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Asia
Supplementary Material

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SM10.1 Detection and Attribution of Observed Climate Changes in Asia

Table SM10.1 | Detection and attribution of observed changes in Asia

Detection: observed impacts	Attribution: climate impact drivers	Geographic region, sub-region	Time period	Evidence	Agreement	Confidence	References
Heatwaves (urban)	Temperature increase	India, Pakistan, Central Eastern China	1969–2005 1951–2015 1973–2012 1948–2010 1961–2010	*High*	*High*	*High*	Mishra et al. (2015); Rohini et al. (2016); Chen and Li (2017); Panda et al. (2017); Mishra et al. (2018); Ross et al. (2018)
Urban drought	Temperature and ET increase	South Asia	Multiple	*Low*	*Medium*	*Medium*	Gu et al. (2015); Pervin et al. (2020)
Extreme rainfall events (in urban areas)	Precipitation increase	India, the Philippines	1901–2010 1951–2010	*Medium*	*Medium*	*Medium*	Ali et al. (2014)
Coastal urban flooding	Precipitation increase, SLR	Across Asia (particularly Southeast Asia)	Multiple	*High*	*High*	*High*	Dulal (2019)
Flood-induced damages	Annual precipitation increase	Northwest China (Xinjiang)	1980–2001	*Low*	*Low*	*Low*	Fengqing et al. (2005)
Sea level rise (only for coastal cities)	Temperature increase	Vietnam,Bangladesh	1993–2014 1974–2004	*High*	*Medium*	*Medium*	Brammer (2014); Shahid et al. (2016); Hens et al. (2018)
Permafrost thawing	Temperature increase	North Asia	2007–2009	*Medium*	*High*	*Medium*	Shiklomanov et al. (2017a)); Shiklomanov et al. (2017b)); Biskaborn et al. (2019)
Wildfire	Summer temperature and precipitation regime, droughts	North Asia	1970–1990	*Medium*	*Medium*	*Medium*	Schaphoff et al. (2016); Brazhnik et al. (2017)
Biodiversity and habitat losses	Climate change and interaction with human disturbance	East Asia	1700–2000	*H igh*	*H igh*	*H igh*	He et al. (2019); Wan et al. (2019)
Primary production	Ocean warming and stratification	Western Indian Ocean	1950–2012	*Low*	*Low*	*Low*	Roxy et al. (2016)
Urban heat island effect	Temperature increase	South Asia (India, Pakistan, Sri Lanka), East Asia (Japan, Hong Kong, the Republic of Korea), Southeast Asia (Thailand, Indonesia, the Philippines), North Asia (Russia)	Multiple	*High*	*Medium*	*Medium*	Choi et al. (2014); Santamouris (2015); Estoque et al. (2017); Ranagalage et al. (2017); Kotharkar et al. (2018); Li et al. (2018a)); Hong et al. (2019)
Dust storms	Temperature increase, precipitation decrease	West Asia (includes Persian Gulf countries)	Multiple	*High*	*High*	*High*	Kelley et al. (2015); Yu et al. (2015); Alizadeh-Choobari et al. (2016); Nabavi et al. (2016)

SM10.2 Sand and Dust Storms

The West Asia region, especially the Tigris–Euphrates alluvial plain, has been recognised as one of the most important dust-source areas in the world (Cao et al., 2015). As a result, six main clusters have been recognised as dust-source areas. Three clusters situated in the Tigris–Euphrates plain have been identified as severe sand and dust storm (SDS) sources. Another cluster in the Sistan plain is also a potential source area (Cao et al., 2015). The main persistent sources of dust storms (in Central Asia) are located in the large 'dust belt' that extends from west to east over the southern deserts, north of the Caspian Sea deserts, south of Balkhash Lake, and the Aral Sea region (Indoitu et al., 2012). Dust storm variability and trends in frequency on decadal time scales have been reviewed by Middleton (2019) in three dust belt settlements with more than 50-year-long meteorological records in Mauritania (Nouakchott), Iran (Zabol) and China (Minqin). The inhabitants of each of these settlements have experienced a decline in dust storms in recent decades, since the late 1980s at Nouakchott, since 2004 at Zabol and since the late 1970s at Minqin. Iran is mostly arid or semiarid, with deserts making up at least 25 million hectares (100,000 square miles) of the country's area (NASA, 2018). Due to the severity of the condition in Sistan-Baluchestan, the National Development Fund (Iran) allocated 115 million euros to fight SDS in the region (Tajrishi, 2019). Southwest regions of Iran, due to dry environmental and climatic conditions, have been identified as one of the five major SDS regions in the world. In recent years, large parts of Iran have been affected by suspended particles from the dust storms (Ghasem et al., 2012). There are some 20 million hectares of SDS hotspots in the country and some are in critical condition (Tajrishi, 2019). These SDS have been striking the southwest province for over 10 years. The numbers of dusty days in the southern province of Khuzestan have increased by 1.5 d on average over a 30-year period. The number of dusty days is different in different seasons, but on average over a 30-year period, SDS hit the area 63 d annually (Sabzehzari, 2019). In Iran, five regions of frequent dust events have been identified. In the order of importance, these areas are the Khuzestan Plain, the coastal plain of the Persian Gulf, western Iran, Tabas and Sistan (Alizadeh-Choobari et al., 2016). Iran is experiencing unprecedented climate-related problems such as drying of lakes and rivers, dust storms, record-breaking temperatures, droughts and floods (Vaghefi et al., 2019). The dust storm event can be considered as severe if it lasts 3–12 h, storms with a wind speed of 10–14 m s–1 and meteorological visibility in the range of 500–1000 m. The extremely severe dust storms last more than 12 h, with the wind speed exceeding 15 m s–1; the dust storms with meteorological visibility less than 50 m are considered as very severe regardless of duration and wind speed (Orlovsky et al., 2013). Deserts and semiarid areas are prone to dust storms, which can drive impacts on health and several other sectors (Tong et al., 2017). The evolution of dust under climate change is uncertain (Mirzabaev et al., 2019), and thus far, there is a lack of evidence and agreement on a change in their frequency or intensity in general (WGI AR5 IPCC 2014).

SM10.2.1 Cause of Sand and Dust Storms

There are three key factors responsible for the generation of SDS: strong wind, lack of vegetation and absence of rainfall (EcoMENA, 2020). Both climatic and human variables have been important, but overall the balance of research conclusions indicates that natural processes (e.g., precipitation totals, wind strength) have had greater impact than human action, in the latter case both in the form of mismanagement (e.g., abandoned farmland, water management schemes) and attempts to reduce wind erosion (e.g., afforestation projects). Understanding the drivers of change in dust storm dynamics at the local scale is increasingly important for efforts to mitigate dust storm hazards as climate-change projections suggest that the global dry-land area is *likely* to expand in the 21st century, along with an associated increase in the risk of drought and dust emissions (Middleton, 2019). This seems to be closely related to the heating surface and the occurrence of local dry instabilities. Analyses of data showed that dust amounts (or volumes) in all the stations have two peaks, the first between 1982 and 1990 and the second between 2005 and 2008. These peaks can be related to a variety of factors including anthropogenic factors such as war, agricultural activities, dam construction and widespread droughts (Ghasem et al., 2012).

SM10.2.2 Harmfulness of Sand and Dust Storms

According to EcoMENA, SDS cause significant negative impacts on society, the economy and the environment at the local, regional and global scales (EcoMENA, 2020). These SDS have significant socioeconomic impacts on human health, agriculture, industry, transportation, and water and air quality (UNCCD, 2019). They erode top soils, blast crops and induce health, transportation, equipment and/or built-infrastructure problems corresponding to the magnitude and duration of high winds and particulate-matter concentrations (Goudie, 2014; Hallegraeff et al., 2014; O'Loingsigh et al., 2014; Crooks et al., 2016; Gabric et al., 2016; Barreau et al., 2017; Bengtson Nash et al., 2017; Bhattachan et al., 2018; Al Ameri et al., 2019; Middleton et al., 2019). Dust storms also cause air pollution and redistribute the soil-based fungus associated with Valley Fever (O'Loingsigh et al., 2014; Barreau et al., 2017; Coopersmith et al., 2017; Tong et al., 2017; Gorris et al., 2018). Dust events may be represented as the number of dust hours per dust storm year (Leys et al., 2011; Spickett et al., 2011). Following recent multi-year droughts, many environmental crises are caused by dust in Iran and other areas of the Middle East. Dust in the vast areas of the provinces occurs with high frequency, creating many health problems as well as social and economic problems (Keramat et al., 2011). The roles of climatic variables and human activities, as drivers of periods of high dust storm frequency and subsequent declines in dust emissions, are assessed in each case (Middleton, 2019). Dust storms present numerous hazards to human society and are particularly significant to people living in the dust belt which stretches from the Sahara across the Middle East to northeast Asia (Middleton, 2019).

SM10.2.3 Observations and Adaptations

The seasonality of the numbers of dusty days (NDD) in Iran shows the highest frequency for summer followed by spring and autumn. The popular Mann–Kendall and the bootstrap MK test to consider serial correlation are then applied for trend assessment. Results showed both negative (across the north and northwest regions) and positive trends (across the south and southeast regions) in the annual and seasonal NDD time series (Modarres and Sadeghi, 2018). According to the statistical calculations, most storms occurred in spring and summer. The lowest number of dust events occurred in autumn and winter particularly in December and January, when there are high possibilities of rainfall occurrence and dynamic instability conditions in the north and west of the region. The results illustrated that the highest amounts of hourly dust occurred in the afternoon and the lowest amounts occurred at 00.00 UTC (3.30 a.m. local time) (Ghasem et al., 2012). Major concerns in Asia are associated particularly with droughts and floods in all regions, heat extremes in South and East Asia, SDS in West Asia and Central Asia (IPCC). Throughout Iran, the frequency of dust events strengthens in spring, peaks in summer and significantly weakens in autumn and winter, with the least observed frequency in winter (Alizadeh-Choobari et al., 2016). In the past decade, West Asia has experienced more frequent and intensified dust storms affecting Iran and other Persian Gulf countries (Nabavi et al., 2016).

In West Asia, the frequency of dust events has increased slightly in some areas (eastern Saudi Arabia and southeast Iraq) and increased markedly in other emerging areas (northwest Iraq and eastern Syria) from 1980 to the present (Nabavi et al., 2016). The marked dust increase during the first decade of the 21st century has been attributed to drought conditions in the Fertile Crescent (Yu et al., 2016) *likely* amplified by anthropogenic warming (Kelley et al., 2015). In terms of long-term frequency of dust events, observational analyses show an overall rising trend in the frequency of Iran's dust events in recent years, predominantly attributed to increasingly frequent dust outbreaks in Iraq due to human activities (Alizadeh-Choobari et al., 2016). Northwest Iraq and eastern Syria have been identified as emerging dusty areas, whereas eastern Saudi Arabia and southeast Iraq have been identified as permanent dusty areas, including both dust sources and affected areas (Nabavi et al., 2016). Southwest Iran and Persian Gulf countries in general have been determined to be the main receptors of summer dust storms in West Asia (Nabavi et al., 2016). Dust storms in Central Iran are a natural hazard, and the Tigris–Euphrates alluvial plain has been recognised as the main dust source in this area (Dastorani and Jafari, 2019). Results have shown that there is a direct relationship between dust event, drought and years of intensive drought (Dastorani and Jafari, 2019). The most important point about a powerful dust storm that brought strong winds to Tehran (Iran's capital), killing 5 and injuring 82 people, was the lack of an early warning system (Fatemi et al., 2015).

The UNCCD supports countries in the mitigation of SDS impacts and anthropogenic dust sources by advocating the following three-pillar approach: (a) early warning systems, (b) preparedness and resilience, and (c) anthropogenic source mitigation (UNCCD, 2019). As Iran was reminded at COP14, the rich body of traditional and modern knowledge on SDS hotspots could help create a stronger knowledge base with regional initiatives (UNCCD, 2019).

SM10.2.4 Projections

Compared with 1980–2004, during 2025–2049, Iran is *likely* to experience more extended periods of extreme maximum temperatures in the southern part of the country, more extended periods of dry (for ≥120 d: precipitation <2 mm, Tmax ≥30°C) as well as wet (for ≤3 d: total precipitation ≥110 mm) conditions and higher frequency of floods (Vaghefi et al., 2019).

SM10.2.5 Regional Precipitation Changes

The slope of precipitation in West Asia shows that during 2016–2045 in January, February, July and August, precipitation would increase and decrease during the other months of the year (Ahmadi et al., 2018). The precipitation season in West Asia, using the Man–Kendall method, also shows a decrease in the prevailing trend throughout the year (Ahmadi et al., 2018). Precipitation shows minor positive trends, except for spring when it decreases (Haag et al., 2019).

SM10.2.6 Regional Temperature Changes

Temperatures in Central Asia have risen significantly in recent decades, whereas mean precipitation remains almost unchanged (Haag et al., 2019); however, climatic trends can vary greatly between different sub-regions, across altitudinal levels and within seasons (Haag et al., 2019). The results show a strong increase in temperature almost uniformly across the topographically complex study site, with particular maxima in winter and spring (Haag et al., 2019).

SM10.3 Summary of Observed and Projected Impacts of Climate Change on Agriculture and Food Systems in Asia Based on Post-IPCC-AR5 Studies

Table SM10.2 | Summary of observed and projected impacts of climate change on agriculture and food systems in Asia based on post-IPCC-AR5 studies

Region	Country	Agriculture sector	Observed impacts	Projected impacts	Scale of analysis	Study
East Asia	China	Crops	Economic loss of 595–858 million USD for the corn and soybean sectors from 2000 to 2009	Projected yield decline of 3–12% and 7–19% for corn and soybean, respectively, by 2100	National	Chen et al. (2016)
	China	Crops		A 1°C increase in annual average temperature could reduce grain output by 1.74 and 1.19% in North and South China, respectively (or a national reduction of 1.45%). An increase in total annual precipitation of 100 mm could increase grain output by 3% in North China but a reduction by 0.59% in South China (an overall increase in national grain output by 1.31%).	National (north and south)	Holst et al. (2013)
	China	Crops		Increase in net crop revenue per hectare between 79 and 207 USD for the 2050s and from 140 to 355 USD for the 2080s Potential advantage for the development of Chinese agriculture for the provinces of the northeast, northwest and northern regions Increased precipitation can lead to a loss of net crop revenue per hectare, especially for the provinces of the southwest, northwest, northern and northeast regions.	National with regional differentiation	Chen et al. (2013)
	China	Crops		A 17% decrease in the northeast region maize production by 2030 (from 624 to 518 million bushels) with temperature increases of 1.32°C and a 30% increase in precipitation from the 2008 levels A 22% increase in southwest Maize production (from 216 million bushels to 263 million bushels) by 2030 considering the same temperature and precipitation scenarios	Subnational: northeast and southwest regions	Li et al. (2014)
	China	Crops		China's rice export will increase by 2.7% as rising rice exports to Republic of Korea outweigh the export decrease to other countries, and import would decrease by 0.04%, which would lead to a slight increase in rice self-sufficiency.	National	Zhang et al. (2019)
	China	Crops		With RCP4.5, the yield of the following crops are projected to increase by 2030 with respect to the 2000s: 0.52% for rice; 0.16% for maize; 0.17% for wheat; and 0.1% for soybean.	Six regions	Zhuo et al. (2014)
	China	Crops		Vulnerability of spring wheat production is expected to significantly increase considering increasing temperature under the RCP4.5 and RCP8.5 scenarios.	Mongolia (region of China)	Dong et al. (2018)
	Republic of Korea	Crops		The following crops are expected to decrease by the end of the 21st century: rice, by 25% or more; maize, by 10–20%; summer potatoes, by more than 30%.	National	Ministry of Environment (2020)
	Republic of Korea	Crops		Rice yield is expected to decrease by 12.95% (RCP4.5) and 16.1% (RCP8.5) in 2050, and 14.7% (RCP4.5) and 23.6% (RCP8.5) in 2080.	Central region	Yoon and Choi (2020)
	Republic of Korea	Crops		Rice yield is expected to decrease by 15.85% (RCP4.5) and 14.3% (RCP8.5) in 2050, and 17.45% (RCP4.5) and 17.1% (RCP8.5) in 2080.	Southern region	Yoon and Choi (2020)

Region	Country	Agriculture sector	Observed impacts	Projected impacts	Scale of analysis	Study
South Asia	Pakistan	Crops	Farmers are experiencing changes in crop yields and crop diseases as a result of climate extremes particularly floods and droughts.		Khyber Pakhtunkhwa province	Fahad and Wang (2018)
	Nepal	Crops	Loss of agricultural productivity brought about by climate change has an adverse impact on the overall national economy.		National	Chalise et al. (2017)
	India	Crops		Aggregate decline in food grain production for rice, wheat, pulses and coarse serials in ten large food grain-producing states by 2.30 and 8.62% for the entire country for 2030 and 2050, respectively, with substantial variations in terms of the specific crop, region (state) and time period	National/ Subnational	Dasgupta et al. (2013)
	India	Crops		Crop yields of wheat, barley and maize will all increase under both the RCP4.5 and RCP8.5 scenarios for the period 2021–2050 with the most significant growth of crop yield projected for wheat followed by barley and maize.	Rajasthan state	Dubey and Sharma (2018)
	India	Crops		Yield reduction in rice production varies from less than 10% to more than 30% depending on the study area and model assumptions based on review of the literature.	Various regions	Balasubramanian et al. (2017)
	India	Crops		Reduction in maize yield by as much as 25, 40 and 70% under a temperature rise by 1°C, 2°C and 4°C , respectively, although maize varieties that combine drought and heat tolerance have the potential to offset some of the negative impacts	Hyderabad	Tesfaye et al. (2018)
	India	Crops		Rice yields could potentially increase in the northern states but could decline in the southern states by 5.0% in the 2030s, 14.5% in the 2050s and 17.0% in the 2080s.	National	Asian Development Bank (2014)
	India	Crops	Forty-five improved varieties are adopted in India, and in each state highly resistant and tolerant varieties are cultivated providing some degree of varietal resilience.		Bihar, Gujarat, Karnataka, Punjab, Uttar Pradesh and West Bengal	Pradel et al. (2019)
	Bangladesh	Crops		Temperature increase could reduce national rice and wheat production by as much as 12.1 and 12.4%, respectively.	National (16 sub-regions)	Ruane et al. (2013)
	Bangladesh	Crops		Overall rice production could decline by about 17% and wheat production by 61% compared with a baseline situation without accounting for the potential impacts of CO2 fertilisation.	National	Asian Development Bank (2014)
	Bhutan	Crops		Rice yields could decrease by 6.7% at middle latitude and 12.6% at low altitude by 2050.	National	Asian Development Bank (2014)
	Sri Lanka	Crops		Rice yields could decline by 3.6–19.8% by 2050 across seasons and climatic zones.	National	Asian Development Bank (2014)
	Sri Lanka	Crops		The future distributions of suitable tea (*Camellia sinensis*) growing areas revealed a decline of approximately 10.5, 17 and 8% in total 'optimal', 'medium', and 'marginal' suitability areas, respectively, implying that climate would have a negative effect on the habitat suitability of tea in Sri Lanka by 2050 and 2070.	National	Jayasinghe et al. (2019)
	South Asian countries	Crops		Reduction in crop productivity in all South Asian countries by 2040 with India *likely* to be the most affected, losing up to 5% of its rice output potential	South Asia	Cai et al. (2016)
				Impact projections for wheat production vary across the South Asian region with Bangladesh, India and Pakistan predicted to be the losers with a decline of 5–10% of their output potentials.		
				Prospects for other regions are quite mixed, ranging from 7% gains to 5% losses, with large interannual variations.		

Region	Country	Agriculture sector	Observed impacts	Projected impacts	Scale of analysis	Study
Southeast Asia	Southeast Asian countries	Crops		Reduction in rice yields under climate change will be largest in Cambodia with a decrease of approximately 45% in the 2080s under RCP8.5, relative to the baseline period 1991–2000, without adequate adaptation.	Southeast Asia	Chun et al. (2016)
				Improved irrigation considering CO2 fertilisation will largely increase rice yields by up to 8.2–42.7%, with the greatest increases in yields in Cambodia and Thailand in the 2080s under RCP8.5 compared with a scenario without irrigation.		
	Vietnam	Crops		Net household revenue from agriculture is projected to decline by 17.7 and 21.2% in 2050 and 2100, respectively, using B2 scenarios under the without-adaptation model, and by 0.37 and 0.20% in 2050 and 2100, respectively, under the with-adaptation model.	Subnational (northwest region)	Huong et al. (2019)
	Vietnam	Crops		Yields in rice decline by 5.5–8.5% annually, on average, depending on the emissions scenario	Can Tho	Kontgis et al. (2019)
	Cambodia	Crops		Yields in lowland rice decreased by 4% for every degree increase from an average annual baseline temperature of 28°C.	National	Poulton et al. (2016)
	Thailand	Crops	Yield losses due to past climate trends (1984–2013) are in the range of <50 kg ha–1 per decade (3% of actual average yields) with large variation in the impacts of climate trends on rice yields across the ten provinces studied.	Yield reduction is *likely* to be more serious in the future if the observed trends of temperature and precipitation continue.	Subnational (Mun River basin)	Prabnakorn et al. (2018)
	Thailand	Crops		Potential reduction in the yield of Thai jasmine rice by 14 and 10% under the RCP4.5 and RCP8.5 scenarios, respectively, by the 2080s	Subnational (Songkhram River basin)	Boonwichai et al. (2019)
	Thailand	Crops		Positive impact on rice yields, especially in rain-fed areas, by 2.6% (RCP8.5: 2080–2099) to 22.7% (RCP6.0: 2080–2099)	Roi Et Province (northeast)	Arunrat et al. (2018)
				Rice yields tend to increase significantly by 0.7% (RCP8.5: 2060–2079) to 18.8% (RCP6.0: 2080–2099), with the exception of 2080–2099 under RCP8.5 which results in a decline in rice yield by 8.4%.		
	Thailand	Crops	The total yield losses due to past climate trends are rather low, in the range of 50 kg ha–1 per decade (3% of actual average yields).		National	Prabnakorn et al. (2018)
	Philippines	Crops		A 1°C increase in minimum temperature during summer decreases yield by 64 kg ha–1; rice yield diminishes by 36 kg ha–1 for every 1% increase in the share of wet days.	National	Bordey et al. (2013)

Region	Country	Agriculture sector	Observed impacts	Projected impacts	Scale of analysis	Study
Asia	Twenty-nine Asian countries	Crops		A warming of 1.5°C (without carbon fertilisation) may reduce the total annual net revenue across all the 29 countries by 13% or a total of 92.6 billion USD, with most of the countries projected to lose net crop revenue except for Afghanistan, Brunei Darussalam, North Korea, Japan, Kyrgyzstan, Republic of Korea and Tajikistan.		Mendelsohn (2014)
				At 3°C warming without carbon fertilisation, overall damages will reach 195 billion USD or a 28% loss of annual net revenue with 11 countries predicted to lose more than 30% of their crop revenue, namely, Bhutan, Cambodia, India, Kazakhstan, Laos, Mongolia, Myanmar, Nepal, Pakistan, Thailand and Turkmenistan.		
				With carbon fertilisation, aggregate damages in the 1.5°C warming scenario are predicted to be offset, leading to a small gain of 18 billion USD (3%).		
				At 3°C warming with carbon fertilisation, a 12% loss in crop net revenue is predicted for Asia with an aggregate value of 84 billion USD yr–1, and with only Afghanistan, North Korea, Japan and Tajikistan gaining in net revenue.		
				In all scenarios, India is the overall loser which accounts for two-thirds of the lost net revenue in Asia in both 1.5°C and 3.0°C warming scenarios without carbon fertilisation.		
Central Asia	Afghanistan, Uzbekistan, Turkmenistan, Tajikistan	Crops	The advanced irrigation modes (e.g., sprinkle and drip) can improve irrigation efficiency and raise unit water benefit from 0.15 to 0.24 USD m–3. Irrigation mode with efficiency of about 0.61 is an effective option in adaption to changed water availabilities, which is beneficial for pursuing balance between water and land relationships.			Sun et al. (2019)
Southeast Asia		Livestock		Climate has a significant impact on farmers' livestock choices. Climate change would increase the probability of raising livestock. The total value of livestock owned per livestock farm will shrink 9–10%.	Five countries	Ou and Mendelsohn (2017)
North Asia	Mongolia	Livestock	Very severe livestock-induced rangeland degradation is overstated in Mongolia (1–18% of land area), with most rangelands slightly (33–53%) or moderately (25–40%) degraded.		National	Jamsranjav et al. (2018)
Southeast Asia	Philippines, Thailand, Malaysia, Indonesia	Fisheries			National	Nong (2019)
South Asia	Nepal	Fisheries		Fishery suitability in the Trishuli River would be greater than 70% of optimal under both RCP4.5 and RCP8.5.	Trishuli River	Mishra et al. (2018)
	Bangladesh and India	Fisheries	Fishers' experience shows that intensity of coastal cyclone is gradually increasing, which causes severe physical and economical damage. Incorporation of local knowledge in governmental policy formulation and public support to improve human skill are essential for the adaptive management.		Meghna River	Jahan et al. (2015)

Region	Country	Agriculture sector	Observed impacts	Projected impacts	Scale of analysis	Study
East Asia	Republic of Korea	Fisheries		The strengthened Tsushima warm current in the Korea Strait, the Tsushima Strait and the Sea of Japan, driven by global warming and the subsequent confinement of the relatively cold water masses within the Yellow Sea, will decrease larval anchovy biomass in the Yellow Sea, but will increase it in the Korea Strait, the Tsushima Strait and the Sea of Japan, by 2030.	Korea Strait, Tsushima Strait and Sea of Japan	Jung et al. (2016)
Asia		Fisheries	Asia has a significant contribution to the world inland-capture fisheries production of 11.5 × 106 t (i.e., about 69%).		Philippines, Indonesia and Lower Mekong (Vietnam)	Amarasinghe and De Silva (2015)
South and Southeast Asia		Fisheries		Climate change is predicted to decrease fish production potential in South and Southeast Asia by 2050.	Global	Barange et al. (2014)
East Asia	China and Republic of Korea	Fisheries	The subsequent shrinkage of habitat range to the southwest was the major cause of the sudden decline of filefish (*Thamnaconus modestus*) catch in the northeast China sea. Shift in water temperature and currents were also identified in the NECS in the early 1990s.			Jung and Cha (2013)
Southeast Asia	Vietnam	Fisheries and aquaculture	Four manifestations of climate-change occurrence in Tam Giang lagoon: an increasing number of intensive storms, extreme temperatures, floods, and sea level rise. Climate change strongly affects aquaculture households, but in some cases climate change also has brought benefits for fishing groups.		Tam Giang-Cau Hai Lagoon, Thua Thien Hue (Vietnam)	d'Amour et al. (2017)
East Asia	Republic of Korea	Aquaculture		The absolute level of vulnerability is high in a long-term period of RCP8.5 in which exposure becomes severe, whereas the relative vulnerability is similar among farming species and regions. Specifically, vulnerability is at the highest level in seaweed, such as laver and sea mustard, while fish, shrimp and abalone are relatively less vulnerable to climate change.	North Korea and Republic of Korea	Kim et al. (2019)
East Asia	China and Japan	Aquaculture	Arctic Oscillation and East Asian monsoon have strongly influenced the aquaculture areas on the Dalian Coast (China) through their effects on temperature during winter. Conversely, ocean conditions and suitable areas in Funka Bay (Japan) have changed rapidly relative to oceanic and atmospheric circulation.		Dalian (China) and Funka Bay (Japan)	Liu et al. (2014)
Southeast Asia	Vietnam	Aquaculture	Decline in the rice crop areas in Ben Tre with 23.4 and 31.5% in the coastal districts due to the conversion of freshwater rice fields into brackish shrimp ponds	It is estimated that a 1-m rise in the current sea level would clear 45.2% of the remaining mangrove forests, 60.9% of the current areas planted with rice, 65% of the aquaculture ponds and 46% of the entire province would be under the water.	Ben Tre, Mekong Delta (Vietnam)	Veettil et al. (2019)
Asia		Aquaculture	Climatic factors increase aquaculture production, whereas energy sources and growth-specific factors have affected the production of aquaculture in a panel of selected countries.			Bhuiyan et al. (2018)

SM10.4 Line of Sight: City-Wise Risks and Adaptation

Table SM10.3 | Risks and key adaptation options in selected cities across Asia

City	Key risks							Adaptation progress				Adaptation effectiveness
	Permafrost thaw	Flood	Drought, water scarcity	Extreme rain	Heat, urban heat island effects	Cyclones	SLR	Infrastructural	Ecosystem based	Institutional	Behavioural	
Salekhard	Streletskiy (2019)		NE	NE	L	NA	NA	Shiklomanov et al. (2017b)); Streletskiy (2019)	NE	L	NE	Shiklomanov et al. (2017b)); Streletskiy (2019)
Riyadh	NA	Nahiduzzaman et al. (2015); Rahman et al. (2016); Ledraa and Al-Ghamdi (2020)	Hasanean and Almazroui (2015); Tarawneh and Chowdhury (2018)		Almazroui et al. (2014); Lelieveld et al. (2016); Pal and Eltahir (2016); Tarawneh and Chowdhury (2018); Al-Bouwarthan et al. (2019)	NA	NA	NE	NE	Nahiduzzaman et al. (2015); Rahman et al. (2016); Ledraa and Al-Ghamdi (2020)	Pal and Eltahir (2016); Howarth et al. (2020)	Al-Bouwarthan et al. (2019)
Guangzhou	NA	Hallegatte et al. (2013); Jevrejeva et al. (2016); Francesch-Huidobro et al. (2017); Zhang et al. (2017); Huang et al. (2018); Abadie et al. (2020)	Ma et al. (2018)		Hu et al. (2019); Liu et al. (2019)		Hallegatte et al. (2013); Jevrejeva et al. (2016); Abadie et al. (2020)	Meng et al. (2011); Francesch-Huidobro et al. (2017); Sajjad et al. (2018)	Meng et al. (2011); Sajjad et al. (2018); Zhu et al. (2019)	Meng et al. (2011); Francesch-Huidobro et al. (2017)		
Shanghai	NA	Yuan et al. (2017a)); Chen et al. (2018); Xian et al. (2018); Yu et al. (2018); Filho et al. (2019); Shan et al. (2019); Du et al. (2020); Wang et al. (2020)	Chen and Frauenfeld (2016)	Chen and Frauenfeld (2016); Yuan et al. (2017b))	Huang and Lu (2015); Chen and Frauenfeld (2016); Yuan et al. (2017b)); Ma et al. (2018); Yu et al. (2018); Hu et al. (2019)	Lam et al. (2017); Xian et al. (2018)	Yan et al. (2016); Yuan et al. (2017b)); Xian et al. (2018); Yu et al. (2018); Yin et al. (2020)	Chen et al. (2018); Xian et al. (2018); Du et al. (2020); Sengupta et al. (2020)	Xia et al. (2017); Filho et al. (2019)	Xian et al. (2018); Du et al. (2020)		Xia et al. (2017); Du et al. (2020); Sengupta et al. (2020)

City	Key risks							Adaptation progress				Adaptation effectiveness
	Permafrost thaw	Flood	Drought, water scarcity	Extreme rain	Heat, urban heat island effects	Cyclones	SLR	Infrastructural	Ecosystem based	Institutional	Behavioural	
Ahmedabad	NA		Aartsen et al. (2018)		Azhar et al. (2014); Kakkad et al. (2014); Knowlton et al. (2014); Vyas et al. (2014); Aartsen et al. (2018); Ahmedabad Municipal, (2018); Wang et al. (2019)	NA	NA	Aartsen et al. (2018); Ahmedabad Municipal (2018); Vellingiri et al. (2020)	Mell (2018)	Aartsen et al. (2018); Knowlton et al. (2014); Ahmedabad Municipal (2018); Vellingiri et al. (2020)	Kakkad et al. (2014); Knowlton et al. (2014); Aartsen et al. (2018); Ahmedabad Municipal (2018); Vellingiri et al. (2020)	
Mumbai	NA	Rana et al. (2014); de Sherbinin and Bardy (2015); Senapati and Gupta (2017); Singh and Kambekar (2017); Shastri et al. (2019); Murali et al. (2020)	Mishra et al. (2016)	Rana et al. (2014); Shastri et al. (2019)	Grover and Singh (2015)	Sobel et al. (2019)	Unnikrishnan et al. (2015); Singh and Kambekar (2017); Dulal (2019); Abadie et al. (2020); Murali et al. (2020)	Boyd et al. (2015); Schaer and Pantakar (2018)	Debnath et al. (2016)	Boyd et al. (2015); Georgeson et al. (2016); Chouhan et al. (2017); Schaer and Pantakar (2018); Weinstein et al. (2019)		
Dhaka	NA	Dastagir (2015); Davis et al. (2018); Filho et al. (2019)	NE	Dastagir (2015)	Brown (2020)	Dastagir(2015); Hoque et al. (2018); Filho et al. (2019); Hoque et al. (2019)	Dastagir (2015); Davis et al. (2018); Filho et al. (2019)	Araos et al. (2017); Ahmed et al. (2018); Zevenbergen et al. (2018); Fatemi et al. (2020)	Huq et al. (2017); Ahmed et al. (2018); Zinia and McShane (2018); Fatemi et al. (2020)	Jabeen and Guy (2015); Araos et al. (2017); Huq et al. (2017); Ahmed et al. (2018); Filho et al. (2019); Fatemi et al. (2020)	NE	

City	Key risks							Adaptation progress				Adaptation effec-tiveness
	Perma-frost thaw	Flood	Drought, water scarcity	Extreme rain	Heat, urban heat island effects	Cyclones	SLR	Infrastructural	Ecosystem based	Institutional	Behavioural	
Kuala Lumpur	NA	Abdullah et al. (2015); Filho et al. (2019); Rani et al. (2020)		Filho et al. (2019);Tang (2019)	Yusuf et al. (2014);Filho et al. (2019);Tang (2019);Rani et al. (2020)		Tang (2019)	Abdullah et al. (2015); Rani et al. (2020)	Ismail et al. (2018); Filho et al. (2019); Rani et al. (2020)	Filho et al. (2019); Rani et al. (2020)		
Jakarta	NA	Hallegatte et al. (2013); Gu et al. (2015); Jan van Oldenborgh et al. (2015); Muis et al. (2015); Takagi et al. (2016)	Siswanto et al. (2016)	Liu et al. (2015)	Estoque et al. (2017); Dar-manto et al. (2019)	NA	Takagi et al. (2016)	Ward et al. (2013); Marfai et al. (2015); Georgeson et al. (2016); Takagi et al. (2016); Budiyono et al. (2017); Esteban et al. (2017); Garschagen et al. (2018); Salim et al. (2019)		Ward et al. (2013); Marfai et al. (2015)	Padawangi and Douglass (2015); Esteban et al. (2017)	Takagi et al. (2016); Gars-chagen et al. (2018); Salim et al. (2019)
Ho Chi Minh City	NA	Ho et al. (2014); Lasage et al. (2014); Phi et al. (2015); Bangalore et al. (2016); Downes et al. (2016); Khoi and Trang (2016); Scussolini et al. (2017); Vachaud et al. (2019)		Khoi and Trang, (2016); Phuong et al. (2019); Vachaud et al. (2019)	Doan et al. (2016)	NE	VCAPS (2013); Lasage et al. (2014); Minh et al. (2015); Downes et al. (2016); Scussolini et al. (2017); Leitold and Diez (2019); Vachaud et al. (2019)	VCAPS (2013); Lasage et al. (2014); Phi et al. (2015); Scussolini et al. (2017); Al (2018); Hinkel et al. (2018)	VCAPS (2013)	VCAPS (2013); Ho et al. (2014); Lasage et al. (2014); Hinkel et al. (2018); Bangalore et al. (2016); Al (2018)	Bangalore et al. (2016)	

SM10.5 Evidence on the Effectiveness of Ecosystem-Based Adaptation (EbA) Using Four Common EbA Options

See Figure 10.10 for final assessment.

Table SM10.4 | Evidence on the effectiveness of EbA using four common EbA options

Risk	EbA option	Risk reduction potential		Ecosystem benefits		Economic and livelihood benefits		Human well-being benefits	
Extreme heat, urban heat island (UHI) effects	Urban parks and green spaces	*Robust Medium*	Reduces UHI, provides thermal comfort (Zhang et al., 2014; Jim, 2015; Koc et al., 2018; Aram et al., 2019; Lai et al., 2019)Increasing urban green cover (UGC) is more effective than increasing urban albedo (i.e., building reflectivity through cool roofs, green facades) to mitigate UHI and improve urban microclimates (Yuan et al., 2017a).Too much UGC can reduce ventilation, trapping heat and leading to temperature increase (Yuan et al., 2017a).	*Medium Medium*	Air-quality regulation was valued between 0.12 and 0.60 USD per square metre of tree cover per year (Wang et al., 2014).	*Medium Medium*	Adjoining vegetation and green roofs provide energy savings of up to almost 250 USD/ tree per year, noise regulation and aesthetic appreciation of 20 and 25 USD/ person per year, respectively (Wang et al., 2014). Proximity to urban parks can increase property value (Wu et al., 2015).	*Robust Medium*	Thermal comfort improves urban liveability (Koc et al., 2018; Aram et al., 2019; Lai et al., 2019) and general quality of life (Kabisch et al., 2015).
Floods	Ecological stormwater man-agement	*Robust Medium*	Effectively mitigates urban flooding caused by high-frequency precipitation events, with additional economic, ecological and social benefits (Mao et al., 2017; Xu et al., 2017; Yau et al., 2017; Li et al., 2018b; Mei et al., 2018; Huang et al., 2020)Less effective at helping cope with pluvial flooding caused by extreme precipitation events over a short period of time (Huang et al., 2020)	*Robust Medium*	Enables natural water natural storage, infiltration and purification (Yau et al., 2017; Qiao et al., 2020)	*Medium Medium*	Enables cities to achieve economic development goalsPromotes tourism through reduced risk and improved urban landscape (Huang et al., 2020)	NE	Global systematic review found no studies assessing well-being and health impacts (Venkataramanan et al., 2019).
Sea level rise	Mangrove restoration	*Medium Medium*	31% wave reduction; provides 50% protection from storms (Ferrario et al., 2014; Narayan et al., 2016)	*Medium Medium*	Contributes to local biodiversity (flora and fauna) and sustains coastal fish (Lee et al., 2014)	*Medium Medium*	Reduces cost of coastal defence structures (Narayan et al., 2016) Supports coastal livelihoods	*Medium High*	Food security benefitsProvides ecosystems that have sociocultural value

Risk	EbA option	Risk reduction potential		Ecosystem benefits		Economic and livelihood benefits		Human well-being benefits	
Food insecurity	Urban agriculture	*Medium* *Low*	Globally estimated to potentially produce 100–180 million tonnes of food annually, and avoid stormwater runoff between 45 and 57 billion cubic metres annually (Clinton et al., 2018), but mixed evidence on UA and food security outcomes, especially in low-income countries (Badami and Ramankutty, 2015)UA reduces energy needs from enhanced rooftop insulation by growth substrate leading to savings of 2.4 billion kWh in China and 1 billion kWh in India (Clinton et al., 2018).Improves local biodiversity and uptake of sustainable agriculture practices, and increases environmental awareness (Thomaier et al., 2015; Zasada et al., 2020)	*Medium* *Low*	Uptake of organic farming, composting, and growing a large variety of plants and trees (Zasada et al., 2020)Can have negative impacts due on fertiliser use, polluted runoff and increased water demand (Ackerman et al., 2014)Mixed evidence on sustainability outcomes and potential for scaling (Weidner et al., 2019)	*Medium* *Medium*	Positive economic impacts for urban farmers (Gasparatos, 2020)	*Medium* *Medium*	Improves quality of life, human well-being and health (Thomaier et al., 2015; Zasada et al., 2020)

Notes:

Effectiveness is examined through four framings: potential to reduce risk (e.g., reduced exposure to hazard); benefits to ecosystems (e.g., through improved ecosystem health, high biodiversity); economic benefits (e.g., improved incomes, fewer man-days lost, better livelihoods); and human well-being outcomes (e.g., health, quality of living). Blue shading denotes score on the effectiveness indicator: high effectiveness (dark blue), medium effectiveness (medium blue) or low effectiveness (light blue). White cells denote no assessment due to inadequate literature. Each cell also contains evidence (*Robust, Medium* or *Low*) and agreement (*High, Medium* or *Low*).

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