World Bank.

Selby J, Daoust G (2021) Rapid evidence assessment on the impacts of climate change on migration patterns. London: Foreign, Commonwealth and Development Office.

Tasri, E. S., Karimi, K., and Muslim, I. (2022) The effect of economic variables on natural disasters and the impact of disasters on economic variables. *Heliyon*, *8*(1). https://doi.org/10.1016/j.heliyon.2021.e08678

Tay, C., Lindsey, E. O., Chin, S. T., McCaughey, J. W., Bekaert, D., Nguyen, M., ... and Hill, E. M. (2022) Sea-level rise from land subsidence in major coastal cities. *Nature Sustainability*, *5*(12), 1049-1057. https://doi.org/10.1038/s41893-022-00947-z

Thacker, S., Pant, R., and Hall, J. W. (2017) System-of-systems formulation and disruption analysis for multi-scale critical national infrastructures. *Reliability Engineering and System Safety*, *167*, 30-41. https://doi.org/10.1016/j.ress.2017.04.023

UNDESA (2018) World Urbanization Prospects: The 2018 Revision. https://population.un.org/wup/publications/Files/WUP2018-Report.pdf

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

Verschuur, J., Koks, E.E., Li, S. et al. (2023) Multi-hazard risk to global port infrastructure and resulting trade and logistics losses. *Commun Earth Environ* 4, 5 (2023). https://doi.org/10.1038/s43247-022-00656-7

WDI (2022) World development indicators 2022. The World Bank. https://wdi.worldbank.org/

Winsemius, H.C., Jongman, B., Veldkamp, T.I.E., Hallegatte, S., Bangalore, M. and Ward, P.J. (2018) Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts. *Environment and Development Economics*, 23, 328–348. doi:10.1017/S1355770X17000444

World Bank (2007) *Dhaka: Improving Living Conditions for the Urban Poor*. Bangladesh Development Series Paper No. 17, World Bank Dhaka, June 2007.

World Bank (2016) Europe and Central Asia - Country risk profiles. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/958801481798204368/Europe-and-Central-Asia-Country-risk-profiles-for-floods-and-earthquakes

World Bank (2020) Demographic Trends and Urbanisation. Washington D.C.: World Bank. https://documents1.worldbank.org/curated/en/260581617988607640/pdf/Demographic-Trends-and-Urbanization.pdf

World Bank (2022a) Bangladesh Country Climate and Development Report. CCDR Series. Washington, D.C.: World Bank Group. http://hdl.handle.net/10986/38181

World Bank (2022b) Kazakhstan Country Climate and Development Report. CCDR Series. Washington, D.C.: World Bank Group. http://hdl.handle.net/10986/38215

World Bank (2022c) Bangladesh: Enhancing Coastal resilience in a Changing Climate. Washington, D.C.: World Bank Group. http://hdl.handle.net/10986/38004

World Bank (2022d) DataBank – World Development Indicators, Accessed July 2023, https://databank.worldbank.org/source/world-development-indicators

World Bank (2023) *Regional Engagement Framework for Central Asia*. January 2023 Update. Washington, DC.

Section 3.5 – Energy

ADB (2016) ADB TA 8727 REG: Study for a Power Sector Financing Road Map within Central Asia Regional Economic Cooperation - Final Report:

ADB (2018) 'ADB Grant to Help Tajikistan Reconnect to the Central Asian Power System'. ADB News Release, 15 November.

ADB (2022) 'Pakistan: Second Power Transmission Enhancement Investment Program (Tranche 4)'. Project webpage. ADB: Manila.

ADB (2023a) *Asian Development Outlook (ADO) July 2023: Robust Growth with Moderating Inflation*. ADB: Manila.

ADB (2023b) 'Nepal: Electricity Transmission Expansion and Supply Improvement Project' Project webpage. ADB: Manila.

ADB (2023c) 'Nepal: South Asia Subregional Economic Cooperation Power System Expansion Project'. Project webpage. ADB: Manila.

ADB (2023d) 'ADB to Help Modernize Uzbekistan's Power Transmission Grid'. ADB News Release, 10 July.

ADB (2023e) 'Tajikistan : Reconnection to the Central Asian Power System Project'. Project webpage. ADB: Manila.

Ali, M., Iqbal, M., and Sharif, M. (2013) 'Relationship between extreme temperature and electricity demand in Pakistan' *International Journal of Energy and Environmental Engineering* 4: 36–41.

Barbar, M., Mallapragada, D.S., and Stoner, R.J. (2023) Impact of demand growth on decarbonizing India's electricity sector and the role for energy storage. *Energy and Climate Change,* Volume 4 (https://www.sciencedirect.com/science/article/pii/S2666278723000053)

Bartos, M. et al. (2016) Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States. *Environ. Res. Lett*.

Burillo, D., Chester, M., Pincetl, S. and Fournier, E. (2018) 'Electricity infrastructure vulnerabilities due to long-term growth and extreme heat from climate change in Los Angeles County' *Energy Policy* 128: 943–953 https://doi.org/10.1016/j.enpol.2018.12.053 .

Burt, C.M. (2017) *The costs of irrigation inefficiency in Tajikistan.* Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/116581486551262816/The-costs-of-irrigation-inefficiency-in-Tajikistan

CAWEP (2023). *Central Asia Water and Enegy Programme, Annual Report 2022 and 2023.* World Bank, Washington DC.

Challa, S.K., Chakravarty, S. and Joshi, K. (2021) Policy-driven approach to demand management from space cooling and water heating appliances: insights from a primary survey of urban Bengaluru, India. *CURRENT SCIENCE*, VOL. 120, NO. 11, 10 JUNE 2021 (https://www.currentscience.ac.in/Volumes/120/11/1712.pdf)

Cheema, T. B., Ul Haque, N. and Malik, A. (2022) *Power Sector: An Enigma with No Easy Solution*. Pakistan Institute of Development Economics, Islamabad (https://rasta.pide.org.pk/wp-content/uploads/PowerSector.pdf).

Colelli, F.P., Wing, I.S. & Cian, E.D. Air-conditioning adoption and electricity demand highlight climate change mitigation–adaptation tradeoffs. *Sci Rep* 13, 4413 (2023). https://doi.org/10.1038/s41598-023-31469-z

Cook, M., King, C., Davidson, F. and Webber, M. (2015) 'Assessing the impacts of droughts and heat waves at thermoelectric power plants in the United States using integrated regression, thermodynamic, and climate models' *Energy Reports* 1: 193–203.

Dodman, D., B. Hayward, M. Pelling, V. Castan Broto, W. Chow, E. Chu, R. Dawson, L. Khirfan, T. McPhearson, A. Prakash, Y. Zheng, and G. Ziervogel, (2022) Cities, Settlements and Key Infrastructure. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907–1040, doi:10.1017/9781009325844.008.

Dawson, R. J., Thompson, D., Johns, D., Wood, R., Darch, G., Chapman, L., ... and Hall, J. W. (2018) A systems framework for national assessment of climate risks to infrastructure. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2121), 20170298. https://doi.org/10.1098/rsta.2017.0298

Duffy, Patrick, Gabriel R. Zuckerman, Travis Williams, Alicia Key, Luis A. Martínez- Tossas, Owen Roberts, Nina Choquette, Jaemo Yang, Haiku Sky, and Nate Blair (2022) *Wind Energy Costs in Puerto Rico Through 2035*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-83434. https://www.nrel.gov/docs/fy22osti/83434.pdf.

Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023) – with major processing by Our World in Data. "Share of electricity generated by hydropower" [dataset]. Ember, "Yearly Electricity Data"; Ember, "European Electricity Review"; Energy Institute, "Statistical Review of World Energy" [original data]. Retrieved February 19, 2024, from https://ourworldindata.org/grapher/share-electricity-hydro

Ember – European Electricity Review (2022) https://ember-climate.org/insights/research/european-electricity-review-2024/

Ember – Yearly Electricity Data (2023) https://ember-climate.org/

Energy Institute – Statistical Review of World Energy (2023). Processed by Our World In Data. Retrived April 2024.https://ourworldindata.org/grapher/share-electricity-renewables

ESMAP (2019) Going Global: Expanding Offshore Wind to Emerging Markets. Washington, DC: World Bank.

ESMAP (2020) 'Offshore Technical Wind Potential in Pakistan'. Washington, DC: World Bank.
Feron, S., Cordero, R.R., Damiani, A. and Jackson, R.B. (2021) Climate change extremes and

photovoltaic power output. *Nature Sustainability* 4, 270–276. https://doi.org/10.1038/s41893-020-00643-w

Eurasianet (2022) 'Uzbekistan commits to buying power from Tajikistan's Roghun plant'. Eurasianet, 3 June (https://eurasianet.org/uzbekistan-commits-to-buying-power-from-tajikistans-roghun-plant).

Feron, S., Cordero, R.R., Damiani, A. and Jackson, R.B. (2021) Climate change extremes and photovoltaic power output. *Nature Sustainability* 4, 270–276. https://doi.org/10.1038/s41893-020-00643-w

Gallagher Re (2023) *Gallagher Re Natural Catastrophe Report of 2022. Expert analysis and insurance implications*. (www.ajg.com/gallagherre/-/media/files/gallagher/gallagherre/gallagher-re-nat-cat-review-2022.pdf).

Gardham, R. (2023) 'Copenhagen Infrastructure Partners invests USD1.3bn in Bangladesh's first offshore wind farm'. Investment Monitor, 25 July (www.investmentmonitor.ai/news/danish-companies-to-open-first-bangladesh-offshore-wind-farm/).

Gutiérrez, J., Jones, R., Narisma, G., Alves, L., Amjad, M., Gorodetskaya, I., Grose, M., Klutse, N., Krakovska, S., Li, J., Martínez-Castro, D., Mearns, L., Mernild, S., Ngo-Duc, T., van den Hurk, B. and Yoon, J.-H. (2021) Atlas. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/.

Hallegatte, S., Rentschler, J. and Rozenberg, J. (2019) *Lifelines: The Resilient Infrastructure Opportunity*. Sustainable Infrastructure Series. Washington DC: World Bank. https://openknowledge.worldbank.org/handle/10986/31805

IEA (2018) *The Future of Cooling.* IEA, Paris https://www.iea.org/reports/the-future-of-cooling,

IEA (2020) *Power Systems in Transition*, IEA, Paris (www.iea.org/reports/power-systems-in-transition).

IEA (2021a) *India Energy Outlook 2021*. IEA, Paris (www.iea.org/reports/india-energy-outlook-2021).

IEA (2021b) *Managing the water-energy nexus is vital to India's future*. IEA, Paris (www.iea.org/commentaries/managing-the-water-energy-nexus-is-vital-to-india-s-future).

IEA (2022) *Strengthening Power System Security in Kyrgyzstan: A Roadmap*, IEA, Paris https://www.iea.org/reports/strengthening-power-system-security-in-kyrgyzstan-a-roadmap.

IEA (2023) *A Vision for Clean Cooking Access for All*, IEA, Paris https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all, Licence: CC BY 4.0

IHA (2019) *Hydropower Sector Climate Resilience Guide*. London: International Association of Hydropower.

IRE, IRENA, UNSD, World Bank, WHO (2023) Renewable energy consumption (% of total final energy consumption, Tracking SDG 7: The Energy Process Report, World Bank, Washington DC, accessed January 2024, https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS?

IRENA (2018) *Renewables Readiness Assessment: Pakistan*. International Renewable Energy Agency (IRENA), Abu Dhabi.

IRENA and WRI (2018) *Water Use in India's Power Generation: Impact of renewables and improved cooling technologies to 2030*. (www.irena.org/publications/2018/Jan/Water-Use-in-India-Power-Impact-of-renewables-to-2030).

IEA, IRENA, UNSD, World Bank and WHO (2022) *Tracking SDG 7: The Energy Progress Report*. World Bank, Washington DC. https://www.worldbank.org/en/topic/energy/publication/tracking-sdg-7-the-energy-progress-report-2022

Jaiswal, S. and Gadre, R. (2022) *Financing India's 2030 Renewables Ambition*. White paper. BloombergNEF. (https://assets.bbhub.io/professional/sites/24/BloombergNEF-Financing-India's-2030-Renewables-Ambition-2022.pdf).

Jha, A. and Jain, M. (2022) *South Asia needs equitable cooling as heat waves worsen*. World Bank blog, 27 October 2022. https://blogs.worldbank.org/en/endpovertyinsouthasia/south-asia-needs-equitable-cooling-heatwaves-worsen

Joshi, M., Polchak, D., De Silva, T., and Stephen, G. (2022) *Reliability and Resiliency in South Asia's Power Sector: Pathways for Research, Modeling, and Implementation*. National Renewable Energy Laboratory (https://www.nrel.gov/docs/fy22osti/81826.pdf).

Karagiannis, G.M., Cardarilli, M., Turksezer, Z.I., Spinoni, J., Mentaschi, L., Feyen, L. and Krausmann, E. (2019) *Climate change and critical infrastructure – storms*. JRC Technical Reports, European Commission. https://joint-research-centre.ec.europa.eu/index_en

Li, D., Lu, X., Walling, D.E. *et al.* (2022) High Mountain Asia hydropower systems threatened by climate-driven landscape instability. *Nat. Geosci.* 15, 520–530. https://doi.org/10.1038/s41561-022-00953-y.

Losz, A. and Mitrova, T. (2023) *Central Asia's Overlooked Energy Crisis: What It Means for the Global Gas Market*. Blogpost March 28, 2023. Centre on Global Energy Policy, Colombia/SIPA. https://www.energypolicy.columbia.edu/central-asias-overlooked-energy-crisis-what-it-means-for-the-global-gas-market/

Luo, T., Krishnan,D. and Sen, S. (2018a) *Parched Power: Water Demands, Risks, and Opportunities for India's Power Sector*. Working Paper. Washington, DC: World Resources Institute. (www.wri.org/publication/parched-power).

Luo, T., Krishnaswami, A. and Li, X. (2018b) *A Methodology to Estimate Water Demand for Thermal Power Plants in Data-Scare Regions Using Satellite Images*. Technical Note. Washington, DC: World Resources Institute. Available online at: www.wri.org/publication/water-power-methodology.

Mima, S. and P. Criqui (2015) The costs of climate change for the European energy system, an assessment with the POLES model. *Environ. Model. Assess*., 20(4), 303–319.

Ministry of New and Renewable Energy (2024) 'Solar Overview'. Webpage. Ministry of New and Renewable Energy, Government of India.

Opitz-Stapleton, S., Cao, Y., Khan, F., Tanjangco, B. and Nadin, R. (2021) *BRI energy infrastructure in Pakistan: environmental and climate risks and opportunities*. ODI Research Report. ODI: London. https://odi.org/en/publications/bri-energy-infrastructure-in-pakistan-environmental-and-climate-risks-and-opportunities/

Opitz-Stapleton, S., Borodyna, O., Nijhar, I., Panwar, V. and Nadin, R. (2022) *Managing climate risks to protect net-zero energy goals: Net-zero transition opportunities in Kyrgyzstan, Tajikistan and Uzbekistan*. Report. London: ODI (www.odi.org/publications/managing-climate-risks-to-protect-net-zero-energy-goals-net-zero-transition-opportunities-in-kyrgyzstan-tajikistan-and-uzbekistan

Our World In Data – Fossil Fuels, Accessed January 2024, https://ourworldindata.org/fossil-fuels

Our World In Data – Share of electricity production from hydropower, 2022, Accessed January 2024, https://ourworldindata.org/grapher/share-electricity-hydro?time=latest

Panat, S. and Varanasi, K.K. (2022) Electrostatic dust removal using adsorbed moisture–assisted charge induction for sustainable operation of solar panels. *Sci. Adv*.8,eabm0078(2022).DOI:10.1126/sciadv.abm0078

Panwar, V., Nijhar, I., Borodyna, O., Opitz-Stapleton, S. and Nadin, R. (2022) *Opportunities and co-benefits of transitioning to a net-zero economy in Kyrgyzstan, Tajikistan and Uzbekistan.* ODI Report. London: ODI www.odi.org/publications/opportunities-and-co-benefits-of-transitioning-to-a-net-zero-economy-in-kyrgyzstan-tajikistan-and-uzbekistan

Paul, R. (2022) 'Cyclone lashed Bangladesh, killing 15, causing power cuts'. Reuters, 16 October (www.reuters.com/world/asia-pacific/cyclone-lashes-bangladesh-killing-nine-flooding-low-lying-areas-2022-10-25/).

Ranger (2013). *Topic Guide: Adaptation – Decision-making Under Uncertainty*. Evidence on Demand, DFID, June 2013. https://www.gov.uk/research-for-development-outputs/topic-guide-adaptation-decision-making-under-uncertainty

Rentschler, J., Kornejew, M., Hallegatte, S. et al (2019) *Underutilized Potential: The Business Costs of Unreliable Infrastructure in Developing Countries.* Policy Research Working Paper 8899. World Bank Group, June 2019. DOI: 10.1596/1813-9450-8899

Reuters (2023) 'Kazakhstan signs deals for 3GW of wind power'. 2 December, Reuters (www.reuters.com/business/energy/kazakhstan-signs-deals-3gw-wind-power-2023-12-02/).

Rodriguez, Diego J.; Delgado, Anna; DeLaquil, Pat; Sohns, Antonia (2013) *Thirsty Energy*. Water Papers; World Bank, Washington, DC. http://hdl.handle.net/10986/16536

Sachar, S., Campbell, I. and Kalanki, A. (2018) *Solving the Global Cooling Challenge: How to Counter the Climate Threat from Room Air Conditioners*. Rocky Mountain Institute.

Samruk Kazyna (2017) *Renewable Energy: Future Trends*. Report. Samruk Kazyna, Kazakhstan (https://sk.kz/upload/iblock/cf5/cf59dbdb5202ea14161a0ed0ea4b2b90.pdf).

Scott, C.A., Zhang, F., Mukherji, A., Immerzeel, W., Mustafa, D., Bharati, L. (2019) Water in the Hindu Kush Himalaya. In: Wester, P., Mishra, A., Mukherji, A., Shrestha, A. (eds) *The Hindu Kush Himalaya Assessment.* Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_8.

Shahid, S. (2012) "Vulnerability of the Power Sector of Bangladesh to Climate Change and Extreme Weather Events." *Regional Environmental Change* 12 (3): 595–606. https://doi.org/10.1007/s10113-011-0276-z.

Shaw, R., Y. Luo, T.S. Cheong, S. Abdul Halim, S. Chaturvedi, M. Hashizume, G.E. Insarov, Y. Ishikawa, M. Jafari, A. Kitoh, J. Pulhin, C. Singh, K. Vasant, and Z. Zhang (2022) Asia. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457–1579, doi:10.1017/9781009325844.012.

Shrestha, P.M. (2022) 'Nepal makes over Rs11 billion selling power to India'. Kathmandu post, 21 December (https://kathmandupost.com/national/2022/12/21/nepal-makes-over-rs11-billion-selling-power-to-india).

Turgali, D., Kopeyeva, A., Dikhanbayeva, D. and Rojas-Solórzano, L. (2021) 'Potential impact of global warming on wind power production in Central Asia', *Environmental Progress & Sustainable Energy*, 40(4), p. e13626. Available at: https://doi.org/10.1002/ep.13626.

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

Usov, A. (2022) 'EBRD supports 1GW of renewable energy generation in Uzbekistan'. EBRD, 13 December (www.ebrd.com/news/2022/ebrd-promotes-wind-power-generation-in-uzbekistan.html).

Usov, A. (2023) 'Central Asia remains resilient to geopolitical headwinds'. EBRD, 16 May.

Wang, Y., Byers, E., Parkinson, S., Wanders, N., Wada, Y., Mao, J., & Bielicki, J. M. (2019) Vulnerability of existing and planned coal-fired power plants in developing Asia to changes in climate and water resources. *Energy & Environmental Science*, 12(10), 3164–3181. https://doi.org/10.1039/C9EE02058F.

Wijayatunga, P. and Fernando P.N. (2013) *An Overview of Energy Cooperation in South Asia*. ADB: Manila.

Martin Wild, Doris Folini, Florian Henschel, Natalie Fischer and Björn Müller (2015) Projections of long-term changes in solar radiation based on CMIP5 climate models and their influence on energy yields of photovoltaic systems. *Solar Energy*, Volume 116, 2015, Pages 12-24, ISSN 0038-092X. https://doi.org/10.1016/j.solener.2015.03.039.

Woetzel, J., Pinner, D., Samandara, H., Gupta, R., Engel, H., Krishnan, M. and Powis, C (2020) *Will India get too hot to work?* Case study, November 2020. McKinsey Global Institute.

https://www.mckinsey.com/capabilities/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts

World Bank (2021) *Variable Renewable Energy Locational Study.* Pakistan Sustainable Energy Series. Washington, DC: World Bank.

World Bank Group (2022a) *Bangladesh Country Climate and Development Report. CCDR Series*.. World Bank Group, Washington, DC (http://hdl.handle.net/10986/38181).

World Bank Group (2022b) *Enterprise Surveys What Businesses Experience, India 2022 Country Profile*. World Bank Group, Washington, DC.

World Bank Group (2023) 'West Bengal Electricity Distribution Grid Modernization Project'. Project webpage. World Bank Group, Washington, DC.

Zhang, F. (2019) *In the Dark: How Much Do Power Sector Distortions Cost South Asia?* South Asia Development Forum. Washington, DC: World Bank. doi:10.1596/978-1-4648-1154-8.

Section 3.6 – Environment

Akramkhanov, S. Strohmeier, Y.A., Yigezu et al. (2021) *The Value of Landscape Restoration in Uzbekistan to Reduce Sand and Dust Storms from the Aral Seabed.* World Bank.

CEPF (2017) *Ecosystem Profile .Mountains of Central Asia Biodiversity Hotspot.* Critical Ecosystem Partnership Fund (www.cepf.net/sites/default/files/mountains-central-asia-ecosystem-profile-english.pdf).

Chhetri, P., Keith D. Gaddis, David M. (2018) Cairns "Predicting the Suitable Habitat of Treeline Species in the Nepalese Himalaya Under Climate Change," Mountain Research and Development, 38(2), 153-163..(2018) Cairns "Predicting the Suitable Habitat of Treeline Species in the Nepalese Himalaya Under Climate Change," Mountain Research and Development, 38(2), 153-163.

Convention on Wetlands. (2021) *Global Wetland Outlook: Special Edition 2021*. Gland, Switzerland: Secretariat of the Convention on Wetlands. (www.ramsar.org/sites/default/files/documents/library/gwo_2021_e.pdf).

Costella, C., McCord, A., van Aalst, M., Holmes, R., Ammoun, J., Barca, V. (2021) *Social protection and climate change: scaling up ambition*, Social Protection Approaches to COVID-19 Expert Advice Service (SPACE), DAI Global UK Ltd, United Kingdom

Davies, M., Béné, C., Arnall, A., Tanner, T., Newsham, A.J. and Coirolo, C. (2013) Promoting Resilient Livelihoods Through Adaptive Social Protection: Lessons from 124 Programmes in South Asia. *Development Policy Review.* 31. 10.1111/j.1467-7679.2013.00600.x.

FAO (2012) *South Asian Forests and Forestry to 2020. Subregional Report of the Second Asia-Pacific Forestry Sector Outlook Study.* FAO (www.fao.org/3/i2785e/i2785e00.pdf).

FAO and UNEP (2020) *The State of the World's Forests 2020. Forests, biodiversity and people.* Rome. https://doi.org/10.4060/ca8642en

Farhadinia M.S., Waldron A, Kaszta Ż. et al (2022) Current trends suggest most Asian countries are unlikely to meet future biodiversity targets on protected areas. Commun Biol. 2022 Nov 29;5(1):1221. doi: 10.1038/s42003-022-04061-w. PMID: 36443482; PMCID: PMC9705440.

Fernandes, R., Panwar, V. and Sen, M. (2022) *Nature-based Solutions for urban climate resilience in South Asia: Cases from Bangladesh, India and Nepal*. Climate Knowledge and Development Network (https://cdkn.org/sites/default/files/2022-11/NbS%20Compendium_Nov%202022_final_web.pdf).

Fluet-Chouinard, E., Stocker, B.D., Zhang, Z. *et al.* (2023) Extensive global wetland loss over the past three centuries. *Nature* 614, 281–286 https://doi.org/10.1038/s41586-022-05572-6

Forrest, J.L., Wikramanayake, E., Shrestha, R. et al. (2012) Conservation and climate change: Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya, Biological Conservation, Volume 150, Issue 1, 2012, Pages 129-135

Global Forest Review (2022) *Forest Gain and Loss Indicators*. Global Forest Review, updated October 27, 2022. Washington, DC: World Resources Institute. Available online at https://research.wri.org/gfr/forest-extent-indicators/forest-gain.

Government of India (2022) World Wetlands Day. The Government of India, 8 February (https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/aug/doc20228269640 1.pdf).

Hoffmann, S., Irl, S.D.H. and Beierkuhnlein, C. (2019) Predicted climate shifts within terrestrial protected areas worldwide. *Nat Commun* **10**, 4787. https://doi.org/10.1038/s41467-019-12603-w

Hughes, A.C. (2017) Understanding the drivers of Southeast Asia biodiversity loss. *Ecosphere*, Vol 8(1), January 2017. https://doi.org/10.1002/ecs2.1624

Hu, Q., & Han, Z. (2022) Northward expansion of desert climate in Central Asia in recent decades. Geophysical Research Letters, 49, e2022GL098895. https://doi.org/10.1029/2022GL098895

IPBES (2018) Summary for Policymakers of the Assessment Report on Biodiversity and Ecosystem Services for Asia and the Pacific (summary for policy makers). Zenodo. https://doi.org/10.5281/zenodo.3237383

IUCN (2021) Key messages and recommendations from the Meghna Knowledge Forum 2021. **(**https://www.iucn.org/sites/default/files/2022-07/meghna_knowledge_forum_2021_final_dec_2021_1_0.pdf).

IUCN (n.d.) *India (Country overview)*. Webpage. (www.iucn.org/our-work/region/asia/countries/india).

Jiang, L., Jiapaer, G. Bao, A. et al (2019) “Monitoring the long-term desertification process and assessing the relative roles of its drivers in Central Asia”. Ecological Indicators, Vol (104), 195-208, https://doi.org/10.1016/j.ecolind.2019.04.067.

Kazmi, F.A., Shafique, F., Hassan, M. et al (2022) Ecological impacts of climate change on the snow leopard (Panthera unica) in South Asia. Brazilian Journal of Biology, 82. e240219. ISSN 1519-6984 (https://doi.org/10.1590/1519-6984.240219)

Kerven, C., Steimann, B., Dear, C. and Ashley, L. (2012) Researching the Future of Pastoralism in Central Asia's Mountains: Examining Development Orthodoxies. *Mountain Research and Development*, Vol. 32(3). doi.org/10.1659/MRD-JOURNAL-D-12-00035.1

Kottawa-Arachchi, Jeevan & Wijeratne, Madawala. (2017) Climate change impacts on biodiversity and ecosystems in Sri Lanka: A REVIEW. *Nature Conservation Research*. 2. 2-22. 10.24189/ncr.2017.042.

Kubiszewski, I., Anderson, S.J., Costanza, R. and Sutton, P.C. (2016) "The Future of Ecosystem Services in Asia and the Pacific," Asia and the Pacific Policy Studies, Wiley Blackwell, vol. 3(3), pages 389-404, September.

Maharjan, S. K., Sterck, F. J., Raes, N., Zhao, Y., & Poorter, L. (2023) Climate change induced elevational range shifts of Himalayan tree species. Biotropica, 55, 53–69. https://doi.org/10.1111/btp.13159

Narbayep, M. and Pavolva, V.(2022) The Aral Sea, Central Asian Countries and Climate Change in the 21st Century. UNESCAP, Bangkok (www.unescap.org/sites/default/d8files/event-documents/ESCAP-2022-WP-Aral-Sea-central-Asian-countries-climate-change.pdf).

Neugarten, R.A., Langhammer, P.F., Osipova, E., et al. (2018) Tools for measuring, modelling, and valuing ecosystem services: Guidance for Key Biodiversity Areas, natural World Heritage Sites, and protected areas. Gland, Switzerland: IUCN.

Nishonov, B.E., Kholmatjanov, B.M., Labzovskii, L.D. et al. (2023) Study of the strongest dust storm occurred in Uzbekistan in November 2021. *Sci Rep* 13, 20042 (2023). https://doi.org/10.1038/s41598-023-42256-1

Norton A, Seddon N, Agrawal A, Shakya C, Kaur N, Porras I. (2020) Harnessing employment based social assistance programmes to scale up nature-based climate action. *Phil. Trans. R. Soc*. B 375:20190127. http://dx.doi.org/10.1098/rstb.2019.0127

Parmesan, C., M.D. Morecroft, Y. Trisurat, R. Adrian, G.Z. Anshari, A. Arneth, Q. Gao, P. Gonzalez, R. Harris, J. Price, N. Stevens, and G.H. Talukdarr, 2022: Terrestrial and Freshwater Ecosystems and Their Services. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 197–377, doi:10.1017/9781009325844.004.

Quillérou, E., Thomas, R.J., Guchgeldiyev, O. , Ettling, S., Etter, H., & Stewart, N. (2016) Economics of Land Degradation (ELD) Initiative: Broadening options for improved economic sustainability in Central Asia. Synthesis report. Report for the ELD Initiative from the Dryland Systems Program of CGIAR c/o ICARDA, Amman, Jordan.

Rahman, M. (2017) Modelling climate change impacts on the water regimes of the river-wetland systems in the data-scarce transboundary Upper Meghna River Basin (Bangladesh and India). Doctoral thesis , UCL (University College London).

Rahman, M.M., Zimmer, M., Ahmed, I. et al. (2021) Co-benefits of protecting mangroves for biodiversity conservation and carbon storage. *Nat Commun* 12, 3875 (2021). https://doi.org/10.1038/s41467-021-24207-4

Ramakrishnan, P.S., Rao, K.S., Chandrashekara, U.M., Chhetri, N. Gupta, H.K., Patnaik, S., Saxena, K.G. and Sharma, E. (2012) South Asia. In: J.A. Parrotta and R.L. Trosper (eds.), *Traditional Forest-Related Knowledge: Sustaining Communities, Ecosystems and Biocultural Diversity, World Forests* 12, DOI 10.1007/978-94-007-2144-9_9,

Rana A.K. and Kumar N. (2023) Current wildlife crime (Indian scenario): major challenges and prevention approaches. Biodivers Conserv. 32(5):1473-1491. doi: 10.1007/s10531-023-02577-z. Epub 2023 Mar 20. PMID: 37063172; PMCID: PMC10025790.

Roy, B., Nag, S., Halder, S. *et al.* (2022) Assessment of wetland potential and bibliometric review: a critical analysis of the Ramsar sites of India. *Bull Natl Res Cent* 46, 59 https://doi.org/10.1186/s42269-022-00740-0.

RSIS (2012) Ramsar Sites Information Service, Ili River Delta and South Lake Balkhash, accessed January 2024, available https://rsis.ramsar.org/ris/2020#:~:text=The%20wetland%20is%20situated%20in,inland%20lake%20in%20Central%20Asia.

Salas, EAL, Valdez, R, Michel, S, Boykin, KG (2018) Habitat assessment of Marco Polo sheep (Ovis ammon polii) in Eastern Tajikistan: Modeling the effects of climate change. Ecol Evol. 2018; 8: 5124–5138. https://doi.org/10.1002/ece3.4103

Setlur, B., Agostini, P. and Jongman, B. (2023) 'Embracing Nature's Resilience: Combating Desertification in Central Asia with Nature-Based Solutions'. World Bank Blogs, 16 June (https://blogs.worldbank.org/europeandcentralasia/embracing-natures-resilience-combating-desertification-central-asia-nature#:~:text=Drylands%20in%20Central%20Asia%20are,over%205%25%20of%20regional%20GDP).

Shrivastava, R. (2022) The making of pastoralisms: An account of the Gaddis and Van Gujjars in the Indian Himalaya. *Pastoralism*, 12 (1). https://doi.org/10.1186/s13570-022-00259-z

Singh, P.B., Mainali, K., Jiang, Z. et al. (2020) Projected distribution and climate refugia of endangered Kashmir musk deer Moschus cupreus in greater Himalaya, South Asia. Sci Rep 10, 1511. https://doi.org/10.1038/s41598-020-58111-6

Singh, R., Kerven, C. (2023) Pastoralism in South Asia: Contemporary stresses and adaptations of Himalayan pastoralists. *Pastoralism* 13, 21 (2023). https://doi.org/10.1186/s13570-023-00283-7

Sharma, S. K., Sharma, A., Saxena, M., Choudhary, N., Masiwal, R., Mandal, T. K. and Sharma, C. (2016) Chemical characterization and source apportionment of aerosol at an urban area of Central Delhi, India, *Atmospheric Pollution Research*, 7(1), 110-121, https://doi.org/10.1016/j.apr.2015.08.002

Shaw, R., Y. Luo, T.S. Cheong, S. Abdul Halim, S. Chaturvedi, M. Hashizume, G.E. Insarov, Y. Ishikawa, M. Jafari, A. Kitoh, J. Pulhin, C. Singh, K. Vasant, and Z. Zhang (2022): Asia. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457–1579, doi:10.1017/9781009325844.012.

Telwala Y, Brook B.W., Manish, K., Pandit M.K. (2013) Climate-Induced Elevational Range Shifts and Increase in Plant Species Richness in a Himalayan Biodiversity Epicentre. PLoS ONE 8(2): e57103. doi:10.1371/journal.pone.0057103

Tesch, N., & Thevs, N. (2020) Wetland Distribution Trends in Central Asia. *Central Asian Journal of Water Research*, 6(1), 39–54. https://doi.org/10.29258/cajwr/2020-r1.v6-1/39-65.eng

UNEP (n.d.) Supporting Central Asian species' resilience to climate change. (www.unep.org/regions/europe/our-projects/supporting-central-asian-species-resilience-climate-change).

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

World Bank (2020) Project Information Document (PID). *Tajikistan Resilient Landscape Restoration Project* (P171524). 26 October 2020.

World Bank (2023a) *Building Back a Greener Bangladesh: Country Environmental Analysis*. Washington DC, The World Bank Group. https://www.worldbank.org/en/region/sar/publication/bangladesh-country-environment-analysis-2023

World Bank (2023b) RESILAND CA+ Program: Kyrgyz Republic Resilient Landscape Restoration Project (https://projects.worldbank.org/en/projects-operations/project-detail/P177407).

World Bank (2023c) *RESILAND CA+ Program: Uzbekistan Resilient Landscapes Restoration Project* (https://projects.worldbank.org/en/projects-operations/project-detail/P174135).

Xu, J. *et al.* (2019) Sustaining Biodiversity and Ecosystem Services in the Hindu Kush Himalaya. In: Wester, P., Mishra, A., Mukherji, A., Shrestha, A. (eds) The Hindu Kush Himalaya Assessment. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1_5

Yin, H., Khamzina, A., Pflugmacher, D. et al. (2017) Forest cover mapping in post-Soviet Central Asia using multi-resolution remote sensing imagery. *Sci Rep* 7, 1375 (2017). https://doi.org/10.1038/s41598-017-01582-x

Zou, J., Ziegler, A.D., Chen, D. *et al. (2022)* Rewetting global wetlands effectively reduces major greenhouse gas emissions. *Nat. Geosci.* 15, 627–632 https://doi.org/10.1038/s41561-022-00989-0

Section 3.7 – Blue economy and the marine environment

Adshead, D., Paszkowski, A., Gall, S.S. et al. (2014) Climate threats to coastal infrastructure and sustainable development outcomes. *Nat. Clim. Chang*. (2024). https://doi.org/10.1038/s41558-024-01950-2

Alam, E. and Dominey-Howes, D. (2014) A new catalogue of tropical cyclones of the northern Bay of Bengal and the distribution and effects of selected landfalling events in Bangladesh. International Journal of Climatology, 35(6), pp.801–835. doi: https://doi.org/10.1002/joc.4035

Alieva, D. *et al.* (2023) 'Fishery culture, sustainable resources usage and transformations needed for local community development: the case of Aral Sea', *Frontiers in Marine Science*, 10, p. 1285618. Available at: https://doi.org/10.3389/fmars.2023.1285618.

Amores, A., Marcos, M., Pedreros, R., Le Cozannet, G., Lecacheux, S., Rohmer, J., Hinkel, J., Gussmann, G., van der Pol, T., Shareef, A. and Khaleel, Z. (2021) Coastal Flooding in the Maldives Induced by Mean Sea-Level Rise and Wind-Waves: From Global to Local Coastal Modelling. Frontiers in Marine Science, 8. doi: https://doi.org/10.3389/fmars.2021.665672

Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., Jennings, S. (2014) Impacts of climate change on marine ecosystem production in societies dependent on fisheries. Nature Climate Change, 4(3). URL: https://www.nature.com/articles/nclimate2119.pdf

Barbour, E.J., Adnan, M.S.G., Borgomeo, E. et al. (2022) The unequal distribution of water risks and adaptation benefits in coastal Bangladesh. *Nat Sustain* 5, 294–302 (2022). https://doi.org/10.1038/s41893-021-00846-9

Becker, M., Papa, F., Karpytchev, M. and Chum, C. (2020) Water level changes, subsidence, and sea level rise in the Ganges-Brahmaputra-Meghna delta, *Earth, Atmospheric, and Planetary Sciences*, 117(4): 1867-1876, https://doi.org/10.1073/pnas.1912921117

Burke, L. and Spalding, M. (2022) Shoreline protection by the world's coral reefs: Mapping the benefits to people, assets, and infrastructure. Marine Policy, 146, p.105311. doi:https://doi.org/10.1016/j.marpol.2022.105311.

Cai, W., Yang, K., Wu, L. *et al.* (2021) Opposite response of strong and moderate positive Indian Ocean Dipole to global warming. *Nat. Clim. Chang.* **11**, 27–32. https://doi.org/10.1038/s41558-020-00943-1

Cai, Wenju & Santoso, Agus & Wang, Guojian & Weller, Evan & Wu, Lixin & Ashok, Karumuri & Masumoto, Yukio & Yamagata, Toshio. (2014) Increased frequency of extreme Indian Ocean Dipole events due to greenhouse warming. Nature. 510. 254-8. 10.1038/nature13327.

Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li and N. Huu Ninh (2007) Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 469-506.

Dasgupta, S., Md. Saiful Islam, Mainul Huq, Zahirul Huque Khan, and Md. Raqubul Hasib (2019) Quantifying the Protective Capacity of Mangroves from Storm Surges in Coastal Bangladesh. *PLoS ONE* 14(3): 1–14. doi: 10.1371/journal.pone.0214079.

Donato, D. C., J. B. Kauffman, D. Murdiyarso, S. Kurnianto, M. Stidham, and M. Kanninen. (2011) Mangroves among the Most Carbon-Rich Forests in the Tropics. *Nature Geoscience* 4: 293-297.

Doney, C., S., Busch, S., R. Cooley, S. and J. Kroeker, K. (2020) *The Impacts of Ocean Acidification on Marine Ecosystems and Reliant Human Communities*.

Esbaugh, A.J. (2017) Physiological implications of ocean acidification for marine fish: emerging patterns and new insights. Journal of Comparative Physiology B, 188(1), pp.1–13. doi: https://doi.org/10.1007/s00360-017-1105-6

FAO (2007) Building adaptive capacity to climate change. Policies to sustain livelihoods and fisheries. New Directions in Fisheries – A Series of Policy Briefs on Development Issues. No. 08. Rome. 16 pp

FAO (2011) APFIC/FAO Regional consultative workshop “Implications of climate change on fisheries and aquaculture: challenges for adaptation and mitigation in the Asia-Pacific Region” 24–26 May 2011, Kathmandu, Nepal. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2011/17, 52 pp.

FAO (2018) Impacts of climate change on fisheries and aquaculture, Food and Agriculture Organization of the United Nations, technical paper, 627, https://www.fao.org/3/i9705en/i9705en.pdf

FAO (2021a) Fishery and aquaculture statistics 2019, Food and Agriculture Organization of the United Nations, yearbook, https://www.fao.org/3/cb7874t/cb7874t.pdf

FAO (2022) *The status of fishery resources*. [online] www.fao.org. Available at: https://www.fao.org/3/cc0461en/online/sofia/2022/status-of-fishery-resources.html.

FAO (2023) Fisheries and Aquaculture, FishStatJ – Software for Fishery and Aquaculture Statistical Time Series, Accessed January 2024, https://www.fao.org/fishery/en/statistics/software/fishstatj

Fernandes, J. (2018) Chapter 13: Climate change impacts, vulnerabilities and adaptations: Southern Asian fisheries in the Arabian Sea, Bay of Bengal and East Indian Ocean, In FAO Impacts of climate change on fisheries and aquaculture, https://www.fao.org/3/i9705en/i9705en.pdf

FitzGerald, D.M. and Hughes, Z. (2019) Marsh Processes and Their Response to Climate Change and Sea-Level Rise. *Annual Review of Earth and Planetary Sciences* 2019, 481-517. https://doi.org/10.1146/annurev-earth-082517-010255

Fluet-Chouinard, E., Stocker, B.D., Zhang, Z. *et al.* (2023) Extensive global wetland loss over the past three centuries. *Nature* **614**, 281–286 https://doi.org/10.1038/s41586-022-05572-6

Fordyce, J., A., D. Ainsworth, T., F. Herron, S. and Leggat, W. (2019) Marine Heatwave Hotspots in Coral Reef Environments: Physical Drivers, Ecophysiological Outcomes, and Impact Upon Structural Complexity. [online] Available at: https://www.frontiersin.org/articles/10.3389/fmars.2019.00498/full.

Ganguly, D., Singh, G., Purvaja, R., Bhatta, R., Paneer Selvam, A., Banerjee, K. and Ramesh, R. (2018) Valuing the carbon sequestration regulation service by seagrass ecosystems of Palk Bay and Chilika, India. *Ocean & Coastal Management*, 159, pp.26–33. doi:https://doi.org/10.1016/j.ocecoaman.2017.11.009.

Giri, C., Long, J., Abbas, S., Murali, R.M., Qamer, F.M., Pengra, B. and Thau, D. (2015) Distribution and dynamics of mangrove forests of South Asia. *Journal of environmental management*, [online] 148, pp.101–11. doi: https://doi.org/10.1016/j.jenvman.2014.01.020.

Good, S.A.; Embury, O.; Bulgin, C.E.; Mittaz, J. (2019) ESA Sea Surface Temperature Climate Change Initiative (SST_cci): Level 4 Analysis Climate Data Record, version 2.1.

Groll, M., Kulmatov, R., Mullabaev, N. *et al.* (2016) Rise and decline of the fishery industry in the Aydarkul–Arnasay Lake System (Uzbekistan): effects of reservoir management, irrigation farming and climate change on an unstable ecosystem. *Environ Earth Sci* 75, 921

Gutiérrez, J., Jones, R., Narisma, G., Alves, L., Amjad, M., Gorodetskaya, I., Grose, M., Klutse, N., Krakovska, S., Li, J., Martínez-Castro, D., Mearns, L., Mernild, S., Ngo-Duc, T., van den Hurk, B. and Yoon, J.-H. (2021) Atlas. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/.

Hansson, L. and Gattuso, J.-P. (2011) *Ocean Acidification*. Oxford University Press.

Haque, U., Hashizume, M., Kolivras, K.N., Overgaard, H.J., Das, B. and Yamamoto, T. (2012) Reduced death rates from cyclones in Bangladesh: what more needs to be done? Bulletin of the World Health Organization, 90(2), pp.150–156. doi: https://doi.org/10.2471/blt.11.088302.

Hosterman, H. and Smith, J. (2015) *Economic costs and benefits of climate change impacts and adaptation to the Maldives Tourism Industry: Increasing Climate Change Resilience of Maldives through Adaptation in the Tourism Sector*. Male', Maldives: Ministry of Tourism, Male', Republic of Maldives.

IPCC (2021) Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

Kais SM, Islam MS. (2019) Perception of Climate Change in Shrimp-Farming Communities in Bangladesh: A Critical Assessment. Int J Environ Res Public Health. Feb 25;16(4):672. doi: 10.3390/ijerph16040672. PMID: 30823558; PMCID: PMC6406781.

Kais, M., S. and Islam, M. (2018) Impacts of and resilience to climate change at the bottom of the shrimp commodity chain in Bangladesh: A preliminary investigation. [online] Available at: https://www.sciencedirect.com/science/article/abs/pii/S0044848617309766.

Kay, S. *et al.* (2023) 'Projected effects of climate change on marine ecosystems in Southeast Asian seas', *Frontiers in Marine Science*, 10, p. 1082170. Available at: https://doi.org/10.3389/fmars.2023.1082170.

Kazi, Swarna, Ignacio Urrutia, Mathijs van Ledden, Jean Henry Laboyrie, Jasper Verschuur, Zahir-ul Haque Khan, Ruben Jongejan, Kasper Lendering, and Alejandra Gijón Mancheño. (2022) *Bangladesh: Enhancing Coastal Resilience in a Changing Climate*. Washington, DC: The World Bank.

Koldewey, H., Atchison-Balmond, N., Graham, N., Jones, R., Perry, C., Sheppard, C., Spalding, M., Turner, J., and Williams, G. (2021) Key climate change effects on the coastal and marine environment around the Indian Ocean UK Overseas Territories. MCCIP Science Review 2021, 31pp.

Koriche, S.A.; Singarayer, J.S. and Cloke, H.L. (2021) The fate of the Caspian Sea under projected climate change and water extraction during the 21st century. *Environ. Res. Lett*. 16 094024. http://dx.doi.org/10.1088/1748-9326/ac1af5

Kumar, S., Chakraborty, A., Chandrakar, R., Kumar, A., Sadhukhan, B. and Chowdhury, R. (2023) Analysis of marine heatwaves over the Bay of Bengal during 1982-2021, *Scientific Reports*, 13: 14235, https://doi.org/10.1038/s41598-023-39884-y

Lam, W., , V., Chavanich , S., Djoundourian, S. and Dupont, S. (2019) Dealing with the effects of ocean acidification on coral reefs in the Indian Ocean and Asia. [online] Available at: https://www.sciencedirect.com/science/article/pii/S2352485518306017.

Leal, M. and Spalding, M. D. (editors) (2022) The State of the World's Mangroves 2022. Global Mangrove Alliance

Ma, X. *et al.* (2024) 'Evaporation from the hypersaline Aral Sea in Central Asia', *Science of The Total Environment*, 908, p. 168412. Available at: https://doi.org/10.1016/j.scitotenv.2023.168412.

Macintosh, D. J. and Ashton, E. C. (2002) A Review of Mangrove Biodiversity Conservation and Management. Centre for Tropical Ecosystems Research, University of Aarhus, Denmark.

Maldives Tourism Ministry (2021) M. of T. Tourism Yearbook 2021. [online] Ministry of Tourism, Maldives. Available at: https://www.tourism.gov.mv/dms/document/2f11c02edec48b0fa37014122e7c39e6.pdf.

Maulu, S. *et al.* (2021) 'Climate Change Effects on Aquaculture Production: Sustainability Implications, Mitigation, and Adaptations', *Frontiers in Sustainable Food Systems*, 5, p. 609097. Available at: https://doi.org/10.3389/fsufs.2021.609097.

Ministry of Environment (2020) Update of Nationally Determined Contribution of Maldives, https://unfccc.int/sites/default/files/NDC/2022-06/Maldives%20Nationally%20Determined%20Contribution%202020.pdf

Mitchell, D., Hawker, L., Savage, J., Bingham, R., Lord, N., Khan, M., Bates, P., Durand, F., Hassan, A., Huq, S., Islam, A., Krien, Y., Neal, J., Sampson, C., Smith, A. and Testut, L. (2022) Increased population exposure to Amphan-scale cyclones under future climates, *Climate Resilience and Sustainability*, 1(2): e36, https://doi.org/10.1002/cli2.36

MoEFCC. (2021) India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India

Mycoo, M., M. Wairiu, D. Campbell, V. Duvat, Y. Golbuu, S. Maharaj, J. Nalau, P. Nunn, J. Pinnegar, and O. Warrick, (2022) Small Islands. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2043–2121, doi:10.1017/9781009325844.017.

Ocean Health Index (2022) *Scores | OHI*. [online] oceanhealthindex.org. Available at: https://oceanhealthindex.org/global-scores/.

Oppenheimer, M., Glavovic, B., Hinkel, J., van de Wal, R., Magnan, A., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B. and Sebesvari, Z. (2019) Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [Pörtner, H-O., Roberts, D., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegria, A., Nicolai, M., Okem, A., Petzold, J., Rama, B. and Weyer, N. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321-445. https://doi.org/10.1017/9781009157964.006

Patro, S., Krishnan, P., Deepak Samuel, V., Purvaja, R. and Ramesh, R. (2017) Seagrass and Salt Marsh Ecosystems in South Asia: An Overview of Diversity, Distribution, Threats and Conservation Status. *Wetland Science*, pp.87–104. doi: https://doi.org/10.1007/978-81-322-3715-0_5.

Payo, A., Mukhopadhyay, A., Hazra, S., Ghosh, T., Ghosh, S., Brown, S., Nicholls, R.J., Bricheno, L., Wolf, J., Kay, S., Lázár, A.N. and Haque, A. (2016) Projected changes in area of the Sundarban mangrove forest in Bangladesh due to SLR by 2100. *Climatic Change*, 139(2), pp.279–291. doi: https://doi.org/10.1007/s10584-016-1769-z.

Prange, M., Wilke, T. & Wesselingh, F.P. The other side of sea level change. *Commun Earth Environ* **1**, 69 (2020) https://doi.org/10.1038/s43247-020-00075-6

Raff, J.L., Goodbred, S.L., Pickering, J.L. et al. (2023) Sediment delivery to sustain the Ganges-Brahmaputra delta under climate change and anthropogenic impacts. *Nat Commun* 14, 2429 (2023). https://doi.org/10.1038/s41467-023-38057-9

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R.

Zaaboul (2021) Climate Change Information for Regional Impact and for Risk Assessment. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1767–1926, doi: 10.1017/9781009157896.014.

Rao, A., Upadhaya, P., Ali, H., Pandey, S. and Warrier, V. (2020b) Coastal inundation due to tropical cyclones along the east coast of India: an influence of climate change impact, *Natural Hazards*, 101: 39-57, https://doi.org/10.1007/s11069-020-03861-9

Rao, A., Upadhaya, P., Pandey, S. and Poulose, J. (2020a) Simulation of extreme water levels in response to tropical cyclones along the Indian coast: a climate change perspective, *Natural Hazards*, 100: 151-172, https://doi.org/10.1007/s11069-019-03804-z

Rathore, S., Goyal, R., Jangir, B., Ummenhofer, C., Feng, M. and Mishra, M. (2022) Interactions Between a Marine Heatwave and Tropical Cyclone Amphan in the Bay of Bengal in 2020, *Frontiers in Climate*, 4, https://doi.org/10.3389/fclim.2022.861477

Rentschler, J. and Salhab, M. (2020) *People in Harm's Way: Flood Exposure and Poverty in 189 Countries.* World Bank Group Policy Research Working Paper 9447, October 2020. https://openknowledge.worldbank.org/entities/publication/04ad161e-7144-5984-8b85-91710f2900b4

Roy, B., Penha-Lopes, G.P., Uddin, M.S., Kabir, M.H., Lourenço, T.C. and Torrejano, A. (2022) Sea level rise induced impacts on coastal areas of Bangladesh and local-led community-based adaptation. International Journal of Disaster Risk Reduction, 73, p.102905. doi:https://doi.org/10.1016/j.ijdrr.2022.102905.

SACEP (2017) South Asia Co-operative Environment Programme, http://www.sacep.org/pdf/General-Publications/2017.05-SACEP-Leaflet.pdf

SACEP (2019) Marine and Coastal Biodiversity Strategy for the South Asian Seas Region: Living in Harmony with our Oceans and Coasts. (2019). Sri Lanka: South Asia Co-operative Environment Programme (SACEP).

Samant, R. and Prange, M. (2023) 'Climate-driven 21st century Caspian Sea level decline estimated from CMIP6 projections', *Communications Earth & Environment*, 4(1), p. 357. Available at: https://doi.org/10.1038/s43247-023-01017-8.

Samanta, S., Hazra, S., Mondal, P.P., Chanda, A., Giri, S., French, J.R. and Nicholls, R.J. (2021) Assessment and Attribution of Mangrove Forest Changes in the Indian Sundarbans from 2000 to 2020. *Remote Sensing*, 13(24), p.4957. doi:https://doi.org/10.3390/rs13244957.

Sammonds, P., Shamsudduha, M. and Ahmed, B. (2021) Climate change driven disaster risks in Bangladesh and its journey towards resilience. Journal of the British Academy, 9s8, pp.55–77. doi: https://doi.org/10.5871/jba/009s8.055.

Seo, S.N. and Bakkensen, L.A. (2017) 'Is Tropical Cyclone Surge, Not Intensity, What Kills So Many People in South Asia?', *Weather, Climate, and Society*, 9(2), pp. 171–181. Available at: https://doi.org/10.1175/WCAS-D-16-0059.1.

Spalding, M., Lauretta Burke, Spencer A. Wood, Joscelyne Ashpole, James Hutchison, Philine zu Ermgassen (2017) Mapping the global value and distribution of coral reef tourism, Marine Policy, Volume 82, Pages 104-113, https://doi.org/10.1016/j.marpol.2017.05.014.

Takagi, H., Le Tuan Anh, Md. Rezuanul Islam and Tajnova Tanha Hossain (2022) Progress of disaster mitigation against tropical cyclones and storm surges: a comparative study of Bangladesh, Vietnam, and Japan. Coastal engineering journal, 65(1), pp.39–53. doi: https://doi.org/10.1080/21664250.2022.2100179

Timirkhanov, S., Chaikin, B., Makhambetova, Z., Thorpe, A. and van Anrooy, R. (2010) Fisheries and Aquaculture in Kazakhstan: Introduction, FAO Fisheries and Aquaculture Circular, thefishsite, accessed January 2024, https://thefishsite.com/articles/fisheries-and-aquaculture-in-kazakhstan-introduction

Tran, T.V., Nguyen, T.D., Nguyen, H.H. and Nguyen, P.L. (2021) Investigating Sea Surface Temperature and Coral Bleaching in the Coastal Area of Khanh Hoa Province. In: *IOP Conf. Series: Earth and Environmental Science*. [online] IOP Publishing. Available at: https://iopscience.iop.org/article/10.1088/1755-1315/964/1/012004/pdf.

UNISDR/UNDP (2012) A Toolkit for Integrating Disaster Risk Reduction and Climate Change Adaptation into Ecosystem Management of Coastal and Marine Areas in South Asia. Outcome of the South Asian Consultative Workshop on "Integration of Disaster Risk Reduction and Climate Change Adaptation into Biodiversity and Ecosystem Management of Coastal and Marine Areas in South Asia", held in New Delhi on 6 and 7 March 2012. New Delhi: UNDP. 173 pages

United Nations (2015) Department of Economic and Social Affairs, Sustainable Development, Accessed February 2024, https://sdgs.un.org/goals

van Woesik, R., Shlesinger, T., Grottoli, A.G., Toonen, R.J., Vega Thurber, R., Warner, M.E., Marie Hulver, A., Chapron, L., McLachlan, R.H., Albright, R., Crandall, E., DeCarlo, T.M., Donovan, M.K., Eirin-Lopez, J., Harrison, H.B., Heron, S.F., Huang, D., Humanes, A., Krueger, T. and Madin, J.S. (2022) Coral-bleaching responses to climate change across biological scales. *Global Change Biology*, 28(14), pp.4229–4250. doi: https://doi.org/10.1111/gcb.16192.

Vinke, K., Martin, M.A., Adams, S., Baarsch, F., Bondeau, A., Coumou, D., Donner, R.V., Menon, A., Perrette, M., Rehfeld, K., Robinson, A., Rocha, M., Schaeffer, M., Schwan, S., Serdeczny, O. and Svirejeva-Hopkins, A. (2016) Climatic risks and impacts in South Asia: extremes of water scarcity and excess. Regional Environmental Change, 17(6), pp.1569–1583. doi: https://doi.org/10.1007/s10113-015-0924-9.

Ward, R.D., Friess, D.A., Day, R.H. and Mackenzie, R.A. (2016) Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosystem Health and Sustainability*, [online] 2(4), p.e01211. doi: https://doi.org/10.1002/ehs2.1211.

Woodroffe, C.D., Rogers, K., McKee, K.L., Lovelock, C.E., Mendelssohn, I.A. and Saintilan, N. (2016) Mangrove Sedimentation and Response to Relative Sea-Level Rise. *Annual Review of Marine Science*, 8(1), pp.243–266. doi: https://doi.org/10.1146/annurev-marine-122414-034025.

World Bank (2017) *What is the Blue Economy?* Available at: https://www.worldbank.org/en/news/infographic/2017/06/06/blue-economy [Accessed 21 Aug. 2023].

World Bank (2021a) *Climate Risk Country Profile: India* (2021a) The World Bank Group and the Asian Development Bank

World Bank and ADB (2021a) *Climate Risk Country Profile: Maldives*. https://climateknowledgeportal.worldbank.org/country-profiles

World Bank and ADB (2021b) *Climate Risk Country Profile: Sri Lanka*. https://climateknowledgeportal.worldbank.org/country-profiles

World Bank (2022) *Bangladesh: Country Climate and Development Report*.

World Travel and Tourism Council (2022) *Sri Lanka - 2022 Annual Research: Key Highlights*. Available at: https://wttc.org/DesktopModules/MVC/FactSheets/pdf/704/207_20220613170910_SriLanka2022_.pdf.

Image location: Eastern mountains near Trashigang, Bhutan

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