HI-AWARE
Himalayan Adaptation, Water and Resilience Research

CARIAA
Collaborative Adaptation Research Initiative in Africa and Asia

Literature Review of Critical Climate-Stress Moments in the Hindu Kush Himalaya

A Resource Kit

Consortium members

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About HI-AWARE

This resource kit was produced by the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development and the International Development Research Centre, Ottawa, Canada. CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The programme supports collaborative research to inform adaptation policy and practice.

HI-AWARE aims to enhance the adaptive capacities and climate resilience of the poor and vulnerable women, men, and children living in the mountains and flood plains of the Indus, Ganges, and Brahmaputra river basins. It seeks to do this through the development of robust evidence to inform people-centred and gender-inclusive climate change adaptation policies and practices for improving livelihoods.

The HI-AWARE consortium is led by the International Centre for Integrated Mountain Development (ICIMOD). The other consortium members are the Bangladesh Centre for Advanced Studies (BCAS), The Energy and Resources Institute (TERI), the Climate Change, Alternative Energy, and Water Resources Institute of the Pakistan Agricultural Research Council (CAEWRI-PARC) and Wageningen Environmental Research (Alterra). For more details see www.hi-aware.org.

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Literature Review of Critical Climate-Stress Moments in the Hindu Kush Himalaya

A Resource Kit

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Contents

1 Introduction

1. Introduction

This resource kit presents a compilation of information on critical climate-stress moments in the Hindu Kush Himalaya (HKH) region. The information is based on a literature review on critical-climate stress moments in agriculture and health due to heat stress and discusses critical moments emerging from downstream and upstream floods. The literature study was carried out by the Himalayan Adaptation, Water and Resilience (HI-AWARE) research project under the Collaborative Adaptation Research Initiative in Africa and Asia with financial support from the UK Government's Department for International Development and the International Development Research Centre, Ottawa, Canada.

Critical climate-stress moments' is a concept elaborated in Research Component (RC) 4 of HI-AWARE. 'Critical climate-stress moments' (hereafter referred to as critical moments) are defined as those moments when households, communities, and the livelihood systems they depend on, are especially vulnerable to climate and weather-related risks and hazards (Groot et al., 2017)[1]. These risks and hazards may include heat waves, cold spells, floods, droughts, riverbank-erosion, and hail storms. Critical moments are a combination of context-specific socio-economic and biophysical conditions, in which climate-stresses are particularly likely to be risky and adverse to a particular household or community and the system they depend on. A 'moment' may be days, weeks or even months, depending on the driver.

The HI-AWARE consortium aims to increase understanding about critical moments of households in terms of timing and context-specific climatic, socio-economic, and biophysical causes. Insights into critical moments will be used to tailor climate modelling and scenarios and will support the identification and prioritisation of adaptation strategies that target the most vulnerable moments. The critical moment assessment methodology is likely to add value to the existing family of vulnerability assessments because of its potential to deepen understanding of the complex interaction of climate, biophysical and socio-economic drivers resulting in critical moments, the impact of these stresses on people's livelihood and its promise to develop tailored adaptation strategies.

The literature review on critical moments serves two purposes:

1. To support the critical moment assessment in the field: Insight into possible critical moments will help to sharpen discussions with community members and other stakeholders on critical moments in different domains; and

2. To contribute to a (peer reviewed) paper on critical moments: Findings from HI-AWARE field studies on critical moments will be positioned and discussed in a broader scientific context.

The resource kit compiles information on:

- Potential critical moments caused by upstream floods in the Indus, Ganges, Gandaki and Teesta river basins;
- Potential critical moments caused by downstream floods in the Indus river basin, and Ganges, Brahmaputra, and Meghna river basin;
- Potential critical moments in agriculture at household level; and
- Potential critical moments for heat stress and health at household level.

We use the term potential critical moments as the literature review did not elaborate on the socio-economic and biophysical conditions of households and communities. Following the definition of critical moments, it is the

[1]Groot, A., Werners, S., Regmi, B., Biemans, H., Gioli, G., Hassan, T., Mamnun, N., Shah, S., Ahmad, B., Siderius, C., Singh, T., Bhadwal, S., Wester, P. (2017). Critical climate-stress moments and their assessment in the Hindu Kush Himalaya: Conceptualization and assessment methods. HI-AWARE Working Paper 10. Kathmandu: HI-AWARE

combination of socio-economic and biophysical conditions, and climatic and weather-related hazards that give rise to critical moments. Interviews with community members and other stakeholders will highlight if potential critical moments are perceived as critical moments.

The literature review was based on peer reviewed articles, project reports and policy papers discussing issues related to critical moments in the HI-AWARE study basins. Only if considered relevant, the information on critical moments focusses on a wider scale.

This resource kit is organised as follows: Chapter 2 presents the literature review on agriculture. Chapter 3 summarizes critical moments caused by upstream floods in the Indus, Ganges, Gandaki and Teesta river basins while Chapter 4 describes the review results for downstream floods in the South Asian Hindu Kush Himalayan river basins. Finally, Chapter 5 shows the results of the literature review on critical moments in health due to heat stress.

2

Critical Moments in Agriculture

2. Critical Moments in Agriculture

2.1. Introduction: Climate Change and Agriculture[2]

South Asia being one of the most densely populated geographical areas, consists of about 1.5 billion people of which one third live in extreme poverty. More than 70% of the population lives in the rural areas and agriculture is the principle occupation of the region (Ahmed and Suphachalasai, 2014). The agricultural sector plays an important role in the development of South Asia and employs 47% of the labour force as average in Bangladesh (47%), India (47%), Nepal (69%) and Pakistan (42%) (CIA, 2017). Even though agriculture is continuing to grow, but in relative importance it is declining in terms of input in GDP and share in labor force. There are various factors which drive and shape the agricultural sector. Ranging from management practices, technology availability, land-use regulations, biophysical characteristics to national and international agricultural policies and market fluctuation. Apart from these factors the integral link of agricultural to natural resources make climatic condition a key factor to control it (Sivakumar and Stefanski 2011). Climate change is a global phenomenon and a challenge that poses wider impact on the world. However, it will not affect all countries equally. Developing countries and especially the poor communities are more vulnerable to climate change. South Asia is considered to be the most disaster-prone region in the world and consequentially at high risk due to climate change. In spite, the global average temperature is increasing; IPCC foresees that there would be both increase and decrease in temperature and precipitation in different regions of the world. These weather changes will have both direct and indirect (negative and positive) impact on agriculture, health, water, biodiversity, and socio-economic sectors. Moreover, the variability in the inter-annual and inter-seasonal is expected with the rainfall becoming more erratic (Parry et al., 2007).

Agriculture is considered to be the most vulnerable sector to be affected by climate variability and change (Mahmood et al., 2012). Small land holders and farmers in developing countries have great dependence on natural weather conditions for their agricultural activities. They have to cope with fluctuations and changes which occur from one year to the next because of climate variability and with long-term trends such as trends towards progressively warmer and drier weather conditions (Helvetas, 2015). Climate change has a negative effect of the production rate of the crops in like maize, wheat and rice in tropical and temperate zones, with proper `adaptation measures (Helvetas, 2015). The factors of climate change which affect the agricultural productivity include temperature, rainfall pattern, and change in sowing and harvesting dates, land suitability, evapotranspiration and water availability (Harry et al., 1993). The increased concentration of CO_2 which is used as in indicator in different research projects, causes an increase in the photosynthesis but increased temperature can result in lower productivity (IPCC, 2007). Increased temperatures have a beneficial effect on agricultural productivity at higher altitudes by allowing earlier planting of crops in spring, faster maturation and earlier harvesting in Himalayan region (Rosenzweig and Hillel, 1995). Some regions may have more intense heat waves or persistent dry spells will impair agricultural productivity causing thermal stress during the critical crop growth stages (Rounsevell et al., 1999; as cited in IPCC, 2001). Considering the already existing water shortages and temperature extremes, the dry lands of South Asia which include both arid and semi-region are most vulnerable to the climatic variation (CGIAR, 2005; Parry et al., 1988). The rate of growth of crops has already been affected by limited water availability (Funk and Brown, 2009; Molden, 2007). Since mid-1990s a slowdown in the growth rate of yield has been seen in large parts of dry tropics particularly in Indian Subcontinent (Milesi et al., 2010). Rise in temperature affects the physiological processes like pollination, basic photosynthesis and grain filling in many crops. Extreme heat stress even for a short period of time to high temperature lasting for several days can have negative impact on these processes (Doreen Stabinsky, 2014). Measurement of accurate impact of climate change on economy of these countries is difficult to access due to several challenges. Cline (2007) estimated the broad impact of climate change on agricultural production in South Asian countries using different approaches as mentioned (Table 2.1).

[2]Bashir Ahmad , Sultan Ishaq, Nelufar Raza, Masooma Hassan (PARC)

Table 2.1: Estimates of climate change impact on agricultural production by 2080 (Cline, 2007).

Country	Farm area	Output per Hectare (US$)	Output (US$mil)	%Change (Ricardian)	%Change (crop models)
Afghanistan	7,827	313	2,448	-9.5	-32.1
Bangladesh	8,429	1,355	11,421	-14.3	-25.3
India	170,115	777	132,140	-49.2	-27.0
Nepal	3,294	728	2,399	-0.9	-25.3
Pakistan	22,120	856	18,935	-17.9	-36.6
Sri Lanka	1,916	1,808	3,465	-9.5	-25.3

It has been noted by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report that, the average annual temperatures could rise by more than 2° C by the mid-21st century as compared to the 20th century. It was also anticipated that the temperature will rise more in high altitude areas which host valley glaciers and fragile ecosystems (IPCC, 2014). Huge populations in Asia currently occupy rain-fed land. Cultivation of staple foods like maize, wheat and rice in the past few years has gone down due to increasing water stress which ultimately arises due to rise of temperature (UNFCCC, 2007). Studies show that climate change impacts in South Asia are more devastating and it may case reduction in 50% wheat productivity by 2050 (MoE, 2009 as cited in Shakoor et al., 2011). Table 2.2 shows statistics of basic information, agricultural area and contribution of agriculture in the GDP of South Asian countries (Lal et al., 2011).

Table 2.2: Statistics of South Asian countries of year 2008 (Lal et al., 2011)

Country	Area (km²)	Population (millions)	Arable land (%)	GDP growth rate %	Agric. contribution to GDP (%)
Afghanistan	652,230	28.40	12.13	3.4	31.0
Bangladesh	143,998	156.05	55.39	4.9	19.1
Bhutan	38,394	0.69	2.3	21.4	22.3
India	3,287,263	1,166.08	48.83	7.4	17.6
The Maldives	298	0.40	13.33	5.7	7.0
Nepal	147,181	28.57	16.07	4.7	32.5
Pakistan	796,095	176.24	24.44	2.7	20.4
Sri Lanka	65,610	21.32	13.96	6.0	13.4

2.2. Critical Moments in Crop Agriculture in Pakistan[3]

2.2.1. Introduction

The effects of climate change have become explicitly apparent from last few decades (Patt and Schröter, 2008) and Pakistan is considered as one of the most susceptible countries to climate change (Schilling et al., 2013). Agriculture is an economic activity for livelihood development and highly dependent on climatic pattern. In Pakistan this sector is more vulnerable to climate change which becomes a great threat to agrarian economy of the country (Shakoor et al., 2011). According to the global long-term climate risk index developed by Germanwatch (see (https://germanwatch.org/en/download/16411.pdf), Pakistan ranks 7th globally (2017) of the countries most affected by

[3]Sultan Ishaq, Bashir Ahmad, Nelufar Raza, Masooma Hassan, Pakistan Agricultural Research Council (PARC)

climatic/natural hazards, with an average annual loss of about 3.8 billion USD-PPP (0.65% of GDP), which ranked as the 2nd most financially affected countries in the world (first is Thailand with 7.6 billion USD-PPP) due to climate change (Kreft et al., 2017). Pakistan is an agriculture dependent country, having 21% of total GDP depending on agriculture sector. Country's 47% of population and their livelihood is dependent on agriculture (Shakoor et al., 2011). Due to lack of financial resource and least adaptive capacity the livelihoods in Pakistan are highly vulnerable to climatic variability (Abid et al., 2015; Adger et al., 2005; Wandel and Smit, 2000).

2.2.2. Critical Moments in Crops

The agriculture sector's susceptibility to climate change, means that it is likely to be hit the hardest due to climatechange impacts. Although extensive research is being conducted throughout the world on climate change,

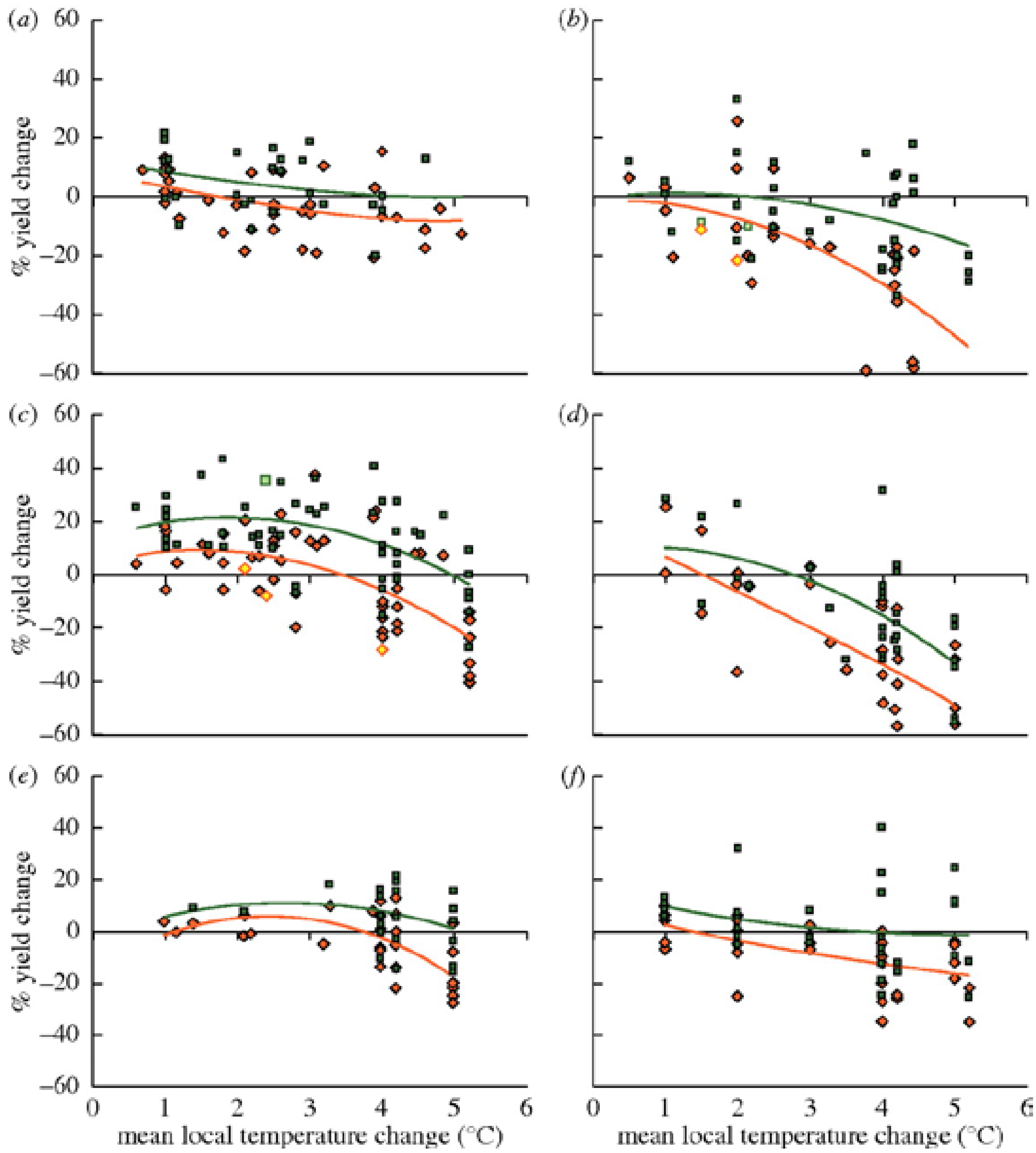

Figure 2.1: Change in crop yield in response to temperature change. It shows the sensitivity of cereal (a,b) maize (mid- to high-latitude and low-latitude), (c,d) wheat (mid- to high-latitude and low-latitude) and (e,f) rice (mid- to high-latitude) to climate change as determined from the results of 69 studies, against temperature change. Results with (green), and without (red) adaptation are shown. Adapted from Easterling et al., (2007), Source: Gornall et al., 2010.

there remains significant ambiguity in the nature and timing of climate effects on agriculture, as well as the associated impacts of these effects on human livelihoods around the world (Easterling et al., 2007; Schmidhuber and Tubiello, 2007).

According to Gornall et al. (2010) different crops have different sensitivities towards climate change. However, it is quite imperative to identify the major uncertainties in crop productivity changes for a given level of warming. It was found in the mid-latitudes (Rawalpindi) that a 2°C rise in local warming would increase wheat productivity nearly by 10 % however at low-altitude (Chaj Doab) the same amount of warming may reduce yields by nearly the same amount (Figure 2.1). A research conducted by Abid et al. (2016) on farm-based vulnerability in Punjab province of Pakistan identified different climate extreme events throughout the region. The farm based climate-related risks identified by farmers included livestock diseases, pest attacks, human diseases and crop attack.

In Punjab erratic rainfall and temperature fluctuation has greatly affected the productivity of staple crops such as wheat, rice and maize. For example, in the summer, extreme maximum temperature can cause heat stress in rice during its flowering time which may lead to a reduction in pollination and grain numbers (Rasul et al., 2011). Similarly, extreme minimum temperatures during the night time effect the respiration rates of plants and reduces the biomass accumulation during the growth stage of rice (Hatfield and Prueger, 2015).

Farm Level Vulnerability

Productivity is also impacted by heavy rainfall. Heavy rainfall events cause flash floods which can inundate and wipe out entire fields with standing crops, and also cause anaerobicity, soil water logging, and reduced plant growth rate (Falloon and Betts, 2010; as cited in Gornall et al., 2010) period. A recent study on climate variability and farm-level risk perception in four major districts of the Punjab province in Pakistan, has found a range of risks and extremes present throughout the year (Abid et. al, 2016). Overall risks include, uncertain or reduced crop productivity, change in cropping calendar and water shortage were among the adverse impacts due to climate-related risks on other hand better yield production was stated as the only positive effect of climate change in some

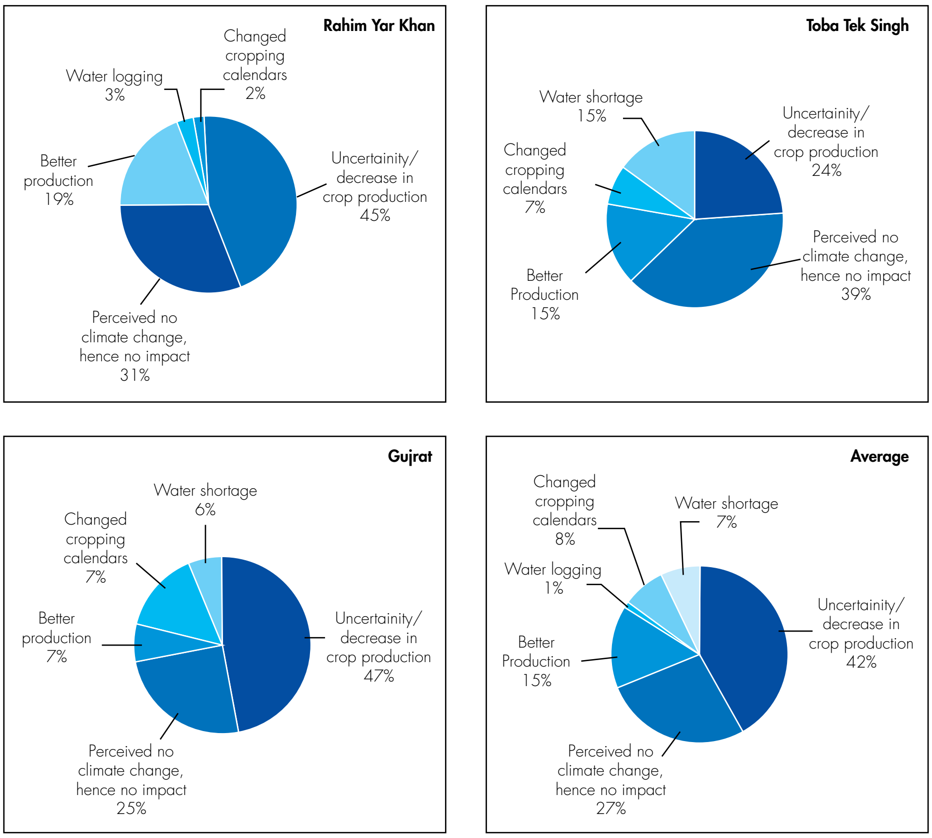

Figure 2.2: Farmer perceived climate related extreme events in the Punjab, Pakistan. Source: Abid et al., 2016

regions. The Figure 2.2 shows the farm-level response. Many other research based studies also support the Abid et al. (2016) findings and reported a significant decline and variation in the productivity of major crops such as maize, wheat, sugarcane, rice and cotton in Pakistan (Ahmad et al., 2013; Baig and Amjad, 2014; Tingju et al., 2014).

Critical Moments in Major (staple) Crops

Research has identified that short-term temperature fluctuations and extremes can be critical, especially if they correspond with key stages of crop development. Temperature higher than 32°C during the flowering stages of many crops can directly alter and reduce the productivity (Wheeler et al., 2000). It has been reported that, even small change in annual rainfall and year to year variability and extreme weather events can alter the crop productivity (Kumar et al. 2004; Sivakumar et al. 2005).

Climate and daily weather patterns are two main key factors that influence agricultural yield. Taking an example, back in 1987 due to weak monsoon rains in Pakistan, Bangladesh and India caused large shortfalls in crop productivity and ultimately contributing reversion to wheat importation by India and Pakistan (World Food Institute, 1988). In Pakistan there are two major seasons for crop production namely kharif from May to November and rabi from November to April. The kharif crops include rice, corn and cotton while rabi or winter crops include wheat, barley and millet (USDA, 2009).

Farmers in Pakistan perceive changes in the climate in terms of a shift in seasons, variability in rainfall resulting in floods and droughts and changes in incidences and frequency of snow fall, frost, fogs, heat, wind and hailstorms (Ahmad et al., 2013). For example, rice–wheat cropping system is adversely affected by windstorms induced by temperature changes (Wassmann et al., 2009). Specifically, during the latter part of crop production in September and October, storms lead to rice crop lodging. This does not only reduce yield but also increases harvesting cost. During harvesting time in October farmers feel particularly insecure, at risk and vulnerable due to a combination of factors including the high likelihood of storms occurring, high sunk costs and the severe impact on yield potentially leading to a significant reduction in income. Crop varieties less sensitive to crop lodging would increase their resilience to climate changes during one of the most vulnerable times of the year.

Rice

Climate is one of the most vital inputs for agriculture productivity all over the world. Studies show that decrease in rainfall may reduce the wheat yield in Turkey (Kayam et al., 2000) whereas an increase in rainfall and temperature have been found to be negatively corelated with rice productivity (Saseendran et al., 2000). Rice is produced in a varied range of different locations under different climatic variations ranging from the driest deserts to the wettest areas in the world. In Asia many small farmers and their families are dependent on rice production, as are millions of landless workers (Mohanty et al., 2013). Temperatures beyond critical thresholds for rice production not only reduces its growth duration but also increases the spikelet sterility, enhances respiratory losses and reduces grain-filling duration. This ultimately results in reduction in yield and also lower quality rice grain (Fitzgerald and Resurreccion, 2009; Kim et al., 2011).

According to Peng et al. (2004), a 1°C rise in the mean minimum temperature could possibly led to a decline by 10% of rice productivity in the dry season in Pakistan. Research shows that the reproductive stages in many crops are relatively more sensitive towards heat stress than the vegetative stage (Hall, 1992). Rice crop is more tolerant to high temperature during its vegetative phase while during its flowering stage, it is more vulnerable to rise in temperature beyond its threshold limit (Jagadish et al 2010). It has been observed that with every increase of 1°C above 24°C during the critical temperature stage, leads to a reduction in 10% of both yield and biomass (Peng et al., 2004; Welch et al., 2010; as cited in Mohanty et al., 2013). According to Mahmood et al. (2012), the t-values for average maximum and minimum temperature during the months of September and October and average maximum temperature during the months of July and August in related to their p-values illustrate that these three temperatures variables are statistically significant and showing high contribution of temperature in rice productivity in the rice wheat cropping zone of Punjab province of Pakistan. In Bangladesh, Sarker et al., 2012, have also found significant climatic variables impact on rice production. The results of Mahmood et al., 2012, shows that, increase in rainfall during the months from September to October is significantly and negatively related with rice productivity. The scenario developed for the rainfall shows that, yield and biomass (Peng et al., 2004; Welch et al., 2010; as cited in Mohanty et al., 2013). According to Mahmood et al. (2012), Prolong and in-depth future research is necessary for explicit research on rice response towards climate change scenarios, for future adaptations. Rice is a salt-sensitive crop with its threshold electrical conductivity up to 3 dS/m (Maas and Hoffman, 1977). As an indirect effect of increased temperature due to climate change and rise in sea-level could affect the coastal wetlands through inundation and salinity in the next 50 to 100 years (Allen et al., 1996). Accompanying the rise in temperature and salinity, drought is another factor affecting the rice productivity. Many rain-fed regions are already facing drought due to climatic variability and are anticipated to experience more frequent drought in the future (Bouman et al., 2001).

Shah et al., (2011) studied impacts of high-temperature stress on rice plant and its traits related to tolerance. The anticipated increase in global temperature i.e., 2 - 4°C by the end of the 21st century poses a threat to rice production. The impact of high temperatures at night is more destructive than day time or mean daily temperature. It was found that booting and flowering stages are most sensitive to high temperature, which may sometimes lead to complete unproductiveness. The study also concluded that responses to temperature stress vary widely among rice germ plasms.

Wheat

Wheat is one of the major food crops in Pakistan. Usually big landholders and small farmers sow wheat in winter season in the months of November and December and harvest it in summer. Farmers cultivate wheat in cold season because, cold temperature increases wheat growth processes while high temperature can cause a delay in the growth of seedlings (Tariq et al., 2014). It was noticed that erratic rainfall can damage wheat productivity during the time of harvesting which directly may lead to food insecurity in Pakistan (Janjua et al., 2010). Research by GFSI (2012) shows that severe weather patterns in Pakistan have badly affected the supplies of agriculture productivity, mainly staple food crops, therefore, food security will be threatened in the coming years as well. Studies show that wheat production in the country has declined in recent years (FAO, 2012; GOP, 2011). It has been observed that the regions having large wheat production, will be adversely impacted by climate change due to increasing in temperatures (Tobey et al., 1992). Studies shows that maturity period of wheat and its yield may decrease by 8% and 6% respectively, due to a 1°C increase in the average temperature (Saseendran et al., 2000). However Xiao et al. (2008) and Ye et al. (2014) found that, increase in temperature and precipitation in the high altitude areas has a positive trend on crop productivity. According to Tariq at al. (2014), mean minimum temperature in November has negative effect on productivity of wheat crop because it requires moderately high temperature at the time of sowing in Punjab. Their results further indicate that, mean maximum temperature during the month of January negatively impacts vegetative growth of wheat in rain-fed areas. Similarly rainfall in February negativly affects wheat production. On the bases of population and climate scenarios, the results further reveal that per capita availability of wheat in the Punjab province would decline for upcoming years. This change demands to develop wheat varieties which are more resilient and have adaptive capacity in climate variability. According to Sivakumar and Stefanski (2011), an increase of 1°C in temperature would decrease wheat productivity by 5 – 7% in Pakistan, while some other studies reveals 40 % decline in wheat productivity by 2035 (Leads 2009).

2.2.3 Summary of Potential Critical Moments in Agriculture in Pakistan

Table 2.3 summarizes the potential critical moments in the agricultural sector in Pakistan. We use the term potential critical moments as the literature review did not elaborate on the socio-economic and biophysical conditions of households and communities which may turn the climate and weather related risks into critical moments.

Table 2.3: Summary table potential critical moments in agricululral sector in Pakistan

Crops	Critical moment(s) incl. crop stage/ management practice	Climate related stress factor leading to risk	Threshold (temperature, hydraulical)	Adaption strategy/ coping strategy in place to address CMs?	Any specific information available for specific research areas	Literature reference
Multiple crops	Flowering stage	Temperature higher than 32°C during the flowing stages can directly alter and reduce productivity (Wheeler et al. 2000)	>32°C			
Rice (in rice-wheat systems) Rice	Booting and flowering time	Extreme maximum temperature can cause heat stress in rice during its flowering time with reduction in pollination and grain numbers. Storms causes rice crop lodging and biomass reduction Extreme minimum temperature respiration rates of plant during night time reduce biomass accumulation	Temperature greater than 35°C cause florte sterility and anther dehiscence	Adjust planting date, change crop rotation and use varieties with shorter maturity and low logging sensitivity	Increase in 1°C critical temperature above > 24°C leads to a reduction in 10% of both grain yield and biomass (Peng et al., 2004; Welch et a.,l 2010, Mahmood et al., 2012) The impact of high temperatures at night is more destructive than day time or mean daily temperatureTemp stress may sometimes lead to complete unproductiveness (Shah et al., 2011) Rice productivity would decline by 5.71% and 15.26% if rainfall will increase by 5% and 15%, respectively (Maas and Hoffman, 1977)	
	Harvesting (Sept.-Oct.)	Storms lead to water logging			Reduction in yield and increased harvesting costs leading to a significant reduction of income	
Wheat (in rice –wheat systems)	Harvest stage (Sept-Oct)	Erratic rainfall affects productivity during harvesting	25°C	Develop varieties which are more resilient and have adaptive capacity.	Erratic rainfall during the time of harvesting can lead to increase the food security in Pakistan (Janjua et al., 2010).	

	Vegetative stage and maturity stage	Increase in temperature of 1°C			Increase in temperature of 1°C lead to decline 5-7 % up to 40% decline in wheat productivity by 2035 (Leads, 2009)	Tariq et al. (2014)
Groundnuts	Sowing - germination	Low temperature at sowing stage increases chances of seed borne diseases besides low germination rate	25-30°C		Minimum rainfall and long term prevailing dry spells are considered as the major factors in lower and average yield of groundnut in Asia (Sherdil et al., 2012)	
Maize	Germination	Delayed monsoon Extremely high temperature and low humidity results in poor grain formation. Adequate rainfall is very important during germination and the first month of the growth (Rashid and Rasul, 2011)	10-27°C	Improving physical and chemical conditions of the soil reduces water runoff, improves rain infiltration and nutrient availability.		

2.2.4 References Critical Moments in Agricultural Sector in Pakistan

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2.3. Critical Moments Faced in Agricultural Sector in Bangladesh with Special Focus in Teesta Floodplains[4]

2.3.1. Introduction

Agriculture sector plays a vital role in economic development of Bangladesh in terms of GDP contribution (15% in 2016) and labour force engaged (47% in 2010) (CIA, 2017). According to Banglapedia (2015b), crops which are grown on ≥1% of the gross-cropped area (GCA) of a country are called major crops. In Bangladesh, only ten crops - rice (74%), wheat (4.5%), jute (3.9%), rape and mustard (3.1%), vegetables and spices (1.6%), lentil (1.5%), chickling vetch (1.3%), potato (1.1%), sugarcane (1.1%), and chilli (1.1%) are grown on ≥1% of the crop area (14.6 million ha) and may hereafter be considered as major crops. Among minor crops, gram (0.8%), millets and maize (0.6%), onion (0.6%), black gram (0.5%), sweet potato (0.5%), groundnut (0.4%), tea (0.4%), green pea (0.4%), sesame (0.3%), linseed (0.3%), garlic (0.2%), pea (0.1%), and barley (0.1%) are important (Banglapedia, 2015b). In Bangladesh, a major portion of farmers live on their own production which is termed as subsistence agriculture. Among major crops, rice, potato, maize, and wheat are major food crops for food security (subsistence agriculture); while sugarcane, mango and other tropical fruits, jute, vegetables, and pumpkin are major cash crops of Bangladesh (FAO, 2013a). Bangladesh ranks among the top producers of jute (2nd), rice (4th), tropical fruit (6th), and potato (7th) in the world (FAO, 2013b).

Critical climate stress moments (hereafter referred to as critical moments) may be defined as those moments when households, communities, and the livelihood systems they depend on, are especially vulnerable to climate and weather-related risks and hazards (Groot et al., 2017). Agricultural development has an overwhelming impact on major macroeconomic activities like employment generation, poverty alleviation, and food security. However, climatic extreme events such as flash and seasonal floods, drought, cyclones and storm surges, heat and cold waves, thunderstorm and hailstorms, salinity intrusion, and tornadoes have devastating impacts on agriculture sector in different parts of Bangladesh. This literature review aimed at evaluating the critical moments of major crops of Bangladesh with a special focus on the Teesta floodplains where floods and droughts both are recurrent phenomena every year. The climate change adaptation strategies in agriculture sector have also been reviewed in the study.

Geographically, Bangladesh is divided into three regions: fertile low lying Ganges-Brahmaputra-Meghna delta; Barind and Madhupur plateaus in northwest and central parts; and evergreen hill ranges in northeast and southeast

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parts (12% of country). Teesta is one of the major tributaries of the Brahmaputra River comprising five districts namely Nilphamari, Rangpur, Gaibandha, Kurigram and Lalmonirhat in the northwestern part of Bangladesh. For the Teesta basin that lies within Bangladesh, 69% of the population is directly or indirectly involved with agriculture while 11% of the total population (13.85 million) depends on business (BBS-GOB, 2014). Average cropping intensity in Rangpur and Dinajpur in Teesta basin is 214 and 221% in 2014-15, respectively, while the country average is 192% (BBS-GOB, 2016). Major crops of Teesta floodplains in Bangladesh are rice, jute, wheat, maize, tobacco and potato while in Jalpaiguri (Teesta floodplains in India) farmers cultivate mainly three crops, groundnuts (March to May), rice or seasonal vegetables (June to September), and potatoes (October to December).

2.3.2. Characteristics of Crop Agriculture of Bangladesh

In Bangladesh, the crop-growing period is divided into two main seasons, namely kharif and rabi. Kharif season extends from May to October, while rabi season starts from November to April. Another transition season, the pre-kharif extends from March to June. Pre-kharif season is characterized by unreliable rainfall and variations in timing, frequency and intensity from year to year, and provides only an intermittent supply of moisture for such crops as jute, broadcast aman, aus, groundnut etc. Kharif season crops are jute, aus, broadcast aman, transplant aman, sesame, different kinds of summer vegetables, ginger, turmeric, pepper, green chili, different kinds of aroids, cotton, mung-bean, black gram, etc. Most kharif crops are subject to drought and flood in areas without water control. Rabi or winter season ranges from 100-120 days in the extreme west (including Teesta floodplains) to 140-150 days in the northeast of Bangladesh. Rabi crops can use moisture stored down to 1.25 m. The mean starting date of the rabi season ranges from 1-10 October in the extreme west (including Teesta floodplains) to 1-10 November in the northeast, and in central and eastern coastal areas. The mean end dates range from 1-10 February in the following year in extreme west (including Teesta floodplains) to 20-31 March in the northeast. Most Rabi crops such as wheat, maize, mustard, groundnut, sesame, tobacco, potato, sweet potato, sugarcane, lentil, chickpea, and grass pea perform better when sown/planted in October-November. They can utilize the residual soil moisture as well as benefit from growth during the cool winter period (Banglapedia, 2015b). Figure 2.3 depicts detail agricultural land use where major cropping areas in three seasons can be observed. Crop rotation is followed by farmers for better use of soil resources not in a planned way e.g., deep rooted crops (e.g., jute) are grown after shallow rooted crops (e.g., rice) followed by winter crops (e.g., mustard, pulses) (Banglapedia, 2015b).

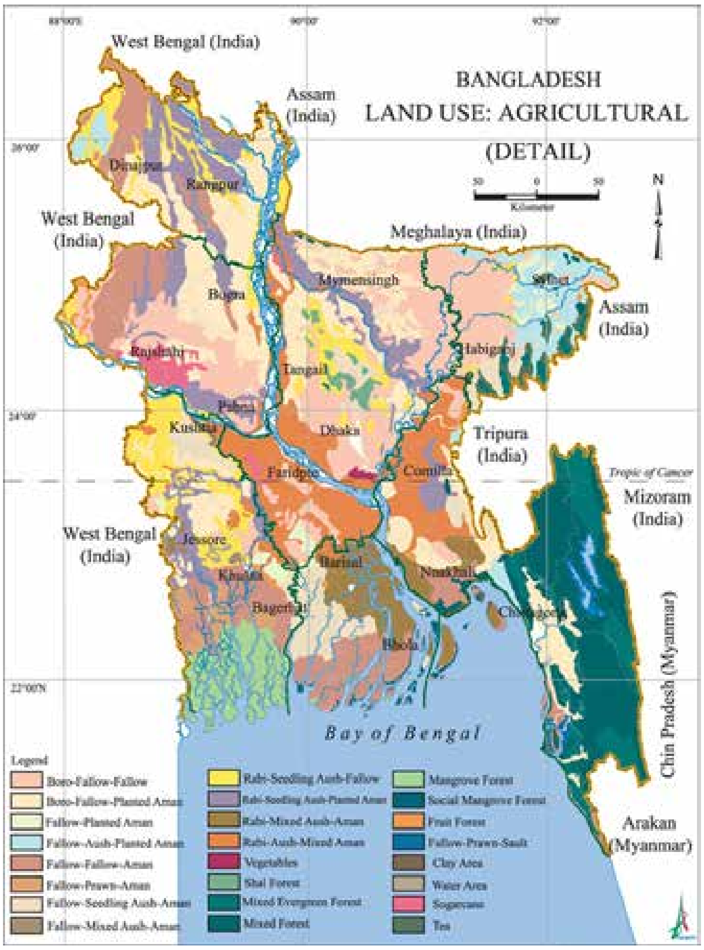

Figure 2.3: Detail agricultural land use of Bangladesh; adapted from Banglapedia (2015d)

Rice dominates the cropping pattern throughout Bangladesh. It has been broadly divided into three classes viz, aman (transplanted and broadcast varieties), boro, and aus according to the season in which they are harvested, in December-January, March-May and July-August respectively. Transplanted aman covers 46.3% of the paddy area, followed by boro (26.9%), aus (17.6%) and broadcast aman (9.3%). Transplanted aman is grown almost everywhere in Bangladesh including Teesta floodplains, while broadcast aman is mostly grown in the low-lying areas of the south and northeast. Boro is grown to a certain extent in every district, especially in the irrigated part, while aus is a well scattered crop. Wheat is cultivated only as a winter crop mainly in the drier parts of the north. Jute is confined mainly to the low-lying areas of Brahmaputra and Ganges floodplains. Mustard (including rape) is grown mainly in the low-lying areas of Brahmaputra and Meghna floodplains. Masur (lentil) and khesari (chickling vetch) are the two important varieties of pulses produced in Bangladesh. Masur is mainly grown in the Gangetic delta while khesari is a well-scattered crop in the islands and chars. Potato mostly grows in Munshiganj, Comilla, Rajshahi, Rangpur, Dinajpur, Bogra, Joypurhat and Nilphamari districts. Sugarcane grows very well in Rajshahi, Natore, and Chuadanga districts. Although chilli is produced to a certain extent in every district of the country, the cultivation is mainly concentrated in the northern districts including Bogra, Sirajganj and Pabna.

2.3.3. Critical Moments of Major Crops in Bangladesh and their Adaptations

Critical climate stress moments of major crops in Bangladesh are broadly categorized into major climate extreme events such as floods, drought and heat waves, cold waves, salinity intrusion and cyclones and storm surges. For this review, majors crops i.e., rice, wheat and jute have been selected for analysis. Table 2.4 summarizes the critical moments of major crops and their adaptation strategies taken into considerations.

Rice

Rice is a year round crop of different varieties including high yielding variety (HYV). The cultivated HYV rice varieties in 2015-16 were (i) in aus season BRRI dhan28 (15% of all rice in aus season) Bangladesh Rice Research Institute (BRRI) dhan48 (11%); (ii) in aman season BRRI dhan49 (10%); and (iii) in boro season BRRI dhan28 (36%) and BRRI dhan29 (28%) (BRRI, 2017). Still local varieties of rice are cultivated in aus and aman season at a large portion. Modern variety (MV) rices of BRRI presently covers 90% of the boro (winter rice), 25-30% of the aus (summer rice), and 50-55% of the T aman (wet season rice) areas of Bangladesh. These varieties together cover 56% of the total rice area and account for about 74% of the total annual rice production of the country (Banglapedia, 2015a). BRRI MV rices and modern rice production technologies played the key role in boosting annual rice production in Bangladesh from 9.9 million metric tons (MMT) of clean rice in 1972-73 to nearly 34.71 MMT of clean rice at present (2014-15) (BBS-GOB, 2016).

As rice is a year round crop, any extreme event due to climate stress has an impact on different rice variety. However, as boro rice contributes to 55% of total rice production, sometimes severe drought may hamper the rice production during March-May. The second aman rice contributes 38% of total rice production, therefore, severe floods (both high depth and long duration) may damage the aman production. Severe cyclone along with storm surge may hamper the rice production in coastal region during pre- (aus) and post-monsoon (aman). However, BRRI continuously contributes to the new varieties of rice e.g., drought/saline/flood tolerant and short duration to adapt with the changing climatic conditions for meeting the food security of the country.

Wheat

The 2nd cereal, wheat grows in Bangladesh from November-December to March-Mid April (rabi and part of pre-kharif seasons). Wheat grows under a wide range of climatic and soil conditions. It however, grows well in clayey loam soils. Well distributed rainfall of 400-1,100 mm is congenial for its growth. Depending on variety and weather conditions, 100-120 days are required from sowing to harvest. Farmers in Bangladesh grow wheat fitting the crop in their intensive rice-based cropping systems. About 80% of wheat area is planted in a three-crop rotation, 60% being aus-transplanted aman rice-wheat and the rest 20% being jute-transplanted aman rice-wheat (Banglapedia, 2014). The total production of wheat in Bangladesh in 2014-15 was 1.35 MMT in 0.44 million ha (BBS-GOB, 2016). However, more than 80% of Bangladesh's wheat consumption is fulfilled by imports mainly from Canada, Ukraine, and Russia (Lagos & Hossain, 2016). Importers credited the rise in domestic consumption of wheat to the lower price of wheat than rice, change in eating habits, and expansion of bakeries and restaurants (Barua, 2017).

Bangladesh government should take strategies to increase domestic wheat production as a long-term goal which will reduce the dependency on imports. There is potential to increase the wheat cultivation area in near future. However, a recent disease (wheat blast) affected approximately 10% production loss of wheat in 2015-16 which diverted farmers to boro rice and other profitable crops (Sadat & Choi, 2017). Moreover, Rahman, Miah, and Saha (2016) summarized that changes of temperature (increase of winter minimum temperature) hamper the production of wheat seriously alongside uneven rainfall triggering insect and pest infestation as well as decrease of ground and surface water availability resultant prolonged drought situation that had slowed but continuous adverse effects on wheat production in northwest region of Bangladesh. Kamrozzaman, Khan, Ahmed, and Sultana (2016) found that 10 days delay of sowing of wheat (November 15 instead of November 5) may increase the production in sandy soils in charlands (sand bars) which is suitable for wheat cultivation. In Bangladesh there is 0.82 million ha of non-saline charlands exist of which 64-97% areas are cultivable (Kamrozzaman et al., 2016).

Jute

Jute is a natural fibre popularly known as the golden fibre of Bangladesh. Jute has many inherent advantages like lustier, high tensile strength, low extensibility, moderate heat and fire resistance and long staple lengths. It is biodegradable and eco-friendly. It has many advances over synthetics and protects the environment and maintains the ecological balance. Jute is used extensively in manufacturing traditional packaging fabrics, Hessian, sacking, carpet backing, mats, bags, tarpaulins, ropes, and twines.

Although jute is grown in almost all the districts of Bangladesh, Faridpur, Tangail, Jessore, Dhaka, Sirajganj, Bogra, and Jamalpur are considered the better growing areas. Total cultivated area of jute in 2014-15 was 673 thousand ha and the total production was 7.5 million bales (BBS-GOB, 2016). Bangladesh jute research institute (BJRI) has developed 36 high-yielding and good quality jute cultivars so far and 11 jute variety seeds are commercially available in the market (BJRI, 2017).

Jute grows well where the annual rainfall is 1,500 mm or more, with at least 250 mm during each of the months of March, April and May. Jute is self-pollinated and has fourteen diploid chromosomes. It needs an ample amount of daylight for growth. After sowing, 4 - 5 months are needed for harvesting. It is done at the flowering stage. The fibre is obtained from the bast or phloem layer of the stem. Jute cultivation is labour intensive and is mostly grown by marginal, poor, and small landowners. The optimum range of temperature required is 18°-33°C. Jute is cultivated in the rainy season. In Bangladesh sowing usually starts at the end of February and continues up to the end of May, depending on the species. Cultivation largely depends upon pre-monsoon showers and moisture conditions. White jute variety *Corchorus capsularis* is more water tolerant and thus generally can be grown in lowlands, and even under water logging conditions, while tossa jute variety *Corchorus olitorious* is more susceptible to water logging and hence cultivated in medium to lower medium elevated lands. Jute can be grown in a number of soil types, ranging from clay to sandy loam with optimum fertility, and soil pH ranging from 5.0-8.6 (Banglapedia, 2015c).

Although jute is an important cash crop of Bangladesh, the global decreasing demand of jute goods and other governance related issues of jute industries affect the farmers' attraction of jute cultivation. The problems of governance of jute industries may include: (i) ever-increasing need of subsidies and rise in cost of production; (ii) share increased in idle looms, managerial vacuum; (iii) lack of effective operating policies; (iv) alleged gross mismanagement in procurement of raw jute; (v) shortage of varied nature of orders received from the buyer; and (vi) imbalance, obsolete and worn out equipment (Uddin, Hossain, & Hoque, 2014).). However, increasing demand of jute goods worldwide after raised awareness about the environment against using synthetic fibres would improve the jute production and marketing. Moreover, Bangladesh's Jute and Textile Product Development Centre (JTPDC) is trying to more diversified use of jute by developing different jute goods mixing with cotton to create new demand worldwide.

2.3.4. Summary Table Potential Critical Climate Stress Moments for Agriculture in Bangladesh

Table 2.4 summarizes the potential critical moments and the current adapation and coping strategies in the agricultural sector in Bangladesh with a focus on the Teesta floodplains.

Table 2.4: Summary table potential critical climate stress moments and current adapation and coping strategies in agriculture, Bangladesh

	Critical moment(s) incl. crop stage/ management practice	Climate related stress factor leading to risk	Threshold (temperature, hydraulically)	Adaption strategy/ coping strategy in place to address CMs	Any specific information available for specific research areas	Literature reference
Rice (year round different varieties)	March-May (boro/aus rice)	Drought	Below -40 kPa soil moisture rice yield reduces significantly as documented by Ghosh and Singh (2010)	• Drought tolerant rice varieties • Short duration rice varieties • Shifting planting time • Use of more fertilizer and pesticides • Community-based water management • Rainwater storage • Agronomic management (manure and composting, seabed method, isle lifting, tillage and shedding); • Water harvesting by re-excavation of pond, khari, canals at community level; • Groundwater exploitation by deep and shallow tube wells in drought prone areas • Crop intensification (diversified crops, cropping pattern) • Alternative enterprise (mango cultivation, homestead gardening, tropical fruit cultivation, intercropping fruits with rice, fodder cultivation) • Non-agricultural livelihoods e.g., cottage industries;	Rajshahi and Chapai Nawabganj districts (Habiba, Shaw, & Takeuchi, 2012) Netrokona (Akash, 2017) Sunamganj (Vodro, 2017) Aila affected area in Khulna district (Haldar, Saha, Ahmed, & Islam, 2017) Patuakhali (Biswas, Islam, Sattar, Mili, & Jahan, 2015)	(Akash, 2017; Biswas et al., 2015; Habiba et al., 2012; Haldar et al., 2017; Vodro, 2017)
Rice (year round different varieties)	December-January boro rice	Cold waves		• Rice early cultivation • Crop intensification (diversified crops, cropping pattern) • Alternative enterprise (mango cultivation, homestead gardening, tropical fruit cultivation, intercropping fruits with rice, fodder cultivation) • Non-agricultural livelihoods e.g., cottage industries;		(Akash, 2017; Biswas et al., 2015; Habiba et al., 2012; Haldar et al., 2017; Vodro, 2017)

Rice (year round different varieties)	July-September aman rice	Flood	Both high depth and long duration rice blast is favored by moderate temperatures (24°C) and high moisture >12h (TeBeest, Guerber, & Ditmore, 2012)	• Flood warning system development • Rice cultivation in raised land • Introduction of submerged tolerant rice varieties, • Crop intensification (diversified crops, cropping pattern) • Alternative enterprise (mango cultivation, homestead gardening, tropical fruit cultivation, intercropping fruits with rice, fodder cultivation) • Non-agricultural livelihoods e.g., cottage industries;		(Akash, 2017; Biswas et al., 2015; Habiba et al., 2012; Haldar et al., 2017; Vodro, 2017) (TeBeest et al., 2012)
Rice (year round different varieties)	Pre (aus rice) and post monsoon (aman rice)	cyclone along with storm surge causing salinity problems		• Saline tolerant rice varieties • Rice-prawn farming in saline prone area • Crop intensification (diversified crops, cropping pattern) • Alternative enterprise (mango cultivation, homestead gardening, tropical fruit cultivation, intercropping fruits with rice, fodder cultivation) • Non-agricultural livelihoods e.g., cottage industries		(Akash, 2017; Biswas et al., 2015; Habiba et al., 2012; Haldar et al., 2017; Vodro, 2017)
Wheat (rabi season)	April-May	heat wave	15 - 32 °C to grow well (Asseng et al., 2015); ; mean temperature variation of ±2 °C at >34 °C may cause production loss upto 50% (Asseng, Foster, & Turner, 2011)	• Pest control by pesticides • Use of new varieties developed by Wheat Research Centre of Bangladesh Agricultural Research Institute (WRC-BARI)	Low lying area of Ganges-Brahmaputra floodplains Charlands (sand bars) (Kamrozzaman et al., 2016)	(Kamrozzaman et al., 2016; Rahman et al., 2016; Sadat & Choi, 2017) Banglapedia, 2014
Wheat (rabi season)	December-January	Cold wave		• Cold wave is good for wheat production in India (Correspondent, 2012; Sud, 2010)		
Wheat (rabi season)	February - May	Drought	Well distributed rainfall of 400-1,100 mm is congenial for its growth	• Drought tolerant wheat varieties e.g., Shatabdi, Prodip, Bijoy and BARI Gom-25 and 26 by WRC-BARI are cultivated	In drought prone Barind area of northwest Bangladesh	Correspondent (2015)

Wheat (rabi season)	December-January	Increase in winter temperature along with uneven rainfall triggering insects and pests as well as water availability		• 10 days delay of sowing of wheat (November 15 instead of November 5) may increase the production in sandy soils in charlands (sand bars)		
Jute (pre-kharif and kharif seasons)	March-June	Drought / low rainfall and high temperature	18° - 33°C Jute grows well where the annual rainfall is 1,500 mm or more, with at least 250 mm during each of the months of March, April and May.	• Bangladesh Jute Research Institute (BJRI) has developed 36 HYVs and good quality jute so far and 11 HYV jute seeds are commercially available • Tossa jute variety Corchorus olitorious is more susceptible to water logging and hence cultivated in medium to lower medium lands.	Bangladesh	(Banglapedia, 2015c; BJRI, 2017)
Jute (pre-kharif and kharif seasons)	July-August	Flood		• White jute variety Corchorus capsularis is more water tolerant and thus generally can be grown in low lands, and even under water logging conditions		
Jute (pre-kharif and kharif seasons)	March -May	Salinity		• 4 white jute genotypes were found high salinity tolerant (upto 14 dS/m)	Satkhira (high salinity), Patuakhali (moderate salinity)	Billah, Sikder, Latif, and Chowdhury (2015)

Conclusions

Critical moments of major three crops namely rice, wheat and jute are mainly during floods in the floodplains of Ganges, Brahmaputra, and Meghna rivers; drought mostly in northwest districts; cyclones and storm surges in the coastal region; and cold and heat waves in the whole country. Teesta floodplains pass critical moments due to floods, drought, heat and cold waves in each year. The adaptation strategies include mainly: (i) flood tolerant rice (deep water aman rice) in the floodplains; (ii) groundwater irrigation during drought period and also supplementary irrigation from both surface and groundwater all year round through deep and shallow tube wells at both public and private sectors; (iii) drought/salinity tolerant varieties of different crops are available in the market; and (iv) government subsidies into seeds, fertilizers, and pesticides also enhance the cultivation. Most importantly, for major crops, there are state owned research organizations (e.g., BRRI for rice, WRC-BARI for wheat, and BJRI for jute) contribute to the new development of the major crops and support services to the farmers. However, to reduce the import of wheat; wheat cultivation area has to be increased instead of other dry season crops and to increase jute cultivation; new demand of jute products has to be enhanced in the long-run.

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2.4. Critical Moments Faced in Agricultural Sector in Nepal[5]

2.4.1. Introduction

Climate has a significant impact on agricultural production but a constant increase in global temperature in recent years has caused noticeable impacts across the world. Developing countries like Nepal are more susceptible to climate change since they lack technical and financial capacity to retort to increased variability.

Rice

Rice is a chief crop that is likely to face profound risk due to lack of certainty in the stream flows, intense but irregular monsoon rainfall and frequent flooding. Rice production is particularly affected because rice fields are heavily dependent on monsoon rainfall and change in the onset and duration of monsoon rains can affect rice yields (Karki & Gurung, 2012).

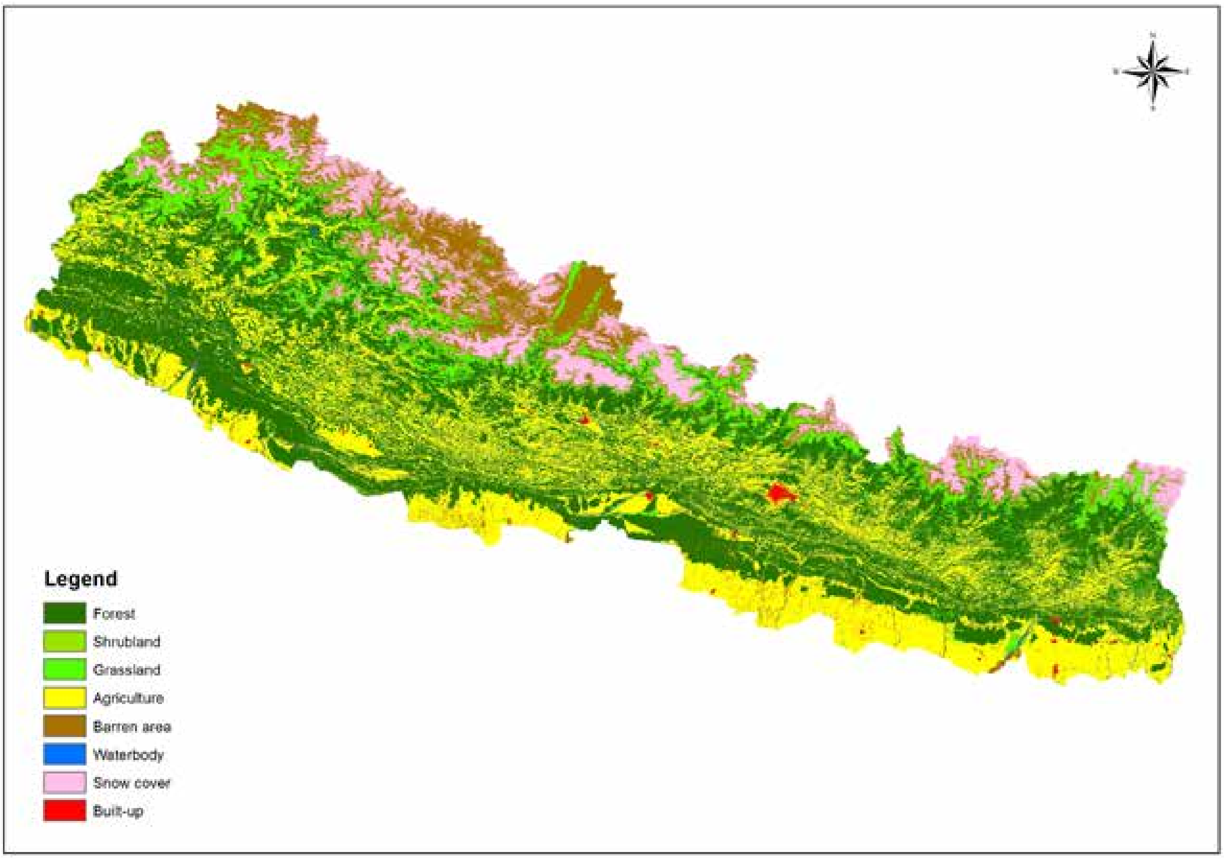

Figure 2.4: Classified land cover map of Nepal, 1992/1993 (Source: Developed by ICIMOD)

Wheat

Devkota and Phuyal (2015) examined the climatic impacts on wheat production in Terai of Nepal. Climate change and wheat yield are interrelated to each other. Wheat yield decreases with rise in temperature (Anwar et al., 2007), while it has been argued in some other studies that yield shows a differential response to increase in temperature i.e. it shows a positive response up to certain degree at high altitude (1,500m) and a negative

[5]Avash Pandey, ICIMOD

response at low altitude (960m) which is relevant to Rasuwa and Nuwakot and Chitwan (Hussain and Mudasser, 2006). Analogous to temperature, precipitation has also mixed effect on wheat yields. The wheat plant cycle runs from October and delayed monsoon affects the plantation. (Devkota & Phuyal, 2015). Poor irrigation facilities and less availability of fertilizers, insecticides and pesticides contribute to low wheat output (Pokherel et al., 2007). Improved fertilizers and seeds can help increase wheat yield and net revenue plus human labour is an active source of production that can maximize wheat productivity (Thapa - Parajuli & Devkota, 2016; Nayava, Singh, & Bhatta, 2009).

Maize

Maize requires 500-600 mm of water for higher yields depending on climate and there should be sufficient water during crop establishment phase. Water shortfall during the grain filling period results in less grain weight. On contrary, rainfall has a negative effect on grain quality during the maturity and harvesting period. Acquaintance of genetic characteristics and principally growth and development pattern of maize varieties is essential to cope with the combination of various climatic requirements for growth development and yield formation. A study done in Maize research center at Rampur, Chitwan found that sunshine hours matter in maize production as well as improved seed quality can enhance maize yields (Nayava & Gurung, 2010). Maize is sensitive to frost and when the temperature is below 10°C development ceases, this happens during the growth stage of the maize. Heat stress occurs when the temperature is above 35°C (Nayava & Gurung, 2010).

Sugarcane

Productivity of sugarcane may reduce from 4-17% by 2030 with a temperature rise of 2.5°C. Some of the critical moments that may be triggered by changing temperature and precipitation trends include soil fertility problems, pest outbreaks and weeds growth, and irrigation difficulties. Sugar mills should try to introduce new sugarcane varieties that can better adapt to climatic stresses (IFC, 2015).

Snow-fed rivers in Nepal, such as the Koshi and Narayani pose flood-risks during the monsoon period and increased glacial melt in this time can cause outbreaks from glacial lakes resulting in catastrophic floods. These floods affect the crops that are grown during the monsoon season such as rice (plantation and growth stage) and maize (maturity stage) (Dewan, 2015) Thunderstorms usually occur during the monsoon season; and hailstorms at the start and end of the monsoon season, causing potential damage to potatoes and other crops further increasing vulnerability to food insecurity (Oxfam, 2017). Droughts present additional stress to food security situation. Tunnel farming is a recommended practice for potato farming that can be helpful in achieving satisfactory yields (WFP, 2013; Paudel, 2016).

2.4.2. Summary Potential Critical Moments in the Agricultural Sector in Nepal

Table 2.5 summarizes the potential critcal moments in the agricultural sector in Nepal. It also shows the climate related stress factors and current coping and adaptation strategies.

Table 2.5: Potential critical moments, climate related stress factors and current coping and adaptation strategies in agriculture, Nepal

Crops	Potential critical moment(s) incl. crop stage/ management practice	Climate related stress factor leading to risk	Threshold? (temperature, hydraulically)	Adaption strategy/ coping strategy in place to address CMs?	Any specific information available for specific research areas	Literature reference
Rice	Onset and duration of monsoon rains can affect rice yields during plantation and growth stage (June-September)	Floods Droughts Landslides		Lack of scientific knowledge, low financial capacity and lack of coordination contribute to (potential) critical moments. No information on particular adaption strategy/ coping strategy in place to address CMs		(Karki & Gurung, 2012)
Wheat	?	Precipitation Temperature Wheat yield decreases with rise in maximum temperature and decreases in rise of minimum temperature in the terai area of Nepal (relevant for Chitwan) (Devkota & Phuyal, 2015) More general, wheat yield decreases with rise in temperature (Anwar et al, 2007). However, others argue that yield shows a differential response to increase in temperature i.e. it shows a positive response up to certain degree at high altitude and a negative response at low altitude (Hussain and Mudasser, 2006)		Population density, manure, human labour, wages, advanced seed and fertilizer Improved fertilizers and seeds, use of manure and improved irrigation facilities		(Anwar et al 2007) (Hussain and Mudasser, 2006) (Devkota & Phuyal, 2015) (Thapa-Parajuli & Devkota, 2016) (Nayava et al., 2009)
Maize	Storage problems during and after harvesting. Rainfall has a negative effect on grain quality during the maturity and harvesting period. Crop plantation and germination phase (due to insufficient water) Grain filling period: Water shortfall during the grain filling period results in less grain weight.	Temperature Erratic Rainfall Precipitation Erratic rainfall during crop plantation, germination and grain filling Precipitation during the maturity and harvesting period.	Maize requires 500-600 mm of water for higher yields depending on climate. Temperature below 10^{0}C affect growth and temperature above 35^{0}C (heat waves) affects crop during maturity stage	Improved seeds Diseases due to high rainfall and humidity do contribute to the emergence of critical moments as well.	Sunshine hours matter in the production, a study done in Maize research centre at Rampur, Chitwan	(Janak Lal Nayava & Gurung, 2010)

Sugarcane		Temperature / heat stress Productivity of sugarcane may reduce from 4-17% by 2030 with a temperature rise of 2.5°C. (IFC, 2015)		New varieties Crop stresses caused by changing temperature and precipitation may become critical moments due to (a combination of) climate and additional constraints such as soil fertility problems, pest outbreaks and weeds growth, and irrigation difficulties		(IFC, 2015)
Potatoes	Start and end of the monsoon season (due to hailstorms) Melting of snow and change in snowfall pattern affect Storage after harvesting	Precipitation Hailstorms Temperature Change in snow melt/fall pattern Precipitation: decrease in post-monsoon rainfall leads to negative impacts on potato production Precipitation during storage affects yield. Winter crops such potatoes are highly sensitive to small changes in rainfall patterns. Hailstorms at the start and end of the monsoon season, cause potential damage to potatoes. Increase in temperature can result in yield losses of potatoes especially in hill and mountain areas. Decrease in snow melt and change in snowfall pattern adversely affect potato yield.		Tunnel farming	The cold wave of 1997/1998 had negative impacts on agricultural productivity resulting in losses of up to 28 per cent for potato (NARC, 1998). The temperature sensitivities are positive for millet, wheat, barley, and potato, suggesting that these crops are more heat-resistant than paddy rice or maize (cf. van Oosteromet al., 1995; Crafts-Brandner and Salvucci, 2002; Barnabas et al., 2007).	(Oxfam, 2017); (WFP, 2013); (Paudel, 2016)

2.4.3 References Critical Moments Faced in Agricultural Sector in Nepal

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2.5. Critical Moments in Agriculture in India[6]

A regular rain pattern is usually essential for agriculture, too much or too little rainfall i.e. floods or drought condition is very harmful even destructive to crops.

Rice

Rice is the major kharif crop in India which is vulnerable to minimum temperature and also highly dependent on rainfall. Rice and rainfall have a positive correlation as is supported in a study by Ahlawat and Kaur (2015). High temperature around flowering stage reduces fertility of pollen grains as well as pollen germination on stigma (Venkateswarlu and Rau, 2013).

Wheat

The ideal temperature range for optimum growth and yield of wheat crop is: 20–22°C at sowing, 16–22°C at tillering to grain filling and slow rise of temperature to 40°C at harvesting (Sharma, 2000). High temperature particularly during sowing speeds up wheat growth, pushing the crop into an early jointing stage, thus shortening tillering period ((Harrison et al, 2000). This leads to less number of tillers which ultimately reduces crop yield. Similarly, the duration of grain filling is reduced resulting in fewer yields if wheat is exposed to high temperature at flowering and grain filling. Choosing a variety that is suitable in relation to sowing and anticipated temperature rise is necessary to acquire an optimum yield under high temperature conditions (Kajla et al., 2015). Sowing time should be adjusted so that the crop escapes from hot and desiccating wind during grain filling period. Additional practices that can help mitigate temperature stress include crop establishment methods, residue retention, selection of heat tolerant varieties, water management, and foliar spray of KNO3 , KCl, 1-Methylcyclopropene (1-MCP) and GA3 (Ahlawat and Kaur, 2015).

Groundnut

In India, 83% of the total groundnut production is grown under rainfed conditions during the main rainy season (Jun/Jul – Oct/Nov) and the remaining 17% is irrigated mainly in the post rainy (Oct – Mar) season. (Birthal et al., 2010). Optimum temperature for the crop germination is 10°C while for emergence it ranges from 25-30°C. When temperature exceeds 44/34°C, it leads to reduced dry matter production and less seed yield. Other factors that can be accountable for negatively affecting yield are water logging, extreme water deficiency or extreme humidity (Kumar and Boote et al., 2012).

Maize

Rise in maximum temperature has a negative and significant effect on yield of maize crop. On the other hand, effect of rainfall has been found positive and significant on maize but excessive rainfall can also incur damaging effect on the crop yield. A rise of 1°C in temperature reduced the yield of maize by 10.4% (Mall et al., 2006), while in another study 10% reduction in maize yield has been reported (Kalra et al., 2007). Research should focus on drought resistant varieties so that crop yield is not significantly affected in current climate changing scenarios (Birthal et al., 2014).

2.5.1 Summary Potential Critical Moments in Agriculture in India

Table 2.6 summarizes the potential critcal moments in agriculture in India. It also shows the climate and wheather related stress factors and current coping/adaptation strategies.

[6]Sultan Ishaq, Bashir Ahmad, Nelufar Raza (PARC)

Table 2.6: Potential critical moments, climate related stress factors and current coping and adaptation strategies in agriculture in India

Crops	Potential critical moment(s) incl. crop stage/ management practice	Climate related stress factor leading to risk	Threshold? (temperature, hydraulically)	Adaption strategy/ coping strategy in place to address CMs?	Any specific information available for specific research areas	Literature reference
Rice	Rice is vulnerable to minimum temperature and also highly dependent on rainfall	Decline in number of rainy days				Venkateswarlu and Rao, 2013
	Flowering stage	High temperature	High temperature around flowering stage reduces fertility of pollen grains as well as pollen germination on stigma reduces yield	Introducing varieties that are tolerant to high temperature		(Venkateswarlu and Rao, 2013).
Wheat	Sowing time	Increased temperature during sowing	20-25°C The ideal temperature for wheat crop is 20–22°C at sowing, 16–22°C at tillering to grain filling and slow rise of temperature to 40°C at harvesting (Sharma, 2000)	Adjustment in sowing time Water management Foliar spray of KNO3 , KCl, 1-Methylcyclopropene (1-MCP) and GA3 c	Increased temperature during sowing speeds up wheat growth (early crop maturity) pushing crop into jointing stage too early, thus shortening tillering period which ultimately reduces grain quality and crop yield adaption: breeding for stress tolerant varieties	Ahlawat and Kaur, 2015; Kajla et al., 2015; Sharma, 2000; Harrison et al., 2000

Ground nuts	Reduced dry matter production and less seed yield.	Increase in temperature above 44/34°C	Optimal temperature 10°C (for germination) Optimal temperature 25-30°C (for emergence)	Proper timing and supply of water		Prasad et al. 2003; Birthal et al., 2010
	Extreme events will reduce yield	Water logging, extreme water deficiency or extreme humidity				
Maize	Reduction in yield	1°C rise above threshold temperature			Research on drought tolerant varieties	Birthal et al., 2014
		Excessive rainfall			Excessive rainfall can also incur damaging effect on the crop yield	

2.5.2. References Critical Moments in Agriculture in India

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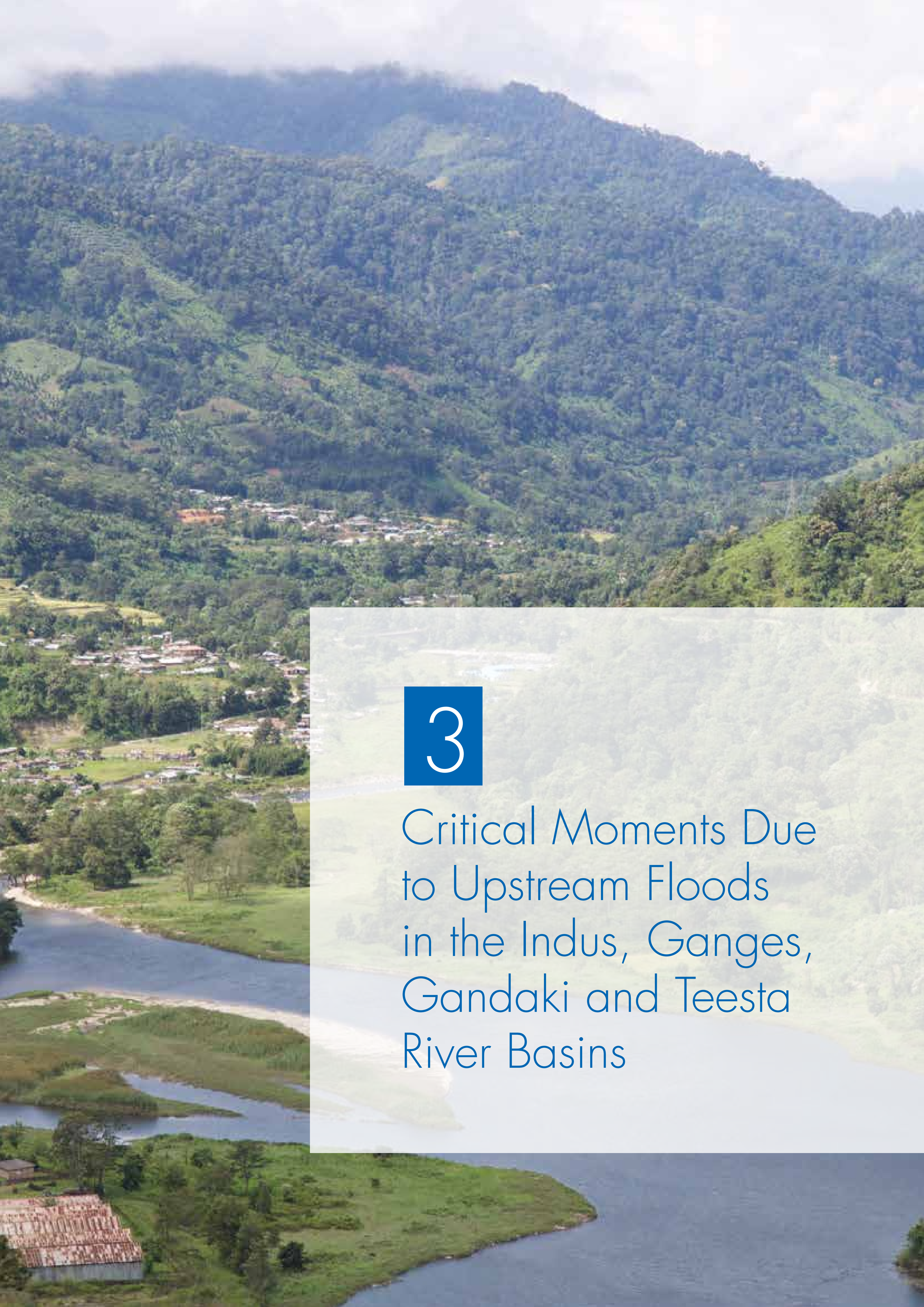

3

Critical Moments Due to Upstream Floods in the Indus, Ganges, Gandaki and Teesta River Basins

3. Critical Moments Due to Upstream Floods in the Indus, Ganges, Gandaki and Teesta River Basins[7]

3.1. Background

Floods are a climatological phenomena mainly influenced by geology, geomorphology, land use, precipitation and climate variability (WHO, 2002). Flooding in the global climate change scenario reveals significant vulnerability and exposure to some ecosystem and human systems (IPCC, 2014). The IPCC report further emphasizes with robust evidence that fractions of the global population affected by major river floods are projected to increase. In the Hindu Kush Himalayan (HKH) region floods accounts for more than third of the total natural disasters and affects millions of people directly or indirectly (ICIMOD, 2013).

A river basin can be typically divided into three zones: Source zone, Transition zone and Floodplain zone as illustrated in figure 3.1. In the case of HKH region source zone consists of high mountains, steep slopes, transition zone consists of high hills, mid-hills and a part of floodplain and the floodplain zone consists of extensive floodplains with wide and deep river channels. In our study we mainly focus on the upstream region of the river basins which is the entire source zone and a part of transition zone consisting of mid-hills.

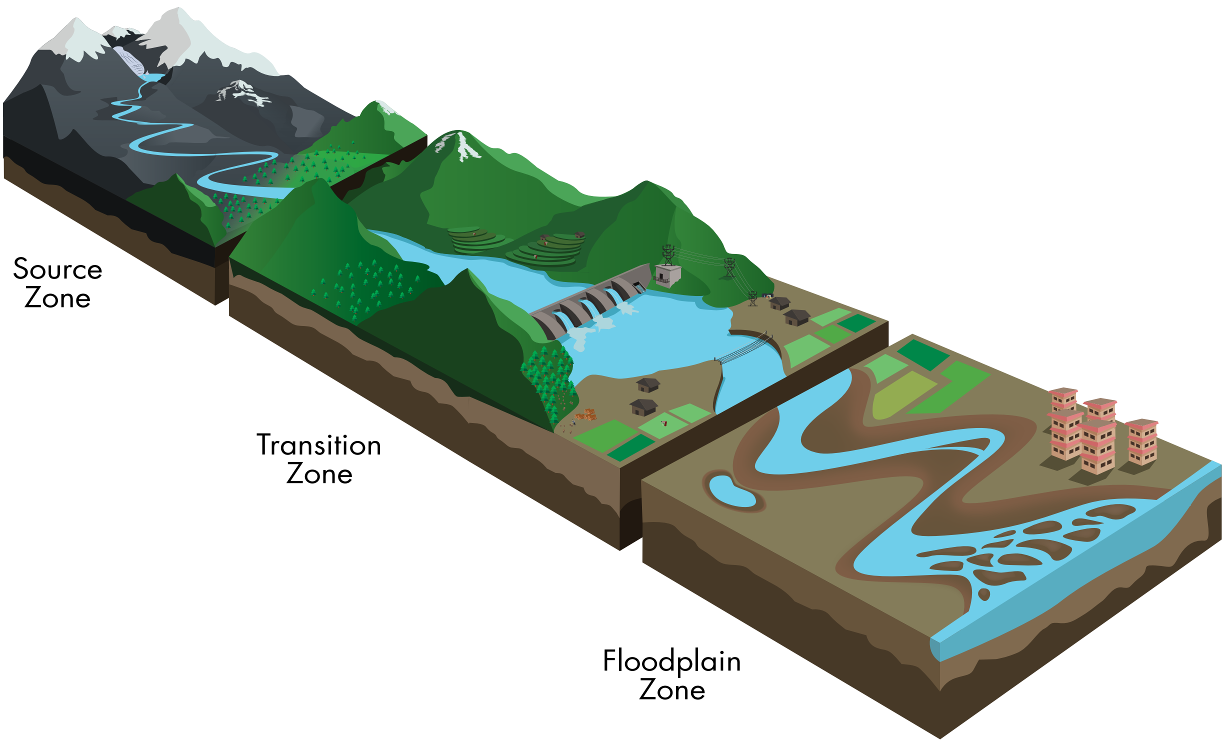

Figure 3.1: Schematic diagram of a river corridor showing three zones and their upstream downstream relationships. (Source: Developed by ICIMOD)

[7]Avash Pandey, Giovanna Gioli (ICIMOD)

3.2. Floods in the Upstream Region of Indus, Ganges, Gandaki and Teesta River Basins

The types of floods that happen in the upstream region of the river basins can be classified as: Seasonal Floods, Glacial Lake Outburst Floods (GLOF), Landslide Induced Dam Outburst Floods (LDOF) and Flash Floods which occur mainly due to intense rainfall and cloudbursts. The upstream area of a river basin is more vulnerable to the oncoming floods mainly due to lack of lead time and the velocity the floodwaters moves with. Floods seem to vary according to geography, the plains of these river basins are more vulnerable to floods as the terrain is flat and the area is densely populated.

3.3. Upper Indus River Basin

In the Indus river basin (IRB) the upstream area which consists of mountains in the north and north-west accounts to 241,647 km^2 and plateau of Baluchistan in the south-west accounts for 242,683 km^2.. The upstream reaches if IRB can be divided as: the upstream segment, from the Singi Khahad spring down to Jinnah Barrage and the mid-stream segment, between Jinnah and Guddu Barrage (Ali, 2013; Framji & Mahajan, 1969). In the IRB, with major tributaries of Jhelum, Chenab, Sutlej and Ravi has an average annual flow of 175 km^3/yr. The three weather system influencing the precipitation patterns in the IRB can be classified as: i. Monsoon depression originating from the Bay of Bengal; ii. Westerly waves coming from the Mediterranean Sea; and iii. Seasonal lows from the Arabian Sea. Rainfall occur in the monsoon and cold weather seasons but floods occur mostly during the monsoon season. These floods, especially in the monsoon, could be put under the seasonal flood category. About 82% of the annual flow happens during summer due to increased rate of snowmelt and monsoon rainfall. Furthermore, glacier melt runoff provides around 40% of the total streamflow in the upstream areas and snow and glacier melt is 151% of the total discharge naturally generated in the downstream areas (Immerzeel et.al., 2010; MoWP, 2002; Tariq & Van de Giesen, 2012).

The scope of this review is to look into the floods in the upper reaches of the river basins. At the Jinnah Barrage, upstream of Indus River, the topography is steep with degraded hill slopes and only one major reservoir lies in this section, at Tarbela Dam. Given the topography, intense rainfall in this section quickly generates high runoff where the reservoir might not be able to withhold the runoffs because of earlier season filling of reservoir for various purposes (Ali, 2013).

Table 3.1: : History of Major Upstream Floods in Upper IRB, Source: Modified from Ali (2013); Tariq & Van de Giesen, (2012)

Year	River/Location	Damage	Remarks
4-6 October 1955	Ravi	• Breached the flood embankments of the Bambanwala–Ravi–Bedian–Dipalpur Link Canal	Seasonal flood
1973	Chenab	• inundated 3.6 million ha • 70,000 cattle and 255,000 houses, and 474 people perished • $2.39 billion worth of damage	Seasonal flood
July and September 1976	Indus	• killed 425 people and affected another 1.7 million people • inundated 8 million ha of land • damaged 11,000 houses • $1.62 billion worth of damage	Seasonal flood

23-26 September 1988	Ravi, Sutlej and Chenab	• deluged 1 million ha of agricultural land and irrigated crops • Killed 500 people • $400 million worth of damage	Seasonal flood
7-11 September, 1992	Indus, Jhelum and Chenab	• killed more than 1,000 and affected 4.8 million people • inundated 13,000 villages • damaged 960,000 houses • $1.4 billion, including $0.5 billion worth of damage to public infrastructure • $396 million worth of damage in agriculture and communication sectors	Seasonal flood, leeve breaching
July-September 1994	Indus and Sutlej	• killed 386 people • damaged 557,000 houses • resulted in the loss of 14,000 cattle and of about 700,000 ha of crops	Seasonal flood
2001	Pothohar Plateau	• Killed 230 people	Flash flood
July 2005 and 2006	Kabul and Chenab	• Killed 591 people • Affected about 1 million ha of land	Seasonal flood
2010	Throughout Pakistan	• killed 1,600 people • damage totaling over $10 billion • inundated an area of about 38,600 km^2 • 50% of the damage in agriculture and livestock sector	Seasonal flood, flash flood
August and September 2011	Sindh and Balochistan Province	• affected 9.6 million with 200,000 people losing their homes	Seasonal flood
August-October 2012	Southern Punjab, Northern Sindh and North-east Balochistan	• 571 reported dead • damaged more than 600,000 houses • ruined crops within an area of 500,000 ha	Seasonal flood

3.4. Upper Ganges and Gandaki River Basins

The Ganges River Basin (GRB), a flow combination of the Alkananda and the Bhagirathi, originates within the mountain range of the Himalayas. A large number of tributaries join from the Himalayan sub-basin including Ramganga, Sarda, Gomti, Ghaghara, Gandak and Koshi (FAO, 2011). Unlike the Indus, the GRB is strongly influenced by summer monsoon with the eastern part receiving the highest rainfall. However, the headwater of the basin is also influenced by snow, glaciers, permafrost and precipitation (Nepal & Shrestha, 2015). Since the Sapta-Gandaki (Gandak) in India lies in the upper reaches of the GRB, this chapter includes the flood events in the Gandaki river basin together with GRB.

The Ganges River is regarded as a holy and scared river by many Himalayan communities. One of the most recent and devastating floods occurred in the pilgrimage site of the Upper Ganges over the northern part of Uttarakhand and Himanchal Pradesh. The flash flood was caused by multiday cloudburst which was about 375 percent more than the normal rainfall where more than 10,000 lives were lost across the states of Uttarakhand, Himanchal Pradesh and some areas in Nepal (Das, 2013). Similar, events has been taking place in the upper reaches of the GRB where cloudbursts, landslides, mass movements, mudflows and flash floods are quite common. Prior to the

2013 floods in the upper GRB, a major breach of flood control embankment of Koshi river happened on 18th August 2008 which affected 50,000 people in Nepal and 3.5 million people in Bihar. At least 75 people were confirmed dead in this disaster. (Dixit, 2009; Memon, 2012). A brief summary of the floods that occurred within the GRB in Bihar is presented in table 3.2 with estimated loss and damages.

Table 3.2: Flood Loss Summary of Ganges in Bihar 1985 to 2006 (Source: The World Bank, 2015)

Year	District	Blocks	Pan-chayat	Village	Human (in Lakh)	Total area (in lakh ha)	Cropped area (in lakh ha)	Crop Dam-aged (in Lakh INR)	House af-fected	Public Prop-erty dam-aged (in Lakh INR)
2006	14	63	375	959	10.89	1.81	0.87	706.3	18,637	8,456.17
2005	12	81	562	1,464	21.04	4.6	1.35	1,164.50	5,538	305
2004	20	211	2,788	9,346	212.99	27	13.99	52,205.64	9,29,773	103,049.60
2003	24	172	1,496	5,077	76.02	15.08	6.10	6,266.13	45,262	1,035.16
2002	25	6	2,504	8,313	160.18	19.69	9.40	51,149.61	419,014	40,892.19
2001	22	194	1,992	6,405	90.91	11.95	6.50	26,721.79	222,074	18,353.78
2000	33	213	2,327	12,351	90.18	8.05	4.43	8,303.70	343,091	3,780.66
1999	24	150	1,604	5,057	65.66	8.45	3.04	24,203.88	91,813	5,409.99
1998	28	260	2,739	8,347	134.70	25.12	12.84	36,696.68	199,611	9,284.04
1997	26	169	1,902	7,043	69.65	14.71	6.55	5,737.66	174,379	2,038.09
1996	29	195	2,049	6,417	67.33	11.89	7.34	7,169.29	116,194	1,035.7
1995	26	177	1,901	8,233	66.29	9.26	4.24	19,514.32	297,765	2,183.57
1994	21	112	1,045	2,755	40.12	6.32	3.50	5,616.33	33,876	151.66
1993	18	124	1,263	3,422	53.52	15.64	11.35	13,950.17	219,826	3,040.86
1992	8	19	170	414	5.56	0.76	0.25	58.09	1,281	0.75
1991	24	137	1,336	4,096	48.23	9.8	4.05	2,361.03	27,324	139.93
1990	24	162	1,259	4,178	39.57	8.73	3.21	1,818.88	11,009	182.27
1989	16	74	652	1,821	18.79	4.71	1.65	704.88	7,746	83.700
1988	23	181	1,616	5,687	62.34	10.52	3.95	4,986.32	14,759	150.64
1987	30	382	6,112	24,518	286.62	47.50	25.7	67,881	1,704,999	680.86
1986	23	189	1,828	6,509	75.80	19.18	7.97	10,513.51	136,774	3,201.99
1985	20	162	1,245	5,315	53.09	7.94	4.38	3,129.52	103,279	204.64

In the Karnali river (known as Ghaghara in India), a major tributary of the Ganges, a three day monsoon rain led to widespread flooding in the western region of Nepal. The flood claimed 222 lives and affected another 120,000 with damage to property and infrastructure (MacClune et al., 2014). In the past, Karnali river has been known to affect the population of mid-western and far western region of Nepal. In the month of October, 2009 floods and landslides affected 14 districts of mid an far western region of Nepal claiming 78 lives and affecting more than 175,000 people where 15,000 people were fully displaced (IFRC, 2010). Of the many disaster that occurs in Nepal, the upstream of the GRB, floods share a fair amount of the disaster inventory. From 1900-2005 floods have occurred 903 times (14.4%), 1,674 times (29.4%) and 163 times (10.3%) in the hills, terai and mountain zones, respectively (Aryal, 2012). The paper further illustrates that the Terai, the floodplains just after the Siwaliks, has the highest number of casualties in various disasters with 2,856,193 (47.3%) caused by floods.

In the month of July in Nepal, 64 people were killed with at least 20 missing. Various structures including flood defenses and bridges were washed away (Fox, 2016). Similarly, in the Kali Gandaki catchment of the Gandaki basin, flash flood in the winter month of December in 2016 damaged 8 wooden bridges and destroyed the drinking water pipes and water mills (The Kathmandu Post, 2016). Although there were no snowfall or any other reason for this flash flood, GLOF has been believed to be the cause of this disaster.

In the upper reaches of the GRB Glacial Lake Outburst Floods (GLOF) also have records of creating havoc in the upstream region of the Himalayas. A GLOF is characterized by a sudden release of a huge amount of lake water, that is created by the melting glaciers, that rushes in great speed to the downstream reaches (WWF, 2005). A list of recorded GLOF events in Nepal are presented in table 3.3. These GLOF events pose significant threat not only to human lives but also to the livelihood of economically vulnerable population of the Himalayan region. A prediction done by Mool et al., (2011) in three glacial lake, Imja Tsho, Tsho Rolpa and Thulagi, shows that the maximum number of people who could be directly or indirectly affected to be 501,773; 524,323; and 2,044,145 respectively.

Table 3.3: Record of GLOFs in Nepal, Upper Ganges Basin, Source: WWF (2005)

Date	River basin	Name of Lake
450 years ago	Seti Khola	Machhapuchhre
August, 1935	Sun Koshi	Taraco, Tibet
21 September, 1964	Arun	Gelaipco, Tibet
1964	Sun Koshi	Zhangzongbo, Tibet
1964	Trishuli	Longda, Tibet
1968	Arun	Ayaco, Tibet
1969	Arun	Ayaco, Tibet
1970	Arun	Ayaco, Tibet
3rd September, 1977	Dudh Koshi	Nare, Tibet
23rd June, 1980	Tamor	Nagmapokhri, Nepal
11th July, 1981	Sun Koshi	Zhangzongbo, Tibet
27th August, 1982	Arun	Jinco, Tibet
4th August, 1985	Dudh Koshi	Dig Tsho, Nepal
17th July, 1991	Tamor Koshi	Chubung, Nepal
3rd September, 1998	Dudh Koshi	Sabai, Tsho, Nepal

Another cause of flood in the Himalayan region is Landslide-induced Dam Outburst Flood (LDOF) given the steep slopes and fragile geography. On May 5, 2012, a rockslide occurred on the western wall of Annapurna peak IV, in the Seti river catchment of Gandaki River Basin, causing the LDOF which led to the death of 40 people with 31 missing and sweeping away an entire settlement. The flood washed away small businesses of the locals which left them jobless (Oi et.al., 2014; Sharma,et.al., 2015). Similarly, in the Koshi river basin, a landslide struck around 2.30 a.m. creating a dam on the Sun koshi River. The landslide claimed 156 lives with 165 houses were damaged. The downstream reaches of the river were on high alert suspecting a probable LDOF (DPNET, 2014).

3.5. Upper Teesta River Basin (TRB)

Teesta river originates in the Phunri glacier, and it flows southwards in the Sikkim Himalayas and is fed by various rivulets with the Rangeet river being the major tributary (Mandal & Chakrabarty, 2016). Teesta, like the other river basins of the Himalayas, has fragile geology contributing to landslides and floods. These landslides sometimes are responsible for floods and vice-versa. Catastrophic floods in the upper TRB, mainly Darjeeling and Jalpaiguri, occurred in the years 1950, 1968, 1973, 1975, 1976, 1978, 1993, 1996, 2000, 2003 and 2015 where the 1968, on 2nd to 5th October, flood is considered the most disastrous (Pal et.al., 2016). The consequences of the floods in 1968 and 2015 is presented in table 3.4 below:

Table 3.4: Consequences of Floods in 1968 and 2015, Modified from Pal et.al., (2016)

S.No.	Year	Human loss	Loss of resources
	1968	About 1000 people were either dead or missing	Flood-protection embankment at Moinaguri, Domohani and Jalpaiguri. Hectors of agricultural field were inundated
	2015	Over 20,000 people are marooned (about 5,000 people were evacuated till 7th October, 2015)	Hectors of agricultural field and numerous houses were inundated

In the upper TRB GLOF seems to be another factor that might cause flooding in the upstream and downstream reaches of the river. There are four glacier lakes in the upper TRB which might create flash flood in the region (CWC, 2015). Recently in June 2016, a vast area of North Bengal had been inundated following heavy rain and the threat of flooding was looming large over the region. Residents of Jalpaiguri, Cooch Behar and Alipurduar districts were under waist deep water with around 10,000 people being affected (Newsmen, 2016). This has created flooding danger in the downstream reaches of the river with estimated hundreds of thousands of people being affected.

3.6. Critical Moments with Respect to Floods

Although floods are needed for agricultural productivity and fisheries by replenishing the soil, large floods results in loss of human lives, property and overall development of the region (Shrestha, 2008). Apart from loss of human lives the major problem that the upstream region is facing due to the floods is inundation and washing away of agricultural crops. Around 50 million hectares of land had been inundated in the upper Indus basin during the peroid of 1973-2012 (Ali, 2013). Similarly, in Bihar, agricultural areas of around 29 million hectares lying within the Ganges basin, were either inundated or affected (The World Bank, 2015). The economic impact of these inundation in these areas of the river basins are unaccounted for. It could have possibly affected tens of millions of residents directly or indirectly.

The agony that the people face after the flood is even more frightening than the peroid of actual flood. Probelms in sanitation, clean drinking water and water borne diseases are to name a few. Floods can increase the transmission of water borne disease such as typhiod fever, cholera, leprospirosis and hepatitis and vector borne diseases such as malaria, dengue, yellow fever and west nile fever (WHO, 2017). However, the indirect effects of floods in helath can be damages to healthcare institutions, damage to water and sanitary infrastructures, disruption of food supplies and lack of shelter increasing exposure to disease-vectors (NDMA, 2008).

The majority of population that are exposed to the floods are the marginalized communities or so called "lower castes" in the Himalayan region. These are the most vulnerable where they have no option to settle and end up in hazard prone areas such as near the banks of the river. They lack access to information and resources and have weak coping mechanisms (MacClune et al., 2014; Wickeri, 2009). A case study done in the upstream areas of Bhote Koshi and Sun Koshi, tributaries to the Ganges, found that the major ethnic groups exposed to flash floods due to GLOF were marginalized and disadvantaged. Nearly 50% of them were poor and 30% were ultra poor (Khanal et.al., 2013).

3.7. Discussion and Conclusions

The rivers that lie in the upstream region of the HKH region are susceptible to flash floods unlike the waterlogging that happens in the downstream region. These flash floods seem to occur in the monsoon region after phenomena such as cloudbursts, GLOF, LDOF, etc. The vulnerability of the population living in the upstream reaches of these rivers could be considered higher given the lack of lead time and the intensity that the flood waters move with. The floods that occur through the 4 river basins seem to occur in the monsoon season influenced by the depression occurring mainly in the Bay of Bengal. However, due to recent deglaciation and rapid melting of snow accumulated during winter, likely due to climate change, has created many glacier lakes in the Himalayan region (Shrestha et.al., 2011). This is contributing to the GLOF events in the mountain areas and relatively dense population of the hilly areas are getting affected.

In the four river basins where the literature review was carried, majority of floods occurred during the monsoon season (June-October). In recent years floods have been occurring almost each year. Few decades ago major floods would hit the region in every five to ten years or so. In the upper Indus basin, successive years of 2010, 2011 and 2013, resulted in killing more than 2,000 people. Similarly, in the Ganges river basin, floods have been occurring almost every year in the past couple of decades affecting crops, human settlements and public infrastructures. Floods coming from the upper reaches of the basin, like in the case of Karnali and Koshi, have resulted in death of hundreds of individuals. Resulting damages to crops and infrastructure, have yet to be recorded. The upper Teesta river basin has also seen a number of floods that occurred in the upstream region though they seem to be less studied. A partcularly difficult task during the literature review period, was to find sources on floods in the region. One reason could be that being a tributary of the Brahmaputra, flood events are studied and recorded in the downstream reaches of the river basin. Furthermore, given the inaccessibility and remoteness of the mountainous reach of the river basin, some events could happen completely unreported.

Cases of GLOF and LDOF are found in all river basins that have a fragile geography. In the western Himalayas of Indus river basin the quick melting of snow and glacier, accumulated during winter, in the spring leads to flash floods (Shrestha et.al., 2013), and higher chances of GLOFs. Millions of hectares of land are either cut or washed away by a single flood event with properties and infrastructures worth in billions of US dollar. The treacherous region of these upstream reaches of the rivers are hard to commute and the floods that occurred have found to wash away the bridges that are permanent or temporary.

Table 3.5: Occurence and impacts of Upstream floods in the Upper Indus River Basin (2010, 2011, 2013)

Months	J	F	M	A	M	J	J	Au	S	O	N	D
Pakistan												
Chenab River									1 million ha of agricultural land			
Ravi River										Breach of embank-ments		
Indus, Jhelum and Chenab									1,000 people killed, 13,000 villages inundated, 960,000 houses damaged			
Indus and Sutlej (July-September)									Killed 386 people, 557,000 houses damaged, loss of 14,000 cattles and 70,000 hectares of crops damaged			
Throughout Pakistan							Killed 1,600 people damage totaling over $10 billion inundated an area of about 38,600 km^2 50% of the damage in agriculture and lives-tock sector					
Sindh and Balochistan Province (August-Sept)								Affected 9.6 million with 200,000 people losing their homes				
Southern Punjab, Northern Sindh and North-east Balochistan Aug-Oct										571 reported dead, damaged more than 600,000 houses, ruined crops within an area of 500,000 ha		

Table 3.6: Occurence and impacts of upstream floods in the Upper Ganges, Gandaki and Upper Teesta river basins (years of occurence: 2008, 2009, 2012, 2013, 2016)

Months	J	F	M	A	M	J	J	Au	S	O	N	D
India												
Uttarakhand and Himanchal Pradesh						10,000 lives were lost						
North Bengal						10000 people affected (Flash Flood)						
Nepal												
Koshi								75 people dead, affected 50,000 people in Nepal and 3.5 million people in Bihar				
Mid-western and far-western										78 lives were lost, 15000 displaced		
Mid-western												Destroyed 8 wooden bridges (GLOF)
Mid-western					40 people dead, LDOF							

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4

Critical Moments Due to Downstream Floods in the Indus River Basin, and Ganges-Brahmaputra-Meghna River Basin

4. Critical Moments Due to Downstream Floods in the Indus River Basin, and Ganges-Brahmaputra-Meghna River Basin[8]

4.1. Introduction to Climate Change and Floods

The Hindu Kush Himalayan (HKH) region is a vast complex of high mountains, inter mountain valleys, and plateaus shared by Afghanistan, Bhutan, China, India, Nepal, Myanmar, and Pakistan. HKH region produces one of the largest freshwater supplies in the earth with mainly earth's largest six rivers namely Indus, Ganges, Brahmaputra, Mekong, Yangtze, and Yellow rivers. South Asian Hindu-Kush Himalayan (SA-HKH) region covers the basins of Indus, Ganges, Brahmaputra, and Meghna rivers in Pakistan, India, Nepal, and Bangladesh. In this literature review, we will summarize the critical moments due to downstream floods in these four river basins of SA-HKH region where Indus flows mainly through Pakistan, and the combined Ganges, Brahmaputra, and Meghna (GBM) rivers flow to the Bay of Bengal through mainly Nepal, India, and Bangladesh.

4.2. Physiography

4.2.1. Indus River Basin

The Indus River, also called Darya-e-Sindh or Sindhu River or Abasin, is a major river in SA-HKH region. It has a length of 3,180 km and an area of 1,165,000 km^2 draining runoff in China (2%), India (5%), and Pakistan (93%). Indus originates in the western part of Tibet in the vicinity of Mount Kailash and Lake Mansarovar. It runs through Ladakh, Jammu and Kashmir, Gilgit-Baltistan, and Khyber Pakhtunkhwa, and then flows along the entire Punjab region, draining into the Arabian Sea near the city of Thatta in Sindh.

4.2.2. GBM Rivers Basin

The Ganges-Brahmaputra-Meghna (GBM) river basin is a transboundary river basin with a total area of 1.7 million km^2 in India (64%), China (18%), Nepal (8%), Bangladesh (7%), and Bhutan (3%). Nepal is located entirely in the Ganges basin and Bhutan entirely in the Brahmaputra basin (FAO, 2011). The GBM river system is considered to be one transboundary river basin, even though three rivers of this system have distinct characteristics and flow through various regions for most of their lengths. They join a few kilometres upstream of the mouth of the Bay of Bengal. The GBM river system is the third largest freshwater outlet to the oceans, being exceeded only by the Amazon and the Congo river systems (Chowdhury & Ward, 2004).

The Ganges River, also called as Ganga, is a transboundary river flowing in Nepal, India and Bangladesh. It originates mainly from the glacier melt water of Gangotri glacier in the Himalayas flows through Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal in India, and Rajshahi, Dhaka, Khulna, and Barisal to the Bay of Bengal. Three major tributaries Ghaghara, Gandaki, and Koshi rivers originate from the high mountains in Nepal in the north and meet the Ganges in the south. The Ganges is the most sacred river to Hindus. It is worshipped as the goddess Ganga in Hinduism.

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The Brahmaputra River (son of Brahma) originates from the glacier melt water of mainly Angsi glacier in Tibet, Himalayas and flows through Tibet (China), Arunachal Pradesh, Assam (India), and Rangpur, Mymensingh, Rajshahi and Dhaka (Bangladesh) to the Ganges at Goalanda, then meets with Meghna at Chandpur and flows to the Bay of Bengal as a combined flow named as Lower Meghna river.

The Meghna River originates mainly from Barak river which rises from the Manipur hills, south of Mao in Senapati district of Manipur, India. It flows then along Nagaland-Manipur border through hilly terrains and enters Assam and further enters Bangladesh where the Barak is divided into Surma and Kushiyara rivers and later meets again and named Meghna river. The Meghna basin is bounded by the Barail range in the north, by the Naga and Lushai hills in the east and by Mizo hills in the south (India-WRIS, 2015).

4.3. Climate

The HKH region is characterised by a variety of climatic conditions from tropical to alpine. There is high variability of rainfall pattern with maximum precipitation during monsoon from west to the east of HKH region. The Himalayas are a major barrier of the monsoon cloud flow from southwest to northwest (5,000 m), hence most of the precipitation occurs due to this barrier and this precipitation pattern dominates in the east than in the west. Mean annual precipitation ranges from 300 mm in Ladakh area in the west to 1,400 mm in Kathmandu and 4,000 mm in Pasighat in the Brahmaputra basin (ICIMOD, 2002). The duration of rainy season increases from the west (2 months) to the east (8 months) of Himalayas, therefore, the duration of high flow season increases from west to the east. Precipitation is also highly influenced by local orography, i.e., it increases from valleys to high mountains where windward slope receives more precipitation than the leeward slope. High intensity rainfall occurs frequently in lowlands near the mountains than in the higher altitude which causes flash floods or upstream floods, however, such rainfall is highly localized. On the other hand, seasonal floods or downstream floods occur in floodplains of large rivers which receive precipitation continuously with medium intensity or a few high intensity rainfall events in their upstream catchment during the rainy season.

4.4. Hydrology

Over 80% of annual rainfall is concentrated in 3-4 months when most of that rainfall occurs during 45 rainy days. Table 1 summarizes the characteristics of major river systems in SA-HKH region with average annual discharge to the Arabian sea (Indus) and Bay of Bengal (GBM). The Indus river basin is the largest in four river basins (1,165,000 km^2) while Ganges is the second and Brahmaputra covers the third largest area. However, Brahmaputra is the longest river (3,848 km) out of these rivers with the highest mean annual flow of 19,800 m^3/s. The Bay of Bengal receives an average annual discharge of 40,048 m^3/s as the combined flow from the GBM basin (Wikipedia, 2017m).

Table 4.1: Characteristics of major river systems in SA-HKH region; adapted from Wikipedia (2017m)

Parameter	Indus	Ganges	Brahmaputra	Meghna
Catchment area (10^3 km^2)	1,165	907	712	82
Total length (km)	3.200	2,500	3,848	1,040
Average annual discharge (m^3/s)	6,600	16,648	19,800	3,600

4.5. Floods in Indus, Ganges, Brahmaputra and Meghna basins

4.5.1. Floods in Indus Basin

Floods hit every year in the river basins in SA-HKH region. Table 4.2 summarizes the flood damage, casualties (lost lives), and affected area since 1950. In terms of casualties, the 1950 flood is the most devastating when 2,910 people died. In recent years, 2010 flood is the most remarkable when 1,600 people have been died, >10 billion US$ direct losses, and >38,000 km^2 inundated. During last 62 years (1950-2011), 22 remarkable floods hit in the Indus floodplains that means 1 devastating flood in every 3 years hit in this river basin. Figure 4.4 shows inundated area in Upper Indus river valley in 2010 flood in Pakistan (right).

Table 4.2: Flood damage in the Indus basin, 1950-2011 (adapted from Ali (2013))

Year	Direct losses (US$ million)	Lost lives	Affected villages	Flooded area (km^2)
1950	227	2,910	10,000	17,920
1955	176	679	6,945	20,480
1956	148	160	11,609	74,406
1957	140	83	4,498	16,003
1959	109	88	3,902	10,424
1973	2,388	474	9,719	41,472
1975	318	126	8,628	34,931
1976	1,621	425	18,390	81,920
1977	157	848	2,185	4,657
1978	1,036	393	9,199	30,597
1981	139	82	2,071	4,191
1983	63	39	643	1,882
1984	35	42	251	1,093
1988	399	508	100	6,144
1992	1,400	1,008	13,208	38,758
1994	392	431	1,622	5,568
1995	175	591	6,852	16,686
1998	na	47	161	na
2001	na	201	na	na
2003	na	230	na	na
2010	10,056	1,600	na	38,600
2011	66	516	38,700	9,098

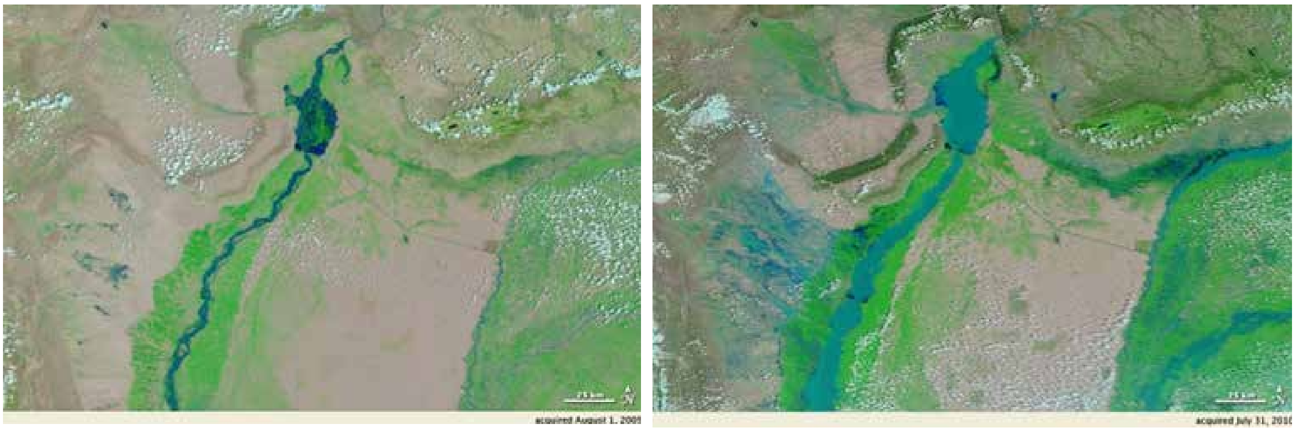

Figure 4.4: Satellite images of upper Indus River valley, comparing water levels on 1 August 2009 (left) and 31 July 2010 (right); blue colour shows the flood extent of the valley (source: Wikipedia (2017k))

4.5.2. Floods in Ganges-Brahmaputra-Meghna Basin

The main causes of floods are widespread and heavy rainfall in the upstream catchment areas and inadequate water carrying capacity of the rivers to contain flood water. India and Bangladesh suffer the most from downstream floods. India Today (2015) summarized the worst floods in India since 1947, however, only HKH river induced floods are listed here. It is documented that 1987 Bihar flood is the most devastating with 1400 people died, and 29 million people affected in 30 districts where more than 24000 villages inundated. Uttarakhand flood in 2013 is also very devastating hit as a flash flood destroyed bridges and roads and more than 5,000 people were presumed dead. The most recent 2016 flood killed 480 people in 11 states in India including Bihar, Maharashtra, Uttarakhand, Madhya Pradesh, Uttar Pradesh, Gujarat, Assam, Arunachal Pradesh and so on (Davies, 2016). Assam flood in 2012 took lives of more than 120 people (IndiaToday, September 7, 2015) and affected crops in more than 70 thousand ha and more than 5 million people evacuated from the affected area. The Jammu & Kashmir flood in 2014 is also remarkable although it is a flash flood in upstream areas of Indus basin when 2,600 villages were affected and 390 villages in Kashmir were completely submerged.

Table 4.3: Recent flood events – Ganges and Brahmaputra basins in India

Date of event	Affected cities/districts	Reference
July 15-28, 2016	Kishanganj, Purnea, Araria, Supaul, Katihar, Bhagalpur, Madhepura, Darbhanga, Saharsa, Gopalganj, East Champaran, Muzafferpur, West Champaran, Saran (Bihar)	Davies (, 2016)
July 1-29, 2016	Lakhimpur, Golaghat, Bongaigaon, Jorhat, Dhemaji, Sivsagar, Barpeta, Kokrajhar, Nagoan, Dibrugarh, Chirang, Goalpara, Tinsukia, Dhubri, Morigaon, Sontipur, Biswanath, Darrang and Nalbari	Davies (, 2016)
September 28, 2008	Lakhimpur, Bahraich, Gonda, Ayodhya, Tanda (Uttar Pradesh)	WB (2015)
August 24, 2008	Gorakhpur, Siwan (Uttar Pradesh); Chhapra, Samastipur, Madhupura, Sahibganj (Bihar)	WB (2015)
August 3, 2007	Bahraich, Ayodhya, Siwan (Uttar Pradesh)	WB (2015)
July 19, 2007	Motihari, Madhubani, Sitamarhi, Samastipur, Munger (Bihar)	WB (2015)

In Nepal, flash floods regularly hit the Koshi and Gandaki river sub-basins, two tributaries of Ganges river. For example, flash floods due to heavy rain for more than 10 days continuously killed 64 people and displaced thousands of people in July 2016 (The Times of India, July 27, 2016). The Makwanpur flood in 2002 (21-24 July) is the deadliest flood in Nepal (Wikipedia, 2017l) where 445 people were reported dead, and 49 out of 75 districts were affected (RedCross, 2003).

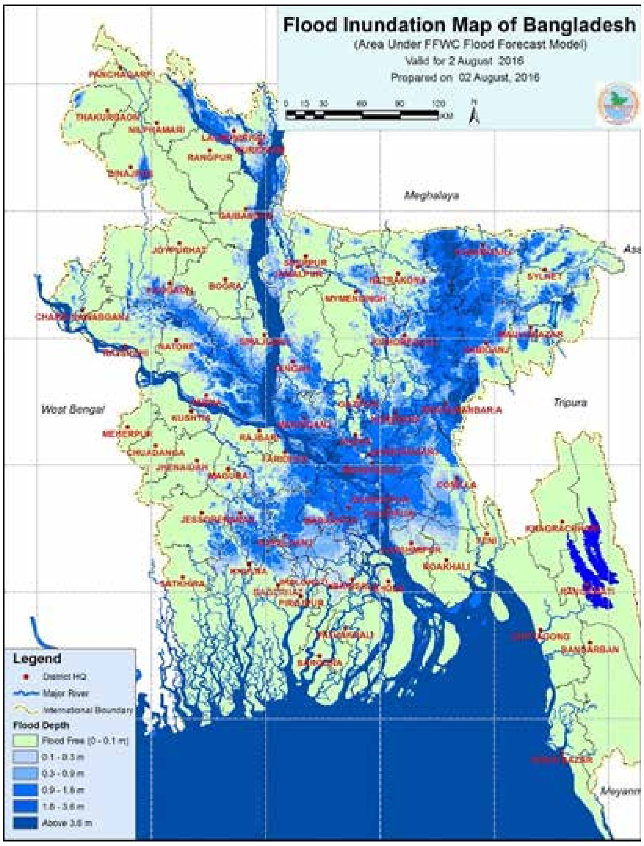

Figure 4.5: Flood depth map of Bangladesh on 2 August 2016 prepared by Flood Forecasting & Warning Centre of Bangladesh; the area inundated in this map is flooded every year (18% area)

In Bangladesh, as a downstream of three major rivers in SA-HKH region, floods hit every year both in the form of flash floods and seasonal long-stay floods. These inundate an average of 26,000 km^2 or 18% of total area of Bangladesh annually (FFWC-GOB, 2015). Figure 4.5 shows the flood extent and depth of inundation of average yearly floods. The areas near the Ganges-Brahmaputra-Meghna Rivers situated in middle, north, and northeast parts of Bangladesh are normally inundated every year and can be considered as floodplains of the major rivers. The areas can be divided into mainly two types of flooding flash floods, and seasonal floods. Northeast Sylhet region receives flash flood each year from the beginning of monsoon and turned as semi-permanent water bodies as haors. The elevation of this haor area is low (2-5 m above sea level), and a natural wetland ecosystem exists there. This region contains about 400 haors and beels, varying in size from a few hectares to several thousand hectares. There are also a few scattered wetlands distributed over the country e.g., Chalan beel in northern Rajshahi division, through which the Atrai River passes; and beel Dakatia and other small beels in Khulna division. The rest middle and northern parts are inundated every year which are mainly active floodplains of large rivers.

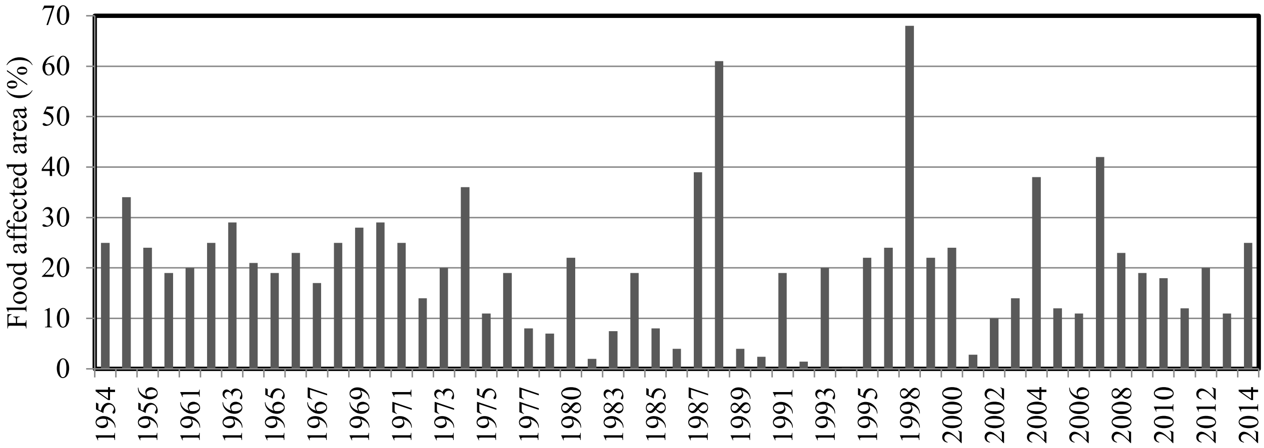

Figure 4.6: Affected area (% of total area) of each year floods in Bangladesh of last 61 years; data used from FFWC-GOB (2015)

Figure 4.6 shows the percentage of flood affected areas every year since 1954. Flood of 1998 is the most devastating when 68% of the country remained under water which is considered as a frequency of one in hundred years. Apart from that, floods of 1988 (61% area inundated), 2007 (42%), 1987 (39%), 2004 (38%), and 1974 (36%) are remarkable. Out of all these, 1974 flood is the deadliest in the history in terms of death toll (28,700 people died) (Wikipedia, 2017l).

In Bangladesh, the areas near the Ganges-Brahmaputra-Meghna rivers situated in middle, north, and northeast parts of Bangladesh are normally inundated every year and can be considered as floodplains of the major rivers (Figure 4.5). The areas can be divided into mainly two types of flooding flash floods, and seasonal floods. Northeast Sylhet region receives flash flood each year from the beginning of monsoon and turned as semi-permanent water bodies as haors. The elevation of this haor area is low (2-5 m above sea level), and a natural wetland ecosystem exists there. This region contains about 400 haors and beels, varying in size from a few hectares to several thousand hectares. There are also a few scattered wetlands distributed over the country e.g., Chalan beel in northern Rajshahi division, through which the Atrai River passes; and beel Dakatia and other small beels in Khulna division. The rest middle and northern parts are inundated every year which are mainly active floodplains of large rivers.

4.6. Critical Moments of Floods in Downstream Areas

Table 4.4 summarizes the important devastating floods in Pakistan, India, Nepal and Bangladesh where it shows that floods hit in SA-HKH region mainly during April to October. In hilly areas or in areas where hills and mountains are nearby, flash floods hit during both pre-monsoon (April - May) and monsoon (June - October) while in floodplains or the areas far from the hilly or mountainous region, normally seasonal monsoon floods occur where river discharge accumulates from a large area of upstream catchment. Therefore, physically the critical moments due to floods in IGB basins may be considered in Pakistan as April, and August – October; in India as June – September; in Nepal as May – September; and in Bangladesh as April – October. However, low-lying areas e.g., in Bangladesh the floodplains of major rivers (Ganges-Brahmaputra-Meghna) are flooded each year which is about 18% of Bangladesh area. Table 4.5 summarizes the adaptations strategies both planned and autonomous practised in the downstream of the IGBM basins at present.

Table 4.4: Summary of upstream and downstream floods in Indus and Ganges-Brahmaputra-Meghna basins

Months	J	F	M	April	May	June	July	August	September	October	Nov	D
Pakistan (not specific for a particular research site)							X Floods / flash floods?? CM?	X Floods / flash floods?? CM?	X Floods / flash floods?? CM?	X Floods / flash floods?? CM?	CM?	
1955 flood: Indus, Ravi river basin (Ali, 2013)										4-6 October; flash flood; 500 mm of rainfall in 2 days; Dalhousie, Sialkot, and Ujh cities inundated		
1973 flood: Indus, Chenab basin (Ali, 2013)									Not mentioned the time			
1976 flood: Indus, Jinnah and Guddu barrages (Ali, 2013)							Whole July and August	425 people killed, $1.62 billion damage; affected >18,000 villages				
1988 flood: Indus; Ravi, Sutlej, and Chenab rivers (Ali, 2013)									23-26 September 4-day long >400 mm rainfall caused flood; 500 people killed, $0.4 billion damaged			
1992 flood: Indus; Jhelum and Chenab rivers (Ali, 2013)									7-11 September 5-day long rainfall caused flood; 1,000 killed, 960,000 houses damaged, 4.8 million people and 13,000 villages affected, $0.5 billion damage			

1994 flood: Indus and Sutlej rivers (Ali, 2013)							5-8 July 133 mm rainfall in Jhelum city caused flood; 386 people killed; 557,000 houses damaged; 14,000 cattle and 700,000 ha crops loss					
2005 and 2006 flood: Kabul and Chenab rivers (Ali, 2013)							2005: A flood peak of 10,987 m^3/s at Jammu (India); 9,770 m^3/s at Marala barrage; and 10,420 m^3/s at Khanki headworks		2006: A flood peak of 4,785 m^3/s at Tarbela dam release from Kabul river to Indus river to generate 14,866 m^3/s at Jinnah barrage 2 floods resulted 591 people killed; 1 million ha crops loss in 117 districts			
2010 flood: Sindh and Balochistan provinces (Ali, 2013)								Rainfall of 2.5 times higher than normal in August and September caused prolonged flood;	571 people killed; >600,000 houses damaged; 500,000 ha crops loss			
2010 super flood: Whole Indus floodplains (Ali, 2013)							29-30 July torrential rainfall caused super flood; 1,600 people killed; $10 billion damaged (43% in Sindh, 26% in Punjab; 12% KPK; 6% Balochistan; 11% national infrastructure damaged);	2 million house damaged; 38,600 km^2 inundated				
2011 flood: Indus in Sindh province (Ali, 2013)								Flood stayed 11 August – 14 September;	434 people killed; >1.5 million houses damaged;			

2012 flood: Indus in KPK, upper Sindh, southern Punjab, and eastern Balochistan (Wikipedia, 2017c)									6-12 September heavy rainfall caused flood; 455 people killed;			
2013 flood: Indus in KPK, Punjab, Sindh, and Baluchistan (Wikipedia, 2017e)								31 July – 5 August heavy rainfall caused flood; 80 people killed;				
2014 flood: Indus, Chenab, and Jhelum rivers (Wikipedia, 2017f)									2-5 September heavy rainfall caused flood in Jammu and Kashmir in India, and Azad Kashmir, Gilgit-Baltistan, and Punjab in Pakistan; 277 people in India and 280 people in Pakistan died			
2015 flood: Indus (FFC-GOP, 2016)								3-4 August heavy rainfall caused flood; 238 people killed in Azad Kashmir, Gilgit-Baltistan, KPK (Chitral valley), Punjab, and Balochistan				
2016 floods: flash flood on April 3; and seasonal flood in August (Wikipedia, 2017g)				71 people killed in April 3-5 flood				82 people killed in August flood				

India (not specific for a particular research site)												
Gandaki: flash flood (Davies, 2016)							July 15-28, 2016: Kishanganj, Purnea, Araria, Supaul, Katihar, Bhagalpur, Madhepura, Darbhanga, Saharsa, Gopalganj, East Champaran, Muzafferpur, West Champaran, and Saran (Bihar)					
Gandaki: flash flood (Davies, 2016)							July 1-29, 2016: affected area- Lakhimpur, Golaghat, Bongaigaon, Jorhat, Dhemaji, Sivsagar, Barpeta, Kokrajhar, Nagoan, Dibrugarh, Chirang, Goalpara, Tinsukia, Dhubri, Morigaon, Sontipur, Biswanath, Darrang and Nalbari					
Upper Ganga and Ghaghara: flash flood (WB, 2015)									September 28, 2008: affected area Lakhimpur, Bahraich, Gonda, Ayodhya, Tanda (Uttar Pradesh)			
Upper Ganga: flash flood (WB, 2015)								August 24, 2008: affected area-Gorakhpur, Siwan (Uttar Pradesh); Gandaki: Chhapra, Samastipur, Madhupura, Sahibganj (Bihar)				

Upper Ganga: flash flood (WB, 2015)								August 3, 2007: affected area- Bahraich, Ayodhya, Siwan (Uttar Pradesh)				
Gandaki: flash flood (WB, 2015)							July 19, 2007: affected area-Motihari, Madhubani, Sitamarhi, Samastipur, Munger (Bihar)					
Upper Ganga: flash flood (Wikipedia, 2017d)						14-17 June 2013; flash flood affected area- Gobindghat, Kedar Dome, Rudraprayag in Uttakhand and adjoining areas in Himachal Pradesh and western Nepal						
2008 Bihar flood (Wikipedia, 2017b)								August 18, 2008: flash flood affected northern Bihar; 434 killed; it is one of the most disastrous floods in history of Bihar				
Nepal						X GLOF	X GLOF	X GLOF	GLOF	Floods / land slides		
Makwanpur (central Nepal) flood 2002 (Red-Cross, 2003)							July 2002 Makwanpur flood is the deadliest flood in Nepal (Wikipedia, 2017l) with 429 people killed. Heavy rain of July 21-24, 2002 was the highest rain in past 3 decades causes floods in 49 districts out of 75 districts of Nepal (RedCross, 2003)					

14 districts in western Nepal including Pyuthan (Correspondent, 2016)							July 2016, 64 people killed due to 10 days continuously heavy rain causes flash flood and landslide; water flow >7,800 m^3/s at Narayani* river at Gandak barrage at Nepal-India border (all gates open)					
Seti Gandaki river flash flood 2012 (Wikipedia, 2013)					On May 5, 2012 GLOF caused 26 killed and 44 missing at 2 villages in Pashchimanchal							
2007 devastating flood (Wikipedia, 2017a)							From 23 July flash flood and landslide 84 killed, 28 out of 75 districts affected					
1993 flash flood (Reliefweb, 1993)							July-August: 1,048 killed;	35 districts affected				
2008 Nepal floods (Correspondent, 2008)								August 18, 2008 flash flood washed away some 10 km of east-west highway in Nepal; Bihar and Uttar Pradesh in India also inundated	19-21 September flash flood hit at Kailali and Kachanpur of western Nepal			

2014 landslide and flash flood (Reliefweb, 2014)								August 2, 2014: heavy rain caused massive land-slides in Sind-hupalchowk district which created a 130 m high artificial dam (2.5 km length) across Saptokoshi river and large volume of water collected above the dam; August 18 that dam caused flash floods down-stream and 156 people killed; August 14-16 another heavy rainfall caused several landslides in 18 districts when 53 people killed				
2013 flash flood (ICI-MOD, 2013)						June 16-17, 2013: Heavy rainfall caused flash flood in 20 districts in Nepal in Ma-hakali river and several districts in Uttakhand and Himalchal Pradesh in Kar-nali river; 550 killed in India; and 10 killed and 19 missing in Nepal						

2012 flash flood (ICIMOD, 2013)						June 2012: 145 families displaced and 2200 HH affected in Dang region						
2011 flash floods and landslides (ICIMOD, 2013)						June 2011: 25 deaths; 515 houses destroyed in 14 districts namely Baitadi, Achham, Kalikot, Jajrkot, Rukum, Rolpa, Kaski, Tanahu, Makwanpur, Gorkha, Nuwakot, Sindhuli, Sarlahi, and Solukhumbu		August 2011: 65 deaths; 35 missing; 24 injured; 110 houses destroyed in 9 districts namely Dailekh, Jajarkot, Rukum, Palpa, Rupandehi, Parbat, Dhading, Sindhuli, and Solukhumbu				
2010 flash floods (ICIMOD, 2013)						June-August 2010: 98 deaths, 8 missing;	2835 houses destroyed in 6 districts namely	Dadeldhura, Bajura, Achham, Rukum, Kaski, and Illam	September 2010: 60 houses damaged on the Mahakali river in Kanchanpur			
Bangladesh (not specific for a particular research site)							Floods / flash floods/ CM	Floods / flash floods/CM	Floods / flash floods/CM	Floods / flash floods/CM	CM	
1974 seasonal flood (Wikipedia, 2017h)								1974 famine was concentrated in areas where floods hit; 1.5 million people killed due to famine (Wikipedia, 2017h); 1987 people killed due to flood (Wikipedia, 2017i); 36% area affected				

1987 seasonal flood (Dartmouth-College, 2003a)							July 23 – September 24, 1987 63 days long flood	Affected districts: Rangpur, Dinajpur, Gaibaha, Kurigram, Noakhali, Noagaon, Mymensing, Sylhet, Netrokona, Jamalpur, Cox's Bazar, Chittagong, and Chapai Nawabganj (39% of country area)	Rivers: Ganges, Brahmaputra, and Teesta; 880 people killed; worst flood in last 40 years			
1988 devastating flood (Dartmouth-College, 2003b)								August 20 – October 3, 1988 45 days long flood	61% of country area (53 out of 64 districts) flooded; Dhaka city 85% inundated by Buriganga river; other cities under 1.5 – 3 m of water; severe damage in Serajganj, Gopalganj, Tangail, Rajbari and Faridpur districts; 1378 people killed; worst flood in last 70 years	Bramahaputra, Ganges and Meghna rivers and their tributaries		
1998 devastating flood (Dartmouth-College, 2006; Relief-web, 1999)							July 5 – September 22, 1998 80 days	68% of Bangladesh area (32 of 64 districts) flooded (Relief-web, 1999); flooded area: Bangaldesh - Dhemaji, Nalbari, Sirajganj, Netrokana, Rangpur, Khagrachari, Magura, Pabna, Dhaka, Dhubri, Madlda, Faridpur, Manikganj, Gai, Bandha, Bogra, Jamlpur, Chittagong, Manikganj, Chandpur, Buriganga India - Uttar Pradesh, Assam, West Bengal, Bihar (Dartmouth-College, 2006)	1050 people killed (Bangladesh) (Relief-web, 1999); 2632 people killed (India, Bangladesh) (Dartmouth-College, 2006)			

2004 three floods in different times (Dartmouth-College, 2005)				April 14 – May 3, 2004 flash flood: north-eastern districts of Bangladesh and Manipur and Tripura in India flooded;	12 people killed in April flood	June 20 – Oct 7, 2004 floods in India, Bangladesh and Myanmar;	India- Bihar 18 out of 38 districts; Assam 26 out of 28 distrcits; Tripura 1 district; Arunachal Pradesh 3 districts; West Bengal 14 districts; Uttal Pradesh 1 district flooded;	Bangladesh 25 out of 64 districts flooded	South Asia's worst monsoon flooding in 15 years; India 2178 deaths since June (Bihar 611, Assam 88, Tripura 3); Bangladesh 898 deaths since June	October 7-18, 2004 12 days flood: India-Krishnai, Ronguli, Dudhnoi, Hugli; Bangladesh- Atrai, Little Jamuna, Surma rivers flooded; 7 districts in Assam, 1 in Meghalaya, 8 districts in West Bengal flooded; 6 districts in Bangladesh flooded; 210 people killed including 160 in Assam;		
2007 two floods (Dartmouth-College, 2008)						June 11-24, 2007 flash floods in Chittagong and Sylhet region; 126 people killed in mudslide in Chittagong	July 21 – October 15, 2007 seasonal floods in India and Bangladesh	1071 peopled killed in Bangladesh since July; crop damage in 56 districts; Dhaka city most area flooded;	September 17 – flood renewed	October 15 – floodwater recession		

*The same river is called Narayani in Nepal and Gandaki in India

Table 4.5: Adaptation/ coping strategy of critical moments due to floods

	CM (e.g. month/ period) and type of flood	Adaptation /coping strategy	Literature reference
Pakistan (not specific for a particular research site)	2010 July floods are the worst flooding in the past 80 years in Pakistan	12 organizations participate in flood mitigation and management work which can broadly be divided into: (i) flood-related planning, operation, maintenance, and management of major infrastructure; (ii) flood forecasting and early warnings; and (iii) rescue and relief operations.	Ali (2013); FFC-GOP (2016)
Research site: Nowshera, KPK, Pakistan		Shelter belt/tree plantation; food grains storage; short duration crops; building modification	Ahmed (2013)
Research site: Dera Allah Yar, Jaffarabad, Pakistan		100 flood resilient shelter and food security through housing support, a climate smart agricultural programme, and a climate based flood adaptation programme	CSD (2017)
Research site: Bindo Gol valley, KPK, Pakistan		Community made flood-control gabion walls	Shaikh and Tunio (2015)
Research site: Badin, Karachi and Thatta districts, Pakistan	2010 floods	Watan card system in Pakistan: Cash transfer scheme-based on so called Watan cards to compensate families directly affected by the 2010 floods. However, local government's capacity and problems of communicating information have been the biggest obstacles to the execution of the scheme as beneficiary needs an ID card as reported by (Schilling, Vivekananda, Khan, & Pandey, 2013)	Schilling et al. (2013)
India			
Research site: Gorakhpur, Uttar Pradesh, India	Seasonal flood	(i) start preparation to face the flooding during March-May for identifying safe places in case of evacuation; storage of food, fodder and fuel; make arrangements to protect houses, repair mud walls and roof tops, raising adjacent areas near habitation etc.; (ii) during floods the whole community unites in saving life and property normally during mid-June to September; and (iii) recovery phase continues October – December and beyond.	Richa, Anil-K, and Mohammad (2012)
Research site: Jagatsinghpur and Puri, Orissa	Seasonal flood	(i) income diversification from agriculture to non-agricultural activities; (ii) 37% HH store food grain or took public shelters; 22% HH construct high shelves for food grain storage; 20% HH took crop insurance (high resilience); and 16% HH constructed flood proof houses (iii) reactive measures taken instantly e.g., 54% HH borrow money from formal (48%) and informal (52%) sources; 15% HH sold cattle and jewellery	WB (2008)

Research site: Flood prone areas in India	All type of floods	Government flood management divided into structural and non-structural measures: (i) Structural measures: embankments (Kosi and Gandak in Bihar, Brahmaputra in Assam, Godavari and Krishna in Andhra Pradesh, Mahanadi, Brahmani, Baitarni and Subarnarekha in Orissa, and Tapi in Gujarat protected by embankments), flood walls , sea walls; dams and reservoirs; natural detention basins; channel improvement; drainage improvement; diversion of flood waters; upto 2005, 34,400 km new embankment; 51,300 km drainage channels constructed; 2,400 towns protected by structures; 4,721 villages raised above flood levels (flood proofed) (ii) Non-structural measures: flood forecasting and warning; floodplain zoning; flood fighting; flood proofing; and flood insurance	Das, Gupta, and Varma (2007)
Nepal			
Research site: 14 districts in Nepal	July 2016 flood	US$7.4 million for immediate rescue, relief, and rehabilitation by GON;	Correspondent (2016)
Research site: Makwanpur, Nepal	July 2002 flash flood	US$2.5 million for immediate rescue, relief, and rehabilitation by Nepal Red Cross along with GON	RedCross (2003)
Research site:			
Bangladesh			
Research site: Goalanda, Rajbari, Bangladesh	Seasonal flood in Ganges and Brahmaputra rivers floodplains	(i) Drinking water: 43% HH collects water from a distant place using boats; 32% protects tubewell from inundation by raising tubewell platform or by adding extra pipe; 17% use flood water with purification; 8% use flood water without purification (ii) Sanitation: only 3% HH use safe toilets by raising platform; 42% use hanging latrines; 28% open defecation; 20% defecation into flood water from boat; and 7% use other unhygienic latrines (iii) Store food: 55% HH don't store food at all; 32% store dry food that directly can be taken (chira-muri-gur); 13% store dry food by to cook (chal-dal-tel-nun) (iv) Health: due to water borne diseases 55% left with no treatment; 18% visited village doctor; 17% health centre; 10% allopathic doctor	Shimi, Parvin, Biswas, and Shaw (2010)
Research site: Flood affected areas of Bangladesh	Seasonal floods in 2004	(i) Rescue operations by army and district administration; (ii) Relief: GOB distributed 47,500 MT rice to 21.4 million people in 41 districts; 9,600 MT to 4.3 million people for additional riverbank erosion; then formal vulnerable group feeding to 22.5 million people 10 kg per month per family until December 2004; (iii) Livelihood programme: cash for work or food for work programmes for road and embankments repair, canal and pond re-excavation, roadside plantation, flood shelter repair, etc. (iv) Community adaptations: raising house plinths and homestead compounds; building houses with concrete pillars; raising internal platforms (machang) or on higher ground; selling labour in advance below market price; migration to main cities; selling of assets like livestock below market price;	Reliefweb (2004)

4.7. Discussion and Conclusions

The critical moments due to floods can be broadly divided into two parts: during flood, and after the flood. When floods hit any areas where people live with their livelihoods, the sufferings and struggling start to protect their lives, livelihoods, and assets. The floods start hitting from the monsoon onset mid-June mainly in the upstream areas; till the end of monsoon (end of September). Several floods can hit in the same areas in a year. Therefore, people normally prepare themselves for the whole monsoon to survive with the floods mainly in floodplains in the river basins of SA-HKH region. The situation at different parts of the river basins is turned to worse as there may be an acute shortage of pure drinking water in addition to improper sanitation. During floods it is very challenging for the flood affected people to secure drinking water and sanitary toilets. The flood affected people sometimes have to sell their livelihood assets at low prices.

With recession of floodwater, diarrhoea and other waterborne diseases spread sporadically among the flood-affected people, intensifying the sufferings of the flood victims especially children, women and elderly people. The victims are mainly suffering from diseases like diarrhoea, dysentery, fever, eczema, itches and other waterborne diseases.

In Bangladesh, during monsoon (kharif cropping season) there are mainly two crops in the field transplanted aman rice, and jute. Jute is harvested when seasonal floods start. Transplanted aman rice can survive even for 72 hours if it is totally inundated by floodwater, or can grow more with the increase of flood depth. However, during floods, the most vulnerable people in the floodplains, the agricultural labourers are out of their jobs, therefore, they need alternative livelihoods.

Monsoon floods affect lives, livelihoods mainly agriculture, drinking water, sanitation, health, energy, and infrastructure including houses. Downstream areas of SA-HKH river basins have large agrarian economy e.g., agriculture sector provides 30% and 19% of GDP in Nepal and Bangladesh respectively and supports 86% and 45% of the total labour forces (Sterrett, 2011). After the floods, water-borne diseases, diarrhoea, snake bites take place in many areas. During 2007 monsoon floods in Bangladesh, snake bites were estimated to be the second cause of death after drowning and caused more deaths than diarrheal and respiratory diseases (Dewan, 2015). Other major impacts of floods include loss of employment, unavailability of fuel-wood for cooking, etc. Fuel-wood such as cow dung, jute stick, tree branches or wood are normally washed away or become wet. Day labourers often starve to death due to staying for long periods with no work or due to sickness. During the 1988, 1998, and 1999 floods in Bangladesh hundreds of industries, especially garments factories went under water which destroyed raw materials, machineries of millions of dollars and a few factories never recovered. Due to this, thousands of workers were unemployed (Dewan, 2015).

During monsoon the seasonal floods occur mainly in July, August and September in the downstream region of Indus and GBM river basins in SA-HKH region. The critical moments due to floods are not restricted to only during floods for mainly the vulnerable people who reside in mainly floodplain area. It extends up to October-November to regain the strength to adapt with the natural disasters again. However, policies and actions to be taken into consideration to save the flood affected people and their livelihoods.

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5

Critical Moments in Health Due to Heat Stress

5. Critical Moments in Health Due to Heat Stress[9]

5.1. Introduction to Climate Change and Health

The impacts of climate change include rising temperatures, changes in precipitation (leading to floods or droughts), increases in the frequency or intensity of some extreme weather events, and rising sea levels. These changes influence human health by affecting the food we eat, the water we drink, the air we breathe, and the weather we experience (Haines, Kovats, Campbell-Lendrum & Corvalan, 2006; Patz, Campbell-Lendrum, Holloway & Foley, 2005). Between 2030 and 2050, climate change is expected to cause roughly 250,000 additional deaths per year from malnutrition, malaria, diarrhoea and heat stress (WHO, 2014). Several direct, indirect and systematically mediated health effects have been acknowledged due to climate change (Kjellstrom & McMichael, 2013).

Direct risks include the primary health impacts of heat waves, extreme weather events, such as storms, floods and droughts, and altered air quality. Excessive daily heat exposures create direct effects, such as heat stroke, homeostatic failure, disease exacerbation, reduce work productivity, and interfere with daily household activities. Such effects are exacerbated by changes in air quality: ground level ozone levels rise with temperature, threatening human health (McMichael, Montgomery & Costello, 2012). It has been firmly established that breathing in the ozone can cause inflammation in the deep lung as well as short-term, reversible decreases in lung function. In addition, epidemiologic studies of people living in polluted areas have suggested that ozone can increase the risk of asthma-related hospital visits and premature mortality (Kinney, 2008). Extreme weather events, including storms, floods, and droughts, create direct injury risks and follow-on outbreaks of infectious diseases, under-nutrition, and mental stress (McMichael et al., 2012) (indirect risks).

Indirect risks arise from changes and disruptions to ecological and biophysical systems, affecting food yields, the production of aeroallergens (spores and pollens), bacterial growth rates, the range and activity of disease vectors (such as mosquitoes), and water flows and quality. These indirect risks cause malnutrition, spread of vector-borne diseases and other infectious diseases, and mental health and other problems caused by forced migration from affected homes and workplaces. In the longer term and with significant discrepancy between populations, indirect health impacts are likely to have a bigger influence than the more direct (McMichael, 2003). Examples of systemically mediated impacts on population health comprise famine, conflicts, and the consequences of large-scale detrimental economic effects due to reduced human and environmental productivity (Kjellstrom & McMichael, 2013).

The severity of these health risks will depend on social mechanisms such as the ability of public health and safety systems to address or prepare for these changing threats, as well as factors such as an individual's behaviour and their socio-economic status and demographics (Watts et al., 2015). Next to elderly people and people with pre-existing medical complications, the poor and children are regarded as the most vulnerable regarding climate induced or exacerbated health issues (Neira, Bertollini, Campbell-Lendrum & Heymann, 2008). Typical childhood maladies of poverty, such as diarrhoea, malaria and infections associated with malnutrition, are seen as the most climate-sensitive ones (Hunter, 2003; Neira et al., 2008; Patz, Gibbs, Foley, Rogers & Smith, 2007). South Asia is projected to be the region most affected by the health effects of climate change (WHO, 2014).

Although additionally to climate there are many other factors such as individual behaviour and social- and economical mechanisms influencing health, the following overview will mainly describe climate parameters, thresholds and critical factors which are associated with heat stress as this is a special focus within HI-AWARE.

[9]Tanya Singh (WENR)

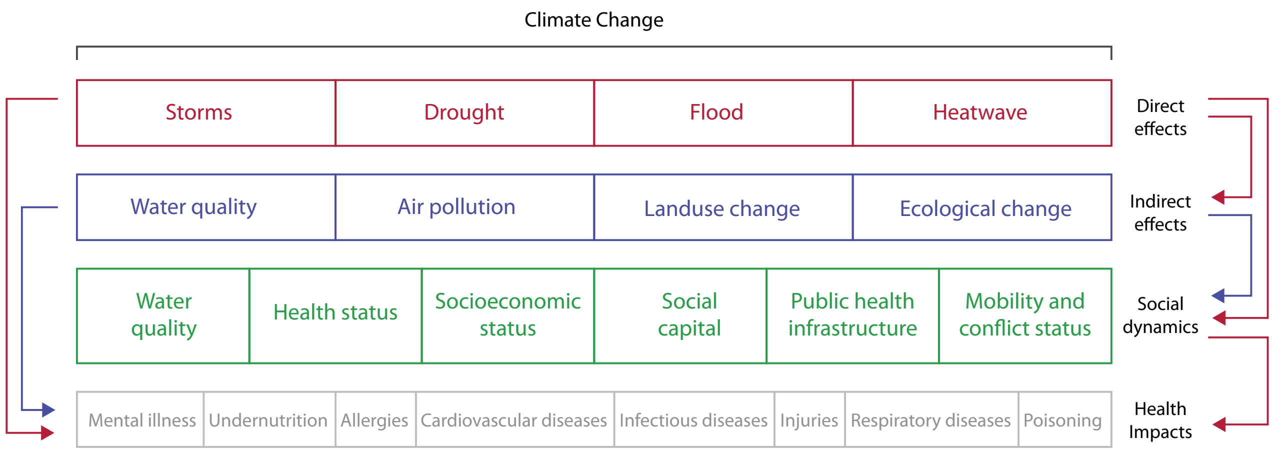

Figure 5.1: Climate change health pathways (Source: Adapted from Watts et al., 2015, p. 1867

5.2. Heat and Health

Heat stress is defined as "any combination of work, airflow, humidity, air temperature, thermal radiation, or internal body condition that strains the body as it tries to regulate its temperature. When the strain to regulate body temperature exceeds the body's capability to adjust, heat stress has become excessive" (Pinkerton & Rom, 2014). It can cause the development of various preventable heat-related medical conditions including heat rash, heat oedema, heat syncope, heat craps, heat exhaustion and a life-threatening heatstroke (Matthies, Bickler, Marín, & Hales, 2008). In addition, it aggravates existing health conditions such as respiratory, cardiac, kidney and psychiatric conditions (Kovats & Hajat, 2008).

People's vulnerability to heat depends not only on climate conditions, but also on socio-economic factors, medical conditions, behaviour and risk awareness, and on environmental determinants (e.g. housing conditions) (Grothmann & Patt, 2005; Tan, 2008). Some population groups are specifically vulnerable to heat-related illnesses. These include the elderly, children, pregnant women, people with chronic diseases, people taking certain medications, and occupations demanding physical labour work in an hot environment (Matthies et al., 2008).

Heat events are especially severe in urban areas as they have higher levels of heat exposure than in rural areas due to the phenomenon called the urban heat island effect whereby city temperatures are higher due to morphological, radiative and thermal properties (Oleson et al., 2015). Around the world there is an increase in urbanisation, ageing population and an increase in non-communicable diseases, adding to the population at risk (A.R., 2015; Burkart et al., 2014; Chaudhry, Rasul, Kamal, Mangrio, & Mahmood, 2015).

Furthermore, slum communities are more susceptible to the negative consequences of heat. This is due to the following factors: poor housing quality (crowding, heat trapping building materials, limited ventilation), carrying out physical labour or working in hot conditions, lack or limited access to medical care and water, pre-existing medical conditions, limited access to cooling resources due to unreliable or unavailable electricity supply, lack of cool public and open spaces and greenery. Also people lack access to information regarding heat adaptation measures and have a low risk perception(2013, 2013).

Without adequate adaptation measures, higher ambient temperatures will lead to increased morbidity and mortality rates.

5.2.1. Challenges in Defining Critical Moments in Heat Health Research

Although heat stress has been identified as a major threat to human health, several aspects make studying the relationship between heath waves and health challenging:

1. There does not exist one universal temperature threshold above which higher health risks start occurring around the world. Human populations are adapted to their local climates due to local behavioural, physiological and technological acclimatization differences and mortality risk increases outside a location-specific optimum temperature range (Kovats & Hajat, 2008). Therefore for each case a location-specific analysis is required when it comes to thresholds.

2. The majority of studies of heat-related mortality were conducted for individual urban populations in Europe, the United States of America and China. There is very limited research on temperature–mortality functions for rural populations and populations in South Asia ((WHO, 2014).

3. Similarly, an universal definition of heat waves is lacking as well. Meteorological conditions during a heatwave make some events potentially more dangerous than others. Uncertainty still remains as to which weather parameters are most hazardous. Most studies focus on temperature alone due to data availability and simplicity when establishing a relation between heat and health. A number of studies have consistently identified high night-time temperatures and high relative humidity, duration, and early seasonal occurrence of heatwaves (due to low acclimatisation) as particularly dangerous conditions (Fischer & Schär, 2010; McGeehin & Mirabelli, 2001; Patz et al., 2005).

   A Lancet Commission on Health and Climate Change projecting future heat exposure under climate change uses following definition of a heat wave: a heatwave is defined as more than 5 consecutive days for which the daily minimum temperature exceeds the summer mean daily minimum temperature in the historical period (1986–2005) by more than 5°C (Watts et al., 2015). Different socio-economic groups and indirect deaths due to heat are not represented in local thresholds, meaning that each group and disease/cause of death could have a different threshold. Heat wave-related deaths are likely to be underreported due to a lack of a clear case definition and the multi-factorial nature of heat-related mortality. Mortality figures usually only include deaths caused directly by heat strokes and ignore that already diseased people suffering from e.g. cardio-respiratory conditions are more susceptible to heat stress. Furthermore, these official data only consider deaths in which heatstroke is established to be the cause in official records through a post-mortem. However, many death cases do not go through a post-mortem in South Asia. This accounts especially for the poor who are less likely to die in hospitals. Also in some cases families are reluctant to conduct post-mortems as superstitions abound about the removal of organs from the dead.

4. Epidemiological studies which derive a relation between health and heat usually make use of temperatures recorded at standardised locations outside city limits. In general, they do not cover the conditions in which the most vulnerable people, the urban poor people, actually live. Urban microclimates have a role in creating higher temperatures in some parts of cities (Azhar et al., 2014). In addition, indoor temperatures can differ greatly from outdoor temperatures. Understanding individual exposure levels of vulnerable groups is not only relevant for defining a more accurate heat stress threshold compared to the conventional studies, but also of importance for health intervention strategies, house constructions and spatial planning purposes.

5.2.2 Heat Related Health Hazards in South Asia and Different Thermal Comfort Indices

Wet bulb temperature

In the summer of 2015 India and Pakistan were struck by a severe heatwave causing thousands of deaths (Khadka, 2015; Ratnam, Behera, Ratna, Rajeevan & Yamagata, 2016). Low air pressure, high humidity and an unusually absent wind played key roles in making high temperatures unbearable (Khadka, 2015). Around this period many newspaper articles, blogs and conference presentations came up arguing that a wet bulb temperature (WBT) around 31-32°C seem to be dangerous levels for an active population (N.A., 2015).

WBT is a physically based index that takes into account both air temperature (dry bulb temperature) and humidity. When WBT is higher than 35°C, human skin can no longer itself cool down through evaporation and exposure to such a temperature level above six hours would be intolerable even for the fittest of humans, resulting in hyperthermia. This value has not been reached yet on Earth. However, according to the grey literature peak WBT

measured in the heat wave in India in 2015 were only 30-31°C. The US military suspends training and physical exercise when this temperature exceeds 32°C, as the 35°C WBT threshold is a value for a healthy, fully hydrated person in the shade who is not active.

Heat Index

A thermal comfort index developed in the US and called the 'heat index', which is a combination of air temperature and relative humidity measures how hot someone feels. A heat index above 41°C can cause heat exhaustion after a prolonged exposure and a heat stroke if combined with continued activity. A heatstroke is not unlikely in an environment with and index more than 54°C and no physical activity (Technical Report on Karachi Heat wave June 2015, Qamar uz Zaman Chaudhry et al 2015). On the heat index scale in Karachi during the heat wave in 2015 the maximum air temperature recorded was 44.8°C, but the heat index was between 58°C and 66°C on the peak heat wave day. For more detail on different critical levels on the heat index see Figure 5.2.

HEAT INDEX °F (°C)

The heat index is an accurate measure of how hot it really feels when the affects of humidity are added to high temperature.

Temp.	RELATIVE HUMIDITY (%) 40	45	50	55	60	65	70	75	80	85	90	95	100
110 (47)	136 (58)												
108 (43)	130 (54)	137 (58)											
106 (41)	124 (51)	130 (54)	137 (58)							nbsp;			
104 (40)	119 (48)	124 (51)	131 (55)	137 (58)									
102 (39)	114 (46)	119 (48)	124 (51)	130 (54)	137 (58)								
100 (38)	109 (43)	114 (46)	118 (48)	124 (51)	129 (54)	136 (58)							
98 (37)	105 (41)	109 (43)	113 (45)	117 (47)	123 (51)	128 (53)	134 (57)						
96 (36)	101 (38)	104 (40)	108 (42)	112 (44)	116 (47)	121 (49)	126 (52)	132 (56)					
94 (34)	97 (36)	100 (38)	103 (39)	106 (41)	110 (43)	114 (46)	119 (48)	124 (51)	129 (54)	135 (57)			
92 (33)	94 (34)	96 (36)	99 (37)	101 (38)	105 (41)	108 (42)	112 (44)	116 (47)	121 (49)	126 (52)	131 (55)		
90 (32)	91 (33)	93 (34)	95 (35)	97 (36)	100 (38)	103 (39)	106 (41)	109 (43)	113 (45)	117 (47)	122 (50)	127 (53)	132 (56)
88 (31)	88 (31)	89 (32)	91 (33)	93 (34)	95 (35)	98 (37)	100 (38)	103 (39)	106 (41)	110 (43)	113 (45)	117 (47)	121 (49)
86 (30)	85 (29)	87 (31)	88 (31)	89 (32)	91 (33)	93 (34)	95 (35)	97 (36)	100 (38)	102 (39)	105 (41)	108 (42)	112 (44)
84 (29)	83 (28)	84 (29)	85 (29)	86 (30)	88 (31)	89 (32)	90 (32)	92 (33)	94 (34)	96 (36)	98 (37)	100 (38)	103 (39)
82 (28)	81 (27)	82 (28)	83 (28)	84 (29)	84 (29)	85 (29)	86 (30)	88 (31)	89 (32)	90 (32)	91 (33)	93 (34)	95 (35)
80 (27)	80 (27)	80 (27)	81 (27)	81 (27)	82 (28)	82 (28)	83 (28)	84 (29)	84 (29)	85 (29)	86 (30)	86 (30)	87 (31)

Category	**Heat Index**	**Possible heat disorders for people in high risk groups**
Extreme Danger	130°F or higher (54°C or higher)	Heat stroke or sunstroke likely.
Danger	105 - 129°F (41 - 54°C)	Sunstroke, muscle cramps, and/or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity.
Extreme Caution	90 - 105°F (32 - 41°C)	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity.
Caution	80 - 90°F (27 - 32°C)	Fatigue possible with prolonged exposure and/or physical activity.

Figure 5.2: Heat index scale and corresponding danger levels (Source: https://www.weather.gov/ffc/hichart)

Universal thermal climate index

A study assessing the effect of heat on all-cause mortality in Bangladesh suggests a threshold above 34°C for the universal thermal climate index (UTCI), a thermo-physiological index (Burkart et al., 2014; Burkart et al., 2011). Different effects were observed amongst different groups. Negative health outcomes were most pronounced amongst the elderly above 65 years of age, men, the urban population and in groups with a higher socio-economic background (Burkart et al., 2014).

The UTCI was developed following the concept of equivalent temperature and has been applied in recent human bio-meteorological studies, such as daily forecasts and extreme weather warnings, bioclimatic mapping, urban and regional planning, environmental epidemiology and climate impacts research. UTCI is defined as equivalent ambient temperature (°C) of a reference environment providing the same physiological response of a reference person as the actual environment. The input variables in modeling this index are air temperature, relative humidity, wind speed and radiation(Bleta, Nastos & Matzarakis, 2014).

When examining the UTCI, according to Matzarakis et al. 1999, the calculation of the physiological response to the meteorological input is based on a multi-node model of human thermoregulation, associated with a clothing model (Matzarakis, Mayer & Iziomon, 1999). The table 5.2 below assessment scale shows different thermal comfort categories.

Table 5.1: UTCI scale (Source: Bröde et al., 2012)

UTCI(°C)	Stress Category
> +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to 32	Moderate heat stress
+9 to +26	No thermal stress
0 to -13	Moderate cold stress
-13 to -27	Strong cold stress
-27 to -40	Very strong cold stress
< -40	Extreme cold stress

Wet bulb globe temperature

Decreased productivity is another consequence of warm temperature. The wet bulb globe temperature (WBGT), developed by the US Army, is often applied as a heat stress index and is used by many international organizations for defining heat exposure thresholds or limits for workers under different heat exposure and work intensity levels. It is computed out of air temperature, humidity, air velocity and radiation, as measured by the dry bulb, wet bulb and globe temperatures. The WBGT, however is criticised for being based on western standards and being too strict for countries with hotter or tropical conditions. The WBGT guideline takes into account WBGT, work intensity and resting time, in order to avoid the core body temperature exceeding 38°C for an average worker. Table 5.2 below shows the WBGT levels that require no hourly rest, or rest to the extent of 25, 50 and 75% (rest/work ratios) during the working hour (Kjellstrom, Holmer & Lemke, 2009). People can acclimatise after regular exposure to heat to a certain extent. In that case slightly more lenient thresholds need to be considered (Lucas, Epstein & Kjellstrom, 2014)
.

Table 5.2: Reference values for WBGT (8°C) at different work intensity levels (in Watts_W), light clothing (Source: (Kjellstrom et al., 2009))

Metabolic rate class[a] (work intensity)	0 (rest)	1 (light work)	2 (medium work)	3 (intense work)	4 (very intense work)
Approximate metabolic rate. M(W)	100	200	300	400	500
WBGT reference values[b] (°C)	33	30	28	25	23

[a]the metabolic rate classes are: 0=Resting, M<117; 1=light work<M<234 W; 2=sustained medium level work, 234<M<360 W; 3=intense work, 360<m<468 W; 4=very intense work, M>468 W

[b]the ISO standard (18 says; 'if these values are exceeded, it is necessary either to reduce the direct heat stress at the workplace, or to carry out a detailed analysis of exposure and prevention.' .. 'These values represent the mean effect', so short peak exposures may be acceptable.

However, the values are set to avoid over-heating (>38°C) in 'almost all individuals'. Thus, some people would be more sensitive and risk over-heating.

Note: Based on recommendations from the United States National Institute of Occupational Safety and Health (NIOSH)(16) and the International Standards Organisations (ISO)(18), If the worker uses heavier clothing or protective clothing, these values need to be reduced, see ISO (18).

Maximum Temperature

In 2010, Ahmedabad, located in the western Indian state of Gujarat, experienced temperatures of 46.8°C in which 4.462 all-cause deaths occurred, comprising an excess of 1.344 all-cause deaths. The highest effects were visible when maximum temperature crossed 43°C and minimum 36°C [16]. In another study 30°C maximum temperature was identified for Delhi as a threshold for increased negative health effects, especially amongst children [22]. Maximum temperatures between 44-48°C were observed for several days across different regions on the subcontinent during the heat wave in India and Pakistan in 2015 (Khadka, 2015).

For Bangladesh, India, and Pakistan following heat wave definitions have been articulated by their respective governmental meteorological departments:

i) Bangladesh:

When the maximum temperature goes above 36°C a heat wave situation occurs over Bangladesh. A heat wave is classified as mild when maximum temperature lies between 36-38°C, moderate when maximum temperature lies between 38-40°C, and as severe heat wave when maximum temperature is greater than 40°C.

ii) India:

When normal maximum temperature of a station is less than or equal to 40°C following conditions apply for declaring an event as a heat wave:

- Heat Wave Departure from normal is 5°C to 6°C
- Sever Heat Wave Departure from normal is 7°C or more

When normal maximum temperature of a station is more than 40°C:

- Heat Wave Departure from normal is 4°C to 5°C
- Severe Heat Wave Departure from normal is 6°C or more

When actual maximum temperature remains 45°C or more irrespective of normal maximum temperature, a heat wave should be declared.

iii) Pakistan:

The Pakistan Meteorological Department (PMD) has defined a heat wave when the temperature of more than five consecutive days exceeds the average maximum temperature by 5°C, the normal period being 1971-2000 (based on the definition recommended by the World Meteorological Organization). However, PMD also acknowledges the role of humidity and timing of extreme temperature, although they do not give any further specification on these points. For Nepal no official definition could be found.

It should be noted that, all three definitions are based on a somewhat arbitrary temperature cut off value and have no public health basis. Interestingly all these definitions also only look at maximum temperature alone and do not consider minimum temperature, number of consecutive hot days and other climate parameters which influence thermal comfort and are important for health.

5.3. Potential Critical Moments for Heat Stress

Concluding from the review above following statements can be made:

- Depending on the local climate, culture, demographics and socio-economic conditions, different local heat-health thresholds occur. An absolute universal threshold does not exit. A Lancet review on climate change and health uses following relative definition for dangerous heat levels: a heatwave is defined as more than 5 consecutive days for which the daily minimum temperature exceeds the summer mean daily minimum temperature in the historical period (1986–2005) by more than 5°C.
- Nonetheless, grey literature shows that maximum temperature above 44°C seem to have a public health relevance in India and Pakistan (for India and Pakistan, but for Bangladesh and Nepal thresholds might be lower, due to different climate patterns).
- However, when studying heat stress ideally other relevant parameters like minimum temperature, relative humidity, radiation, wind velocity, and consecutive hot days should also be considered. Wet Bulb Temperatures (WBT) above 30°C, a heat index above 30°C, UTCI above 26°C and WBGT above 25°C are heat thresholds which take such additional climate parameters into account and should be considered for South Asia when people are engaged in heavy physical activity (e.g. outdoor workers). For Nepal cooler thresholds might be more appropriate. With higher heat intensity work load has to be obviously decreased.
- The most vulnerable to heat stress are the elderly, children, pregnant women (and their unborn offspring), people with chronic diseases, and occupations demanding physical labour work in a hot environment.

Table 5.3: UTCI scale (Source: Bröde et al., 2012)

Indicator	Parameter	Threshold/ critical moments and aspects
Minimum temperature	Minimum air temperature	• For a 'good nights' sleep in western societies a temperature around 18.5°C is recommended (Bailey, 2014). • In a deadly heat wave in Chicago in 1995 minimum temperature of 26°C were recorded (however, also high humidity was prevalent)(Karl & Knight, 1997). • Some studies argue that the thermoneutral temperature inside the sleep microclimate lies around 30°C, with 28°C to 31°C being the thermal comfort zone for most humans (Joshi et al., 2016). This range is also often found in studies conducted in the tropics.
Maximum temperature	Maximum air temperature	Depends on the local environment. However, start being cautious when temperature start exceeding 40°C in South Asia.

WBT	Relative humidity and temperature	31-32°C WBT seem to be dangerous levels for an active person. 35°C WBT has been defined as an universal threshold above which humans are not able to survive longer than 6 hours (Im, Pal, & Eltahir, 2017). At the moment this 35°C threshold is not reached anywere in the world. However, with global warming this can be for the Indo-Gangetic Plains a threshold which could be reached in the near future.
WBGT	Air temperature, humidity, air velocity and radiation, as measured by the dry bulb, wet bulb and globe temperatures	• 32°C WBGT is a threshold for someone who is doing some light work (if people work harder the threshold lowers) • at 33°C WBGT no work at all should be conducted
Heat index = apparent temperature	Relative humidity and temperature	• 31.5°C minimum apparent temperature for 2 consecutive nights in Chicago (Karl & Knight, 1997) • 58°C in Karachi, Pakistan • 32°C marked as an extreme caution level (comes from the US) in combination with physical activity or prolonged exposure. • 54°C should be avoided (no physical work should be conducted)
UTCI	Air temperature, relative humidity, wind speed and radiation	• 32-38°C strong heat stress starts occurring
Consecutive hot days	Several hot days and nights in a row.	3 - 5 days are often used (minimum temperature in combination with humidity seems to be important)
Early onset of extreme heat	Extreme heat just when hot seasons starts or way before	Relevant months might be end of April, beginning of May for South Asia
Activity level	Metabolic rate	Depends on the corresponding heat exposure, activity level, clothing and/or thermal comfort index applied (see WBGT, UTCI and heat index/apparent temperature)
Combination of different indicators from above		For example: • Early onset of heat wave with high physical activity (as people are not acclimatised yet and may have to conduct heavy workloads due to their occupation, e.g. sowing, harvesting, construction) • Heat wave in combination with high physical activity (e.g. due to occupation) • Consecutive hot days and nights in combination with high relative humidity could potentially be critical (such a combination might especially be dangerous at the beginning of the hot season or after a relatively cooler period during the summer) • Any of the indicators in combination with different socio-economic and demographic profiles of the study population can aggravate the impact of heat stress

5.4. Heat Health Management and Adaptation[10]

Although there are many heat adaptation measures recommended in guidelines (McGregor, Bessemoulin, Ebi & Menne, 2010; WHO, 2011), they are usually analysed and applied in developed countries. Moreover, apart from the Ahmedabad heat action plan 2014, there remain limited measures implemented against heat waves in Asia (Knowlton et al., 2014).

The Heat Action Plan from Ahmedabad focuses on three aspects: I) building public awareness of the risks of heatwaves and the measures to prevent heat-related illnesses (e.g. taking regular rest, drinking enough water, staying in the shade, restrain from drinks which cause dehydration), II) developing an early warning systems and III) capacity building among health care professionals (Knowlton et al., 2014). Ahmedabad's Heat Action Plan is considered a pioneer in dealing with extreme heat events. Its effectiveness has been evaluated and showed the municipality is considered more prepared for heatwaves as awareness has increased, fewer reported deaths and temperature forecasts and heat alerts have been accurate. However, the Heat Action Plan does not consider minimising heat exposure level or the effect of the built environment on thermal comfort in its recommendations. Furthermore, its reach towards vulnerable communities such as slum dwellers can be questioned. A heat warning system should be based on a thorough local analysis of weather related health data. More research is needed regarding adaptation measures for households in urban areas.

Speaking in more general terms regarding thermal comfort a large variety of heat adaptation measures can be adopted at household and community level in the short, medium and long-run:

- Active cooling (air conditioners, electric fans, dehumidifiers and evaporative coolers);
- Passive cooling (cool roofs, night ventilation, closed windows, window design, insulation, thermal mass and shading devices); and
- Green infrastructure (green roofs, vertical greenery systems and private gardens).

These adaptation measures shown below in the tables 5.5-5.18 have been evaluated according to a range of criteria (references can be found under the reference list in the end):

Effects on:

- Thermal comfort: By what means a measure improves thermal comfort (e.g. reducing air temperature, humidity levels, circulates air, etc.) and by how much it improves indoor thermal comfort. Also whether a measure improves thermal comfort at night and during long-term extreme heat (≥ 3 days based on McGregor et al., 2015).
- Health: Positive & negative consequences of the measure on individual's physical & mental wellbeing not related to heat illnesses.
- Socio-economic: The combination of positive and negative economic and social factors are interconnected. The economic factors focus on the land & capital resources needed. Land encompasses the natural resources of a country such as water. Capital represents the monetary resources which refers to the financial abilities to buy goods and services. Furthermore, capital also refers to the physical assets which include infrastructure such as electricity and building/plant materials. Social factors focus on stakeholder involvement, aesthetic appeal, etc.
- Environment: Positive & negative consequences on the environment; whether it alleviates or exacerbates environmental issues such air pollution, urban heat island effect, biodiversity, etc.
- Conditions: The circumstances that are required for the measure to be effective for improving indoor thermal comfort. E.g. climate, maintenance, etc.

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a) Active Cooling

Table 5.4: Electrical fans

Thermal Comfort	• More peer-reviewed scientific research needed on thermal comfort effects • Circulates air
Health	• Risk of dehydration • Much confusion & uncertainty of health effects
Socio-economic	• Requires financial resources (purchasing & energy) • Requires access & reliable supply of electricity (susceptible to blackouts) • Risk of non-usage (fear of robbery due to open windows and inability to open windows)
Environment	• Consumes energy
Conditions	• Large variety of ranges suggested by various sources: temperature and humidity levels range from 32.3°C up to 51.1°C and humidity 10% up to 50% • Provides heat relief when the heat index (combination air temperature and relative humidity) is low as well as dangerously high • Air temperature should be less than an individual's skin temperature

Table 5.5: Dehumidifiers

Thermal comfort	• Lack of peer-reviewed scientific research on thermal comfort effects • Useful at night & long-term extreme heat • Removes humidity
Health	• Reduces allergies
Socio-economic	• Requires financial resources (purchasing & energy) • Requires access & reliable supply of electricity (susceptible to blackouts)
Environment	• Consumes energy
Conditions	• Applicable in moderate temperature levels but humidity ranges seem unclear • Windows & doors should be closed • Presumed to be applicable in warm & humid climates • Requires maintenance

Table 5.6: Evaporative Cooler

Thermal comfort	• Cools air by 5°C to 9°C yet lack of peer-reviewed scientific research • Useful at night & long-term extreme heat • Increased humidity may cause thermal discomfort • Reduces indoor temperature
Health	• Risk of Legionnaire's disease • Risk of mosquito-borne diseases
Socio-economic	• Requires financial resources (purchasing & energy) • Requires access & reliable supply of electricity & water (susceptible to blackouts)
Environment	• Consumes energy • Depending on the model, it can cause noise disturbance
Conditions	• Applicable in hot & dry climates • Requires maintenance

Table 5.7: Air Conditioners

Thermal comfort	• Available peer-reviewed scientific research: strong protective effect against heat-related mortality • Useful at night & long-term extreme heat • Directly reduces indoor temperature
Health	• Reduces air pollution related mortality, respiratory symptoms & asthma • Reduces risk for cardiovascular diseases • Reduces risk for vectorborne diseases • Reduces physiological acclimatization • Increases risk for airborne infections
Socio-economic	• Requires financial resources (purchasing & energy) • Requires access & reliable supply of electricity (susceptible to blackouts)
Environment	• Consumes energy • Worsens urban heat island effect
Conditions	• Applicable in hot (humid & dry) climates • Requires maintenance

b) Passive Cooling

Table 5.8: Thermal mass (materials (high density or low density) that act as a barrier to cool flow)

Thermal comfort	• Lack of peer-reviewed scientific research on thermal comfort effects • Unclear whether it is useful at night & during long-term extreme heat • Barrier to heat flow
Health	• No other health effects found
Socio-economic	• Reduces energy costs • Requires availability of building material • Requires financial investment • Various stakeholders involved • Unsuitable for retrofitting buildings
Environment	• Saves energy between 18%-50%

Conditions	• Applicable in hot and cold climates (depends on materials used)
	  o Use high density materials in climates with high diurnal temperature ranges (≥10°C)
	  o Use low density materials in climates with low diurnal temperature ranges (≤6°C)
	• Use with other cooling techniques
	• Performance dependent on thermal properties of the different materials, the location & distribution of thermal mass, insulation, ventilation and occupancy patterns
	• Consider governmental/ building regulations

Table 5.9: Insulation

Thermal comfort	• Lack of peer-reviewed scientific research on thermal comfort effects • Unclear whether it is useful at night & during long-term extreme heat • Barrier to heat flows	
Health	• No other health effects found	
Socio-economic	• Reduces energy costs • Requires financial investment yet costs dependent on construction type & location • Extends lifespan of building • Requires availability of building material • Various stakeholders involved • Suitable for retrofitting	
Environment	• Saves energy between 7%-31% • Reduces noise pollution • Protects against fires	
Conditions	Effects depend on: o Type of insulation material o Location in building/room o Local climate conditions o Building type, function, size, shape & construction	• Prevents moisture penetration & infiltration • Adequate ventilation is needed • Use with other cooling techniques • Applicable in hot and cold climates

Table 5.10: Shading device

Thermal comfort	• Reduces indoor temperature up to 5°C • Blocks solar radiation • Useful at night (indirectly) & potentially during long-term extreme heat with high solar radiation • External shading devices most effective • Internal shading devices least effective	
Health	• Improves visual comfort	
Socio-economic	• Reduces energy costs • Requires financial investment costs differ according to shading device • Suitable for retrofitting • Requires availability of material • Stakeholders involved • Improves/ deteriorates aesthetic appeal	
Environment	• Saves energy between 2% and 11%	
Conditions	Effects depend on: o Design, size, distance, angle & materiality o Building's orientation o Climate o Latitude	• Requires maintenance yet dependent on shading device • Use with other cooling techniques • Applicable in many climates depending on purpose

Table 5.11: Window device

Thermal comfort	• Lack of peer-reviewed scientific research on thermal comfort effects • Effects on thermal comfort, night temperatures and long-term extreme heat depend on type of window design	
Health	• Other health effects not found	
Socio-economic	• Reduces energy costs • Requires financial investment • Suitable for retrofitting • Availability of building material • Stakeholder involvement	
Environment	• Saves energy • Reduces noise pollution • Reduces indoor air pollution	
Conditions	Effects depend on: o Window type o Orientation o Size o Glazing type o Amount of external shading	• Applicable in hot and cold climates • Use with other cooling techniques

Table 5.12: Close windows

Thermal comfort	• Lack of peer-reviewed scientific research on thermal comfort effects • Usefulness at night and during long-term extreme heat dependent on weather conditions • Blocks heat gain
Health	• Reduces risk for airborne diseases • Reduces risk for air pollution diseases
Socio-economic	• Reduces energy costs • No financial investment needed
Environment	• Saves energy • Reduces indoor pollution • Reduces noise pollution
Conditions	• Indoor temperature should be lower than outdoor temperature • Use with other (active) cooling techniques • Applicable in hot and cold climates

Table 5.13: Open windows during night

Thermal comfort	• Effectiveness depends on the specific conditions making it difficult to give concrete conclusions regarding how much night ventilation reduces indoor temperatures (between 2.5°C and 14.5°C) • Useful at night when outdoor temperatures are lower yet may be ineffective during long-term extreme heat • May be ineffective in urban areas due to high outdoor temperatures and low wind velocity • Circulates air
Health	• Risk for respiratory diseases • Risk for vectorborne diseases

Socio-economic	• Reduces energy costs • No financial investment needed • Security risk (burglary & animal intrusion) • Risk for weather changes	
Environment	• Saves energy between 10% and 40% • Increases indoor noise pollution • Increases indoor air pollution	
Conditions	Effects depend on: o Building characteristics (air exchange rate, thermal storage capacity of a building) o Climatic and microclimatic conditions (outdoor temperatures, relative humidity & wind speed)	• Outdoor temperature should be lower than indoor temperature at night • Applicable in hot and dry climates • Use with other cooling techniques

Table 5.14: Cool surfaces/roofs (Light-coloured coatings or materials with high solar reflectance and high thermal emittance

Thermal comfort	• Indoor temperature reduction up to 7°C • Useful at night (indirectly) & long-term extreme heat • High solar reflectance and thermal emittance
Health	• Increases visual discomfort and glare
Socio-economic	• Requires financial investment (yet same cost to traditional roofs) • Reduces energy costs • Suitable for retrofitting • Extends lifespan of building materials • Various stakeholders involved in planning & construction • Availability of building materials
Environment	• Saves energy between 10% and 40% • Mitigates the urban heat island effect
Conditions	• Effects depend on building type, season & local climate • Various materials available (white or light-coloured coatings and paints, membranes consisting of fibreglass or polyester in combination with polymeric materials and tiles) • Only applicable in hot climates • Requires maintenance (against dirt accumulation & weathering) • Use with other cooling techniques

c) Green Infrastructure

Table 5.15: Private/domestic gardens

Thermal comfort	• Lack of peer-reviewed scientific research on thermal comfort effects • Less effective at night, might be effective during the day when there is long-term extreme heat if there is frequent irrigation • Shading (intercepting radiation) and evapotranspiration	
Health	• Form of retreat • Reduces mortality, lowering blood pressure & cholesterol levels • Increases exercise • Risk for injuries • Positive psychological effects	
Socio-economic	• Requires water supply • Requires financial investment (design, purchasing plants, materials) • Requires plants & space • Improves aesthetic appeal • Increases interaction with others • Increases sense of attachment • Provides opportunities to grow food	
Environment	• Saves energy (possibly between 20%-40%) • Reduces air pollution (remove air pollutants & carbon emissions) • May reduce air quality due to BVOCs emissions • Improves stormwater management	• Increases biodiversity • Use of fertilizers & pesticides – contribute to GHG emission & water pollution • Risk for invasive species
Conditions	Effects depend on: • Water availability • Suitability of soil • Requires maintenance • Applicable in various climates (depending on the purpose)	

Table 5.16: Vertical greenery system

Thermal comfort	• Indoor temperature reduction up to 5°C • Less effective at night, might be effective during the day when there is long-term extreme heat if there is frequent irrigation • More peer-reviewed scientific research needed on indoor effects • Providing shading (intercept radiation), evapotranspiration and insulation	
Health	• Reduces risk of air pollution diseases • Reduces eyes and skin irritation	
Socio-economic	• Requires financial investment, yet differ between green façade & living walls • Reduces energy costs • Requires water supply • Extends lifespan of building materials	• Suitable for retrofitting • Stakeholder involvement in planning & construction • Improves aesthetic appeal
Environment	• Saves energy between 5% and 50% • Reduces noise pollution • Increases biodiversity	• Improves stormwater management • Reduces air pollution (remove air pollutants & carbon emissions)

Conditions	Effects depend on: o Plant species o Climate o Physical structure, materials & dimensions of the panels o Water availability	o Substrate type, composition, depth & moisture content • Applicable in hot & dry climates • Requires maintenance but differ between green façade and living walls

Table 5.17: Green roofs

Thermal comfort	• Indoor temperature reduction up to 3°C • Less effective at night, might be effective during the day when there is long-term extreme heat if there is frequent irrigation • Providing shading (intercept radiation), evapotranspiration and insulation	
Health	• Reduces risk of air pollution diseases • Reduces eyes and skin irritation	
Socio-economic	• Requires financial investment yet differ between extensive and intensive types • Reduces energy costs • Requires water supply • Extends lifespan of building materials • Suitable for retrofitting • Stakeholders involved in planning & construction • May require structural support • Improves aesthetic appeal • Provides opportunities to grow food	
Environment	• Saves energy between 0.6% and 14.5% • Reduces noise pollution • Increases biodiversity • Improves stormwater management • Reduces air pollution (remove air pollutants & carbon emissions) • May reduce air quality due to BVOCs emissions	
Conditions	Effects depend on: o Climate & microclimate o Substrate composition & depth o Plant types o Time of planting (ideally spring) o Water availability & maintenance (yet differs between intensive & extensive types) o Insulation	• Not suitable for steep sloped roofs • Suitable for low rise buildings • Requires maintenance • Applicable in hot (humid & dry) and cold climates

5.5. References Critical Moments for Heat Stress

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