Chapter 10: Asia
Supplementary Material

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SM10.1 Detection and Attribution of Observed Changes in Asia

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

Detection: observed impacts	**Attribution: climatic impact-drivers**	**Geographic region, sub-region**	**Time period**	**Evidence**	**Agreement**	**Confidence**	**References**
Heat waves (urban)	T increase	India; Pakistan; Central Eastern China	1969–2005 (Ross et al., 2018) 1951−2015 (Misra et al. 2017) 1973–2012 (Mishra et al., 2015) 1948–2010 (Khan et al. 2018) 1961–2010 (Chen and Li, 2017)	*High*	*High*	*High*	(Ross et al., 2018)；Decadal surface temperature trends in India based on a new high-resolution data set (Mishra et al., 2018); An integrated assessment approach for estimating the economic impacts of climate change on River systems: An application to hydropower and fisheries in a Himalayan River`, (Mishra et al., 2015); Changes in observed climate extremes in global urban areas (Rohini et al., 2016); On the Variability and Increasing Trends of Heat Waves over India (Panda et al., 2017); Increasing heat waves and warm spells in India`, observed from a multi aspect framework (Chen and Li, 2017); An Inter-comparison of Three Heat Wave Types in China during 1961–2010: Observed Basic Features and Linear Trends
Urban drought	T and ET increase	South Asia	Multiple papers with multiple durations	*Low*	*Medium*	*Medium*	(Pervin et al., 2020); Adapting to urban flooding: a case of two cities in South Asia (Gu et al., 2015); Risks of exposure and vulnerability to natural hazards at the city level: A global overview. Population Division Technical Paper No. 2015/2. New York: United Nations Department of Economic and Social Affairs
Extreme rainfall events (in urban areas)	Precipitation increase	India, Philippines	1901–2010 1951–2010 (Cinco et al., 2014)	*Medium*	*Medium*	*Medium*	(Ali et al., 2014); Observed and projected urban extreme rainfall events in India

Coastal urban flooding	Precipitation increase, SLR	Across Asia, specifically SE Asia	Multiple papers with multiple durations	*High*	*High*	*High*	(Dulal, 2019); Cities in Asia: how are they adapting to climate change?
Flood induced damages	Annual P increase	Northwest China (Xinjiang)	1980–2001	*Low*	*Low*	*Low*	(Fengqing et al., 2005); Magnification of Flood Disasters and its Relation to Regional Precipitation and Local Human Activities since the 1980s in Xinjiang`, Northwestern China
Sea level rise (only for coastal cities)	T increase	Vietnam Bangladesh	1993-2014 1974-2004	*High*	*Medium*	*Medium*	(Brammer, 2014); (Hens et al., 2018) (Shahid et al., 2016); Climate variability and changes in the major cities of Bangladesh: observations`, possible impacts and adaptation
Permafrost thawing	T increase	North Asia	2007–2009	*Medium*	*High*	*Medium*	(Biskaborn et al., 2019); Permafrost is warming at a global scale (Shiklomanov et al., 2017b); Climate Change and Stability of Urban Infrastructure in Russian Permafrost Regions: Prognostic Assessment based on GCM Climate Projections (Shiklomanov et al., 2017a), Conquering the permafrost: urban infrastructure development in Norilsk`, Russia
Wildfire	Summer temperature and precipitation regime, droughts	North Asia	1970–1990	*Medium*	*Medium*	*Medium*	(Brazhnik et al., 2017); Simulating changes in fires and ecology of the 21st century Eurasian boreal forests of Siberia (Schaphoff et al., 2016)；Tamm Review: Observed and projected climate change impacts on Russia’s forests and its carbon balance
Biodiversity and habitat losses	Climate change and interaction with human disturbance	East Asia	1700-2000	*high*	*high*	*high*	(He et al., 2019); Moral hazard and adverse selection effects of cost-of-production crop insurance: evidence from the Philippines (Wan et al., 2019); Historical records reveal the distinctive associations of human disturbance and extreme climate change with local extinction of mammals
Primary production	ocean warming and stratification	Western Indian Ocean	1950-2012	*Low*	*Low*	*Low*	(Roxy et al., 2016); A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean

Urban Heat Island Effect (UHI)	T increase	South Asia (India, Pakistan, Sri Lanka), East Asia (Japan, Hong Kong in China, S Korea), South East Asia (Thailand, Indonesia, Philippines), North Asia (Russia)	Multiple papers with multiple durations	*High*	*Medium*	*Medium*	(Kotharkar et al., 2018); Urban Heat Island studies in South Asia: A critical review} (Choi et al., 2014); Assessment of Surface Urban Heat Islands over Three Megacities in East Asia Using Land Surface Temperature Data Retrieved from COMS (Estoque et al., 2017); Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia (Santamouris, 2015); Analysing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions (Li et al., 2018a); Comparative Analysis of Urban Heat Island Intensities in Chinese`, Russian`, and DPRK Regions across the Transnational Urban Agglomeration of the Tumen River in Northeast Asia (Ranagalage et al., 2017); An Urban Heat Island Study of the Colombo Metropolitan Area`, Sri Lanka`, Based on Landsat Data (1997–2017)} 2017 (Hong et al., 2019); Analysing 56 years (1962-2017) of UHI variation in Seoul, Korea, using surface observation, UHI is reinforced by heat waves.
Dust storms	T increase, P decrease	West Asia, Iran, Persian Gulf Countries	Multiple papers with multiple durations	*High*	*High*	*High*	(Alizadeh-Choobari et al., 2016); Temporal variations in the frequency and concentration of dust events over Iran based on surface observations (Nabavi et al., 2016); Climatology of dust distribution over West Asia from homogenised remote sensing data (Yu et al., 2015); Variability of Suitable Habitat of Western Winter-Spring Cohort for Neon Flying Squid in the Northwest Pacific under Anomalous Environments (Kelley et al., 2015); Climate change in the Fertile Crescent and implications of the recent Syrian drought

SM10.2 Sand and Dust Storms Occurrence Frequency

West Asia Region, especially 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 were recognised as dust source areas. Three clusters situated in Tigris–Euphrates plain were identified as severe Sand and Dust Storms (SDS) sources. Another cluster in 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 Caspian Sea deserts, south of Balkhash Lake, and Aral Sea region (Indoitu et al., 2012). Dust storm variability and trends in frequency on decadal timescales has been reviewed by Middleton (2019) in three dust belt settlements with more than fifty years 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 allocated 115 million euros from the National Development Fund (Iran) to fight sand and dust storms 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 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 sand and dust storm hotspots in the country and some are in a critical condition (Tajrishi, 2019). Sand and dust storms have been striking the southwestern province for over 10 years. The numbers of dusty days in southern province of Khuzestan have increased by day-and-a-half over a 30-year period per annum on average. The number of dusty days is different in different seasons, but on average over a 30-year period sand and dust storms hit the area 63 days annually (Sabzehzari, 2019). In Iran, five regions of frequent dust events are identified. In the order of importance, these areas are the Khuzestan Plain, the coastal plain of the Persian Gulf, west of 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 wind speed 10–14 m/s 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; the dust storms with meteorological visibility less than 50 m are considered as very severe regardless to duration and wind speed (Orlovsky et al., 2013). Deserts and semi-arid 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 there is a lack of evidence and agreement of a change in their frequency or intensity so far in general (WGI AR5).

SM10.2.1 Cause of Sand and Dust Storms

There are **three key factors** responsible for the generation of sand and dust storms – **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 natural processes (**precipitation totals, wind strength**) have had greater impact than human action, in the latter case both in the form of mismanagement (abandoned farmland, water management schemes) and attempts to reduce wind erosion (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 twenty-first century, along with an associated increase in the risk of drought and dust emissions (Middleton, 2019).

It seems that it is 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 climactic peaks, first between 1982 and 1990 and second between 2005 and 2008 periods. 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 Sand and Dust Storms harmfulness

According to EcoMENA sand and dust storms cause significant negative impacts on society, economy and environment at local, regional and global scale (EcoMENA, 2020). Sand and Dust Storm (SDS) have significant socio-economic impacts on human health, agriculture, industry, transportation, water and air quality

(UNCCD, 2019). Sand and dust storms erode top soils, blast crops and induce health, transportation, equipment 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's drought, many environmental crises caused by dust in Iran and Middle East. Dust in the vast areas of the provinces occurs with high frequency. By dust affecting many problems created in terms of health, social and economic (Keramat et al., 2011). The roles of climatic variables and human activities are assessed in each case, as drivers of periods of high dust storm frequency and subsequent declines in dust emissions (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 Observed and Adaptation

The seasonality of the numbers of dusty days (NDD) in Iran shows the highest frequency for summer followed by the spring and autumn seasons. 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 northwestern regions) and positive trend (across south and south eastern regions) in the annual and seasonal NDD time series (Modarres and Sadeghi, 2018). According to the statistical calculations, most storms occurred in the spring and summer. The lowest number of dust events occurred in the fall and winter particularly in December and January, when there are high possibilities of rainfall occurrence and dynamical 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 00UTC (3.30 am local times) (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, sand and dust storms 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 witnessed more frequent and intensified dust storms affecting Iran and Persian Gulf countries (Nabavi et al., 2016).

Sand and dust storm: In West Asia, the frequency of dust events has increased slightly in the some areas (east Saudi Arabia and southeast Iraq), and increased markedly in other emerging areas (northwest Iraq and east Syria) from 1980 to present (Nabavi et al., 2016). The marked dust increase during the first decade of the 21st Century has been associated 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 of the frequency of Iran's dust events in recent years, predominantly attributed to increasingly frequent dust outbreaks in Iraq due to human intervention (Alizadeh-Choobari et al., 2016). The northwest of Iraq and east of Syria are identified as emerging dusty areas, whereas east of Saudi Arabia and southeast of Iraq are identified as permanent dusty areas, including both dust sources and affected areas (Nabavi et al., 2016). Southwest of Iran and Persian Gulf countries were determined as main receptors of summertime dust storms in West Asia (Nabavi et al., 2016). Dust storms in central Iran are a natural hazard, and Tigris-Euphrates alluvial plain has been recognised as the main dust source in this area (Dastorani and Jafari, 2019). Results showed that there was a direct relationship between dust event and drought and years having intensive drought (Dastorani and Jafari, 2019). The most important point in a powerful dust storm brought winds to Tehran, which killed 5 and injured 82 people in the capital of Iran, 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 pillars approach: 1- Early warning systems; 2- Preparedness and resilience; 3- Anthropogenic source mitigation (UNCCD, 2019). As Iran reminded in COP14, the rich body of traditional and modern knowledge on SDS hot spots could help create a stronger knowledge base regional initiatives (UNCCD, 2019).

SM10.2.4 Projections

Compared to the period of 1980–2004, in the period of 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 days: precipitation <2mm, Tmax ≥30°C) as well as wet (for ≤3 days: total precipitation ≥110mm) conditions, and higher frequency of floods (Vaghefi et al., 2019).

SM10.2.5 Precipitation changes – region

The slope of precipitation, in West Asia region showed that during the period of 2016-2045 in January, February, July and August, precipitation would increase and decrease in other months of the year (Ahmadi et al., 2018). The Precipitation season in West Asia region with the Man-Kendall method also shows that the prevailing trend is decreasing throughout the year (Ahmadi et al., 2018). Precipitation depicts minor positive trends, except for spring when precipitation is decreasing (Haag et al., 2019).

SM10.2.6 Temperature changes – region

Temperatures in Central Asia have risen significantly within the last 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 uniform 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 to Agriculture and Food Systems in Asia based on post IPCC-AR5 Studies

Table SM10.2: Summary of observed and projected impacts of climate change to 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 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		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%)	National (North and South China)	Holst et al. (2013)
				Increase in total annual precipitation of 100 mm could increase grain output by 3.0% in North China but a reduction by 0.59% in South China (an overall increase in national grain output by 1.31%)		
	China	Crops		Increase in net crop revenue per hectare between 79 USD79 and USD207 for the 2050s and from USD140 to 355 USD for the 2080s	National with regional differentiation	Chen et al. (2013)
				Potential advantage for the development of Chinese agriculture for the provinces of the Northeast, Northwest and North regions		
				Increased precipitation can lead to a loss of net crop revenue per hectare, especially for the provinces of the Southwest, Northwest, North and Northeast regions		
	China	Crops		17% decrease in Northeast Region maize production by 2030 (from 624 million to 518 million bushels) with temperature increases of 1.32°C and 30% increase in precipitation from the 2008 levels	Subnational - Northeast and Southwest Regions of China	Li et al. (2014)
				22% increase in Southwest Maize production (from 216 million bushels to 263 million bushels) by 2030 considering the same temperature and precipitation scenarios		
	China	Crops		China's rice export will increase by 2.7% as rising rice exports to Republic of Korea overweight the export decrease to other countries, and import would decrease by 0.04%, which leads to a slight increase in rice self-sufficiency	National	Zhang et al. (2019)

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
	China	Crops		With RCP 4.5, the yield of 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.	China (6 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 RCP 8.5 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% (RCP 4.5) and 16.1% (RCP 8.5) in 2050; and 14.7% (RCP 4.5) and 23.6% (RCP 8.5) in 2080.	Republic of Korea (Central region)	Yoon and Choi (2020)
	Republic of Korea	Crops		Rice yield is expected to decrease by 15.85% (RCP 4.5) and 14.3% (RCP 8.5) in 2050; and 17.45% (RCP 4.5) and 17.1% (RCP 8.5) in 2080.	Republic of Korea (Southern region)	Yoon and Choi (2020)
South Asia	Pakistan	Crops	Farmers are experiencing changes in crop yields and crop diseases as a result of climate extremes particularly floods and droughts		Provincial (Khyber Pakhtunkhwa province)	Fahad and Wang (2018)
	Nepal	Crops	Loss of agricultural productivity brought about by climate change has adverse impact to 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 10 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, the region (state) and the 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 in India	Dubey and Sharma (2018)

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
	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 literature	Different parts of India	Balasubramanian et al. (2017)
	India	Crops		Reduction in maize yield by as much as 25%, 40 % and 70% under a rise of temperature by 1, 2 and 4°C , respectively although maize varieties that combined drought & heat tolerance have the potential to offset some of the negative impacts	Hyderabad, India	Tesfaye et al. (2018)
	India	Crops		Rice yields could potentially increase in the northern states but could decline by 5.0% in the 2030s, 14.5% in the 2050s, and 17.0% in the 2080s in the southern states.	National	Asian Development Bank (2014)
	India	Crops	45 improved varieties are adopted in India and that in each state high resistant and tolerant varieties are cultivated providing some degree of varietal resilience		Bihar, Gujarat, Karnataka, Punjab, Uttar Pradesh, and West Bengal, India	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 of Bangladesh)	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 CO_2 fertilisation	National	Asian Development Bank (2014)
	Bhutan	Crops		Rice yields could decrease by 6.7% in mid-latitude and 12.6% in low altitude by 2050.	National	Asian Development Bank (2014)
	Sri Lanka	Crops		Rice yields could decline by 3.6% to 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	South Asia	Cai et al. (2016)

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
				negatively affected, losing up to 5% of its rice output potential		
				Impact projections wheat production vary across the South Asian region with Bangladesh, India and Pakistan predicted to be the losers with a decline of 5% to 10% of their output potentials		
				Prospects for other regions are quite mixed, ranging from 7% gains to 5% losses, with large inter-annual variations		
Southeast Asia	Southeast Asian countries	Crops		Reduction on rice yields under climate change will be largest in Cambodia with a decrease of approximately 45% in the 2080s under RCP 8.5, 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 RCP 8.5 compared to a scenario without irrigation		
	Vietnam	Crops		Net household revenue is from agriculture is projected to decline at 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 (Northwestern Vietnam)	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, Vietnam	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) in the range of < 50kg/ha per decade (3% of actual average yields) with large variation in the impacts of climate trends on rice yields across the 10 provinces studied	Yield reduction *likely* to be more serious in the future if the observed trends of temperatures and precipitation continue	Subnational (Mun River Basin, Northeast Thailand)	Prabnakorn et al. (2018)

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
	Thailand	Crops		Potential reduction on the yield of Thai Jasmine rice by 14% and 10% under RCP4.5 and RCP8.5 scenarios, respectively, by 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 Thailand	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 of rice yield by −8.4%.		
	Thailand	Crops	The total yield losses due to past climate trends are rather low, in the range of b50 kg/ha 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; rice yield diminishes by 36 kg/ha for every 1% increase in the share of wet days.	National	Bordey et al. (2013)
Asia	29 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 US$92.6 billion 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 to US$195 billion 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 is predicted to be offset leading to a small gain of US$18 billion (+3%)		

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
				At 3.0 °C warming scenario with carbon fertilisation, a 12% loss in crop net revenue is predicted for Asia with an aggregate value of US$84 billion per year and with only Afghanistan, North Korea, Japan, and Tajikistan gaining in net revenue		
				In all scenarios, India is the overall loser which accounts for two thirds of the lost net revenue in Asia in both 1.5 °C and 3.0 °C warming scenarios without carbon fertilisation		
Central Asia	Afghanistan, Uzbekistan, Turkmenistan, Tajikistan	Crops	The advanced irrigation modes (e.g., sprinkle and drip) can improve irrigation efficiency and raise unit water benefit from 0.15 US$/m3 to 0.24 US$/m3. 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 farmer's livestock choice. Climate change would increase the probability of raising livestock. The total value of livestock owned per livestock farm will shrink 9%-10%	5 Countries in Southeast Asia	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)

Region	**Country**	**Agriculture Sector**	**Observed Impacts**	**Projected Impacts**	**Scale of analysis**	**Study**
South Asia	Nepal	Fisheries		Fishery suitability in the Trishuli River would be greater than 70% of optimal under both RCP 4.5 and RCP 8.5	Trishuli River, Nepal	Mishra et al. (2018)
South Asia	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, Bangladesh and West Bengal, India	Jahan et al. (2015)
East Asia	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 Japan Sea by 2030.	Korea Strait /the Tsushima Strait and the 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 that is c. 69%.		Philippines, Indonesia, and Lower Mekong, Vietnam	Amarasinghe and De Silva (2015)
South and Southeast Asia		Fisheries		Climate change is predicted to decrease fish productive potential in South and Southeast Asia by 2050	Global	Barange et al. (2014)
East Asia	China and 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 northern east China sea. Shift in water temperature and currents were also identified in the NECS in early 1990s			Jung and Cha (2013)

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
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	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 (AO) and East Asian monsoon (EAM) 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 changed rapidly relative to oceanic and atmospheric circulation.		Dalian, China and Funka Bay, Japan	Liu et al. (2014)
Southeast Asia	Vietnam	Aquaculture	Declined in the rice crops 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			Bhuiyan et al. (2018)

Region	Country	Agriculture Sector	Observed Impacts	Projected Impacts	Scale of analysis	Study
			specific factors affected the production of aquaculture in a panel of selected countries			

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	Floods	Drought, water scarcity	Extreme rain	Heat, UHI	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)		(Lelieveld et al., 2016) (Pal and Eltahir, 2016) (Tarawneh and Chowdhury, 2018) (Al-Bouwarthan et al., 2019) (Almazroui et al., 2014)	NA	NA	NE	NE	(Nahiduzzaman et al., 2015) (Rahman et al., 2016) (Ledraa and Al-Ghamdi, 2020)	(Howarth et al., 2020) (Pal and Eltahir, 2016)	(Al-Bouwarthan et al., 2019)

Guangzhou	NA	(Jevrejeva et al., 2016) (Huang et al., 2018) (Zhang et al., 2017) (Abadie et al., 2020) (Hallegatte et al., 2013) (Francesch-Huidobro et al., 2017)	(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)	(Zhu et al., 2019) (Sajjad et al., 2018) (Meng et al., 2011)	(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)	(Yuan et al., 2017b) (Xian et al., 2018) (Yu et al., 2018) (Yan et al., 2016) (Yin et al., 2020)	(Xian et al., 2018) (Chen 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)

Ahmedabad	NA		(Aartsen et al., 2018)		(Knowlton et al., 2014) (Ahmedabad Municipal, 2018) (Azhar et al., 2014) (Kakkad et al., 2014) (Vyas et al., 2014) (Aartsen et al., 2018) (Wang et al., 2019)	NA	NA	(Ahmedabad Municipal, 2018) (Aartsen et al., 2018) (Vellingiri et al., 2020)	(Mell, 2018)	(Knowlton et al., 2014) (Ahmedabad Municipal, 2018) (Aartsen et al., 2018) (Vellingiri et al., 2020)	(Knowlton et al., 2014) (Ahmedabad Municipal, 2018) (Kakkad et al., 2014) (Aartsen et al., 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) (Dulal, 2019) (Singh and Kambekar, 2017) (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)	(Hoque et al., 2018) (Hoque et al., 2019) (Dastagir, 2015) (Filho 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) (Zinia and McShane, 2018) (Ahmed et al., 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	
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) (Takagi et al., 2016) (Gu et al., 2015) (Muis et al., 2015) (Jan van Oldenborgh et al., 2015)	(Siswanto et al., 2016)	(Liu et al., 2015)	(Estoque et al., 2017) (Darmanto et al., 2019)	NA	(Takagi et al., 2016)	(Ward et al., 2013; Marfai et al., 2015) (Budiyono et al., 2017) (Georgeson et al., 2016) (Esteban et al., 2017) (Takagi et al., 2016) (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) (Garschagen et al., 2018) (Salim et al., 2019)

Ho Chi Minh City	NA	(Ho et al., 2014) (Scussolini et al., 2017) (Lasage et al., 2014) (Phi et al., 2015) (Bangalore et al., 2016) (Khoi and Trang, 2016) (Downes et al., 2016) (Vachaud et al., 2019)		(Khoi and Trang, 2016) (Phuong et al., 2019) (Vachaud et al., 2019)	(Doan et al., 2016)	NE	(VCAPS, 2013) (Scussolini et al., 2017) (Lasage et al., 2014) (Minh et al., 2015) (Downes et al., 2016) (Leitold and Diez, 2019) (Vachaud et al., 2019)	(VCAPS, 2013) (Lasage et al., 2014) (Al, 2018) (Scussolini et al., 2017) (Phi et al., 2015) (Hinkel et al., 2018)	(VCAPS, 2013)	(VCAPS, 2013) (Lasage et al., 2014) (Ho et al., 2014) (Hinkel et al., 2018) (Bangalore et al., 2016) (Al, 2018)	(Bangalore et al., 2016)	

SM10.5 Evidence on Effectiveness of Ecosystem-based Adaptation 'EbA' using Four Commonly used EbA Options

See Figure 10.10 for final assessment.

Table SM10.4: Evidence on effectiveness of ecosystem-based adaptation using four commonly used EbA options. Effectiveness is examined through four framings: potential to reduce risk (e.g., reduced exposure to hazard; reduced risk); benefits to ecosystems (through improved ecosystem health, high biodiversity); economic benefits (e.g., improved incomes, fewer man-days lost, better livelihoods); and human wellbeing outcomes (e.g., health, quality of living etc.). Blue shading denotes high score on effectiveness indicator (dark blue); medium effectiveness (medium shading); and low effectiveness (light blue shading). White cells denote no assessment due to inadequate literature. Each cell also has evidence (robust/medium/low) and agreement mentioned (high/medium/low).

Risk	EbA option	Risk reduction potential	Ecosystem benefits	Economic/livelihood benefits	Human wellbeing benefits

Extreme heat, urban heat island effects	Urban parks and green spaces	Robust Medium	Reduces UHI, provide thermal comfort (Zhang et al., 2014; Jim, 2015; Koc et al., 2018; Aram et al., 2019; Lai et al., 2019) Increasing urban green cover is more effective than increasing urban albedo (i.e. building reflectivity through cool roofs, green facades) to mitigate UHI, improve urban microclimates (Yuan et al., 2017a) Too much UGC can reduce ventilation, trapping heat and leading to temperature increases (Yuan et al., 2017a)	Medium Medium	Air quality regulation was valued between \$0.12 and \$0.6/m2 tree cover/year (Wang et al., 2014)	Medium Medium	Adjoining vegetation and green roofs provide energy savings of up to almost \$250/tree/year, noise regulation and aesthetic appreciation of \$20 and \$25/person/year, respectively (Wang et al., 2014) Proximity to urban parks can increase property rates(Wu et al., 2015)	High 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 management	Robust Medium	Effectively mitigate 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 goals Promotes tourism through reduced risk, improved urban landscape (Huang et al., 2020)	NE	Global systematic review found no studies assessing wellbeing and health impacts (Venkataramanan et al., 2019)

Sea Level Rise	Mangrove restoration	Medium Medium	31% wave reduction; provide 50% protection from storms (Ferrario et al., 2014; Narayan et al., 2016)	Medium Medium	Contribute to local biodiversity (flora and fauna) and sustain 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 benefits, provides ecosystems that have socio-cultural value
Food insecurity	Urban agriculture (UA)	Medium Low	Globally estimated to potentially produce 100–180 million tonnes food annually, avoid storm water runoff between 45 and 57 billion cubic meters 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, 1 billion kWh in India (Clinton et al., 2018) Improves local biodiversity, uptake of sustainable agriculture practices, 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 to fertiliser use, polluted runoff, 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 wellbeing and health (Thomaier et al., 2015; Zasada et al., 2020)

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