CLIMATE SMART DISASTER RISK REDUCTION INTERVENTIONS IN AGRICULTURE SECTOR – FLOOD HAZARD

A Report

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Executive Summary

Climate Change is inevitable and the agriculture and water sectors are the most vulnerable. Recent studies have shown that due to climate change, the world is moving towards scenarios of either too much, or too little, water. Agriculture is an open system and provides livelihoods for 60% of the world's population. More than 2.2 billion people depend on agriculture for their livelihoods in Asia. Thus, climate induced natural hazards, especially floods, are likely to affect the sector as well as the livelihoods of the dependent population considerably.

Due to the distinct climatic variability across the Asian continent and its geophysical setting, the majority of countries on the Asian continent are subject to natural disasters. The frequency of these extreme events, especially the hydro-meteorological events, has shown an increasing trend. The present study explores the consequences of these extreme events in three countries of the Asian region, namely: Thailand, Nepal and Sri Lanka which have distinct geographical settings. These three countries are subject to frequent natural disasters, especially floods and droughts, due to their respective geographical exposure and climatic regime, which in turn, result in disastrous consequences of varying degrees, affecting the agricultural sector of the respective countries.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has revealed that warming of the climate is unequivocal, and that rapid climate change over the past 50 years is anthropogenic-driven. Climate change has already affected both South and Southeast Asia with rising temperatures, decreasing rainfall, rising sea levels and increasing frequency and intensity of extreme events.

One of the major shortfalls of conventional disaster management strategies is a lack of adequate blends of climatic information on the nature of future climate risks and post-disaster reconstruction processes or modalities which eventually lead to an increased risk of disaster rather than a decrease. The present initiative, funded by the Asia Pacific Network for Global Change Research, Japan, looks into an entire gamut of flood mitigation interventions in the agricultural sector in the three countries of intervention starting from floodplain management, land treatment, flood modification measures and agronomic practices to Integrated Water Resource Management. One of the unique recommendations is a climate inclusive, flood early warning system in these countries which is generally lacking. We are aware that low-income countries and small islands and their rural communities (whose main livelihood is agriculture in the flood-plain and low-lying areas) are the most endangered communities by flood hazards. Environmental degradation and socio-economic factors like poverty and urban population growth, contribute additionality to the vulnerability by flood hazards of the communities in these three countries where a Flood Early Warning System could make a paradigm shift in community resilience regarding flood hazard.

We sincerely hope that the Climate Smart Disaster Risk Reduction Interventions in the Agriculture Sector, with special reference to flood hazards, will contribute to the various DRR initiatives in these three countries and in Asia as a whole.

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1. Introduction

Asia is the Earth's largest and most populous continent, located primarily across the northern hemisphere. Asia covers an area of 44,579,000 km^2, which is about 30% of the Earth's total land area and about 8.7% of its total surface area, comprising 51 countries/regions. Based on geographical location and coastal peripheries, it can be broadly divided into six sub regions. These are, in alphabetical order: Central Asia (5 countries), East Asia (7 countries/regions), North Asia (2 countries), South Asia (8 countries), Southeast Asia (12 countries) and West Asia (17 countries). This continent has long been home to the majority of the Earth's human population and was the site of many of the first civilizations in the world. Though Asia is characterized by its overall large size and population, it has contrasting regions of dense and large settlements on the one hand and very sparsely populated, or uninhabited, regions on the other. Having a population of 4.5 billion (as of September, 2018), Asia constitutes roughly about 60% of the world's population (Anon, 2019). Asia varies greatly across and within its regions in the context of ethnic groups, cultures, environments, economics, historical ties and government systems. Asia is bounded on the east by the Pacific Ocean, on the south by the Indian Ocean and on the north by the Arctic Ocean. The western boundary of Asia is the Isthmus of Suez and the Red Sea through which it separates from the African continent (Figure 1).

Figure 1 A schematic map of Asia (Source: https://www.freepik.com)

2. Climate of Asia

The enormous expanse of land and its abundance of mountain barriers and inland valleys have resulted in many different climatic regions in Asia ranging from the equatorial in the south, to hot desert in the Middle East, temperate areas in the east, to continental areas in the middle, to vast, sub-arctic and polar areas in the Siberian region (Figure 2). The southern parts of Asia are mild to hot, while far, north-eastern areas, like Siberia, are very cold. East Asia has a temperate climate while West Central Asia experiences some of the largest diurnal temperature ranges on Earth (WMO, 2011).

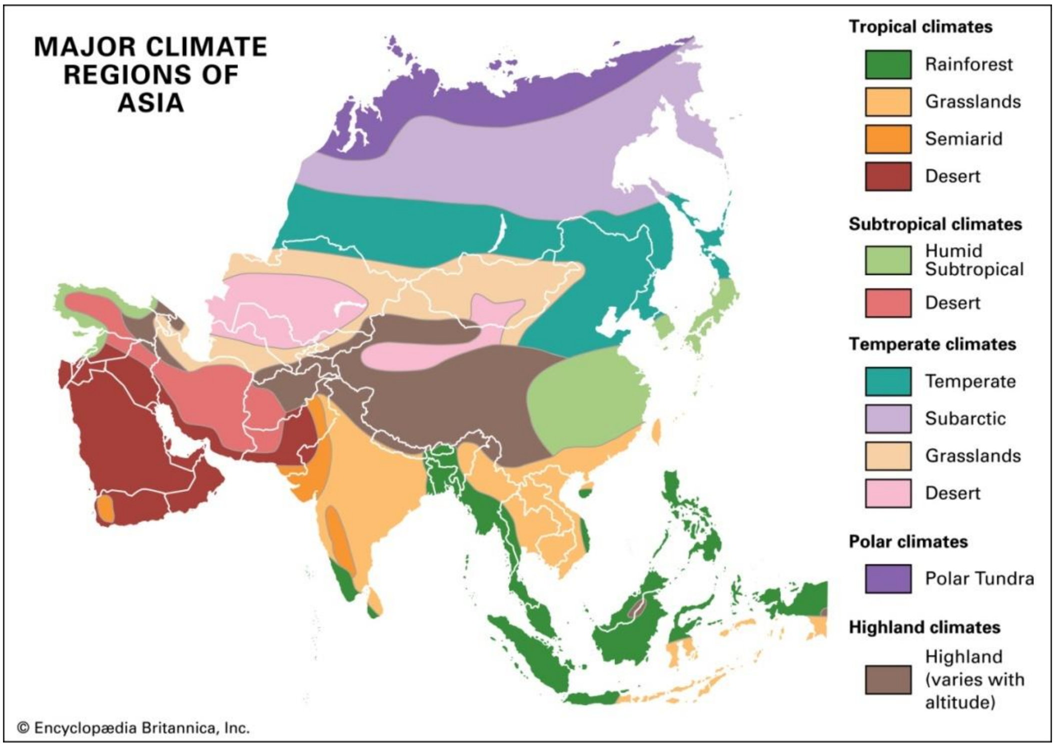

Figure 2 Major climatic regions of Asia

The rainfall regime of the southern and eastern regions of Asia is mainly governed by the monsoon circulation due to the presence of the Himalayan mountain range. This separates the plains of the Indian sub-continent from the Tibetan plateau which mainly runs across five countries of Asia, namely: India, Nepal, China, Bhutan and Pakistan, covering a length of about 2,400 km. The south western sections of the continent are characterized by a low relief, overlying, sub-tropical, high pressure belt; they are hot in summer, warm to cool in winter, and may experience snow at higher altitudes. The most active place on earth for tropical cyclone activity lies northeast of the Philippines and south of Japan. Two of the wettest places in the world, as per the available recorded data, are

Mawsynram (12,178 mm) and Cherrapunji (11,172 mm), located in the Khasi Hills on the Shillong Plateau of Meghalaya, India. They are about 16 km from one another and are the highest average, annual rainfall receiving stations in the world (2001-2010) (IMD, 2012) and are in Asia. The desert regions of Asia stretch from the Gobi Desert in the west-southwest of Mongolia, through to the Taklamakan Desert in western China, the Thar Desert in western India and the Iranian plateau into the Arabian Desert in the Arabian Peninsula.

3. Rationale of the Study

Due to the distinct climatic variability across the Asian continent and its geophysical setting, the majority of countries in the Asian continent are subject to natural disasters. The frequency of these extreme events, especially the hydro-meteorological events, has shown an increasing trend. The present study explores the consequences of these extreme events and their effects in three countries of the Asian region, namely: Thailand, Nepal and Sri Lanka which have distinct geographical settings (Figure 3). These three countries are subject to frequent natural disasters, especially floods and droughts, due to their respective geographical exposure and climatic regime, which in turn, result in disastrous consequences of varying degrees, affecting the agricultural sector of the respective countries. Hence, the following sections will mainly focus on the rainfall climatology of these three countries as both floods and droughts are a result of the extreme anomaly of rainfall regime.

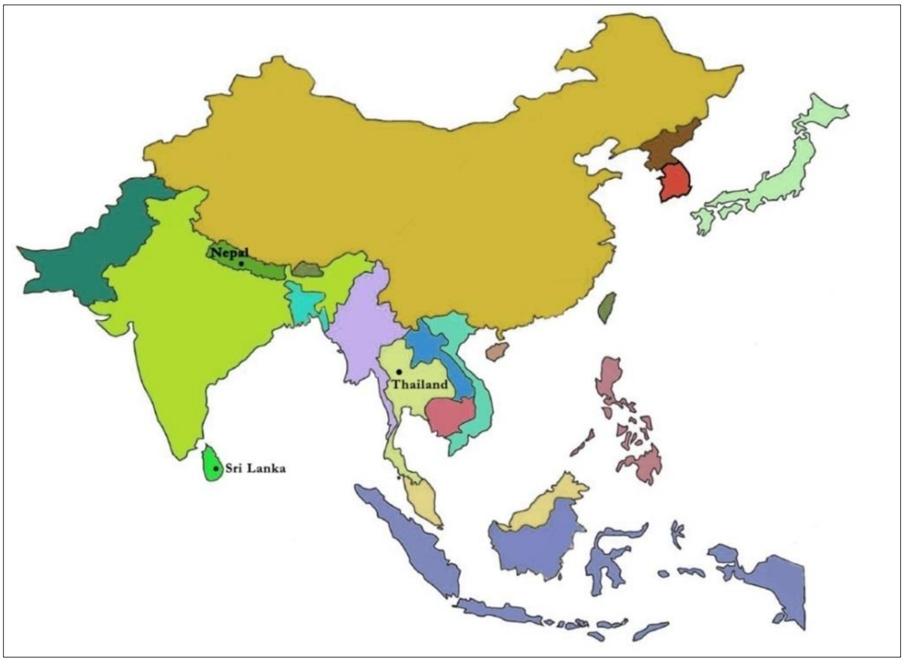

Figure 3 Location of the study area (three countries) in Asia

3.1. Geography of Thailand

Thailand is located in the tropical area between latitudes 5° 37′N to 20° 27′N and longitudes 97° 22′E to 105° 37′E. The total area is 513,115 km^2 bordered by five Asian countries (Figure 3):

- North: Myanmar and Laos
- East: Laos, Cambodia and the Gulf of Thailand

- South: Malaysia
- West: Myanmar and the Andaman Sea

As per the topography and prevailing climatic conditions, Thailand has been divided into five regions, namely: Northern, North-eastern, Central, Eastern and Southern parts. The topography of each region varies distinctly (Figure 4) with most of the areas of the northern region being hilly and mountainous. These high mountains are incised by steep river valleys and upland areas that border the central plain. Most rivers, including the Nan, Ping, Wang and Yom, unite in the lowlands of the lower-north region and the upper-central region. The Ping River and the Nan River unite to form the Chao Phraya River, one of the most important river basins of the country.

Figure 4 Geographical regions of Thailand

Source (https://www.stevenandrewmartin.com/thai-geography/)

The Northeast region is a naturally occurring plain which has a higher altitude than the surrounding areas and is called the Northeast Plateau. The northwest/southeast oriented PhuPhan Ridge, in the north eastern part, separates this region into two basins. One is a large plateau in the west while the other is smaller and slopes towards the east. The Central region is a flood plain where the Ping, Wang, Yom and Nan Rivers, originating in the Northern region, join together to form the Chao Phraya River at Nakhon Sawan province. The capital, Bangkok City, is part of the central plain. The Central region, being a flat terrain, is subject to frequent flooding. The south and southwest parts of the Eastern region are adjacent to the Gulf of Thailand. Further inland, most areas are plains and valleys but there are some small hills in the northern, central and eastern portions of the region. The Southern region of Thailand is a peninsula between the Andaman Sea to the western side and the South China Sea on the eastern side. The long ridge of western mountains in the Northern and Central parts extend to this region. The Phuket Ridge along the west coast and the Nakhon Si Thammarat Ridge in the lower central part of the region form the backbone of the Southern part, separating this region into two sub-regions: Southern Thailand east coast and Southern Thailand west coast.

Administratively, the country has been divided into 76 Changwats (provinces), 4 regions and the Bangkok Metropolitan area. The four administrative regions correspond approximately to the aforesaid physiographical regions of Thailand.

Agriculture is one of the major livelihoods of the country's population with about 26.8 million ha considered as cultivable, which represents 52% of the country. In 2009, the cultivated area was estimated as 18.995 million ha. Of this total, 15.300 million ha were under annual crops (mainly rice) and the remaining 3.695 million ha were under permanent crops (FAO, 2011a).

3.2. Climate of Thailand (TMD, 2015)

Temperature

The Northern, Northeastern, Central and Eastern parts of Thailand usually experience a long period of warm weather as they are landlocked and located in a tropical latitudinal zone. The hottest period of the year spans from March to May with maximum temperatures usually around 40^{o}C or more, except along coastal areas, where sea breezes moderate the afternoon temperatures. The onset of the rainy season also significantly reduces the temperatures from mid-May and they are usually lower than 40^{o}C. In winter months, the flow of cold air from China occasionally reduces temperatures to fairly low values, especially in the Northern and Northeastern parts, where temperatures may dip near, or below, zero. In the Southern part, temperatures are generally mild throughout the year because of the maritime characteristics of this region.

Rainfall

The rainfall climatology of Thailand is mainly under the influence of monsoon winds of seasonal character such as the southwest monsoon and northeast monsoon. The southwest monsoon, which starts in May, brings a stream of warm, moist air from the Indian Ocean towards Thailand, causing abundant rainfall over the country, especially in the windward side of the mountains. Rainfall during this period is not only caused by the southwest monsoon, but also by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones which produce a large amount of rainfall. May sees the first arrival of the ITCZ to the Southern part. It moves northwards rapidly and lies across southern China around June to early July, leading to a dry spell over Northern Thailand. The ITCZ then moves in a southerly direction to lie over the Northern and North eastern parts of Thailand in August and later, over the central and southern parts in September and October, respectively. The northeast monsoon which starts in October brings the cold and dry air from the anticyclone in China mainland over major parts of Thailand, especially the Northern and North eastern parts which have higher latitudinal areas. In the Southern part, this monsoon causes mild weather and abundant rain along the eastern coast. The onset of monsoons varies to some extent. The southwest monsoon usually starts in mid-May and ends in mid-October while the northeast monsoon normally starts in mid-October and ends in mid-February. With respect to seasonality of rainfall, the climate of Thailand may be divided into three seasons as follows:

Rainy or southwest monsoon season (mid-May to mid-October)

The southwest monsoon prevails over Thailand and abundant rain occurs over the country. The wettest period of the year is August to September. The exception is found on the Southern Thailand East Coast where abundant rain occurs until the end of the year which is the beginning of the northeast monsoon period. November is the wettest month.

Winter or northeast monsoon season (mid-October to mid-February)

This is the mild period of the year but quite cold in December and January in the upper regions of Thailand. Abundant rainfall occurs in the East Coast of Southern Thailand, especially during October to November.

Summer or pre-monsoon season (mid-February to mid-May)

This is the transitional period between the northeast and southwest monsoons. The weather becomes warmer, especially in upper Thailand, with April being the hottest month.

3.3. Geography of Nepal

Nepal, situated in South Asia, is a landlocked country surrounded by India in the east, west and south and China in the north (Figure 3). It occupies 0.03% and 0.3% land area of the World and Asia respectively. It has a diverse topography and climate. It stretches from east to west with an average length of 885 kilometres and extends north to south with an average breadth of 193 kilometres. Geographically, Nepal lies between a latitude of 26° 22'N to 30° 27'N and longitude of 80° 04´E to

88°12´E, with a total area of 147,181 km^2. The high mountains lying in the northern belt comprise eight peaks higher than 8,000 metres, including the world's highest peak, Mt. Everest (8848 metres). The Terai belt is the plain area situated in the southernmost part of Nepal which is usually known as the grain house of the country, as most of the crops produced in Nepal are farmed in this region (Figure 5) (Central Bureau of Statistics, 2018). Physiographically, the country can be divided into three parts (FAO, 2011b):

- The high Himalayas in the north (24% of the country's total area).
- The hill and mountain slopes in the centre (56% which include the lower hills called Siwalik where elevations vary between 300 and 700 m.
- The plain called Terai in the south at elevations below 300 m (20%).

The Himalayas mainly consist of mountains but also, temperate forests and alpine pastures. The inner valley regions of the Himalayas are cold deserts. The Himalayan region's altitude ranges from between 3,000 to 8,848 m. This region is home to the tallest mountains in the world and is sparsely populated due to the cold weather and paucity of arable land. The mountain slopes in the Mid-Hill are the main region which has a broad diversification and is inhabited by various ethnic groups. The people living in this region are mainly dependent on agriculture on the mountain slopes as their main livelihood. The Terai Region (Plain Land) spreads across an altitude of between 63 – 300 m. It is known as the main agricultural area of the country. Being relatively flat terrain, it has easier access compared to the other regions; thus, many groups have migrated to this region from the mountains and adopted agriculture as their main livelihood.

The cultivable area of Nepal is about 4.00 million ha, of which, 34% is in the Terai, 8% in the Siwalik, 48% in the mountain and hill region and 10% in the high Himalayas. In 2009, the total cultivated area was around 2,520,000 ha, of which, 95% (2,400, 000 ha) was for annual crops and 5% (120,000 ha) for permanent crops (FAO, 2011b).

Recently, Nepal has practised the federal structure and the constitution of Nepal (2015) has declared the country as a Federal Democratic Republic, with seven provinces which are further divided into 753 local units, including 460 rural municipalities, 276 municipalities, 11 sub-metropolises and 6 metropolises. The number of administrative districts has been increased to 77 from 75.

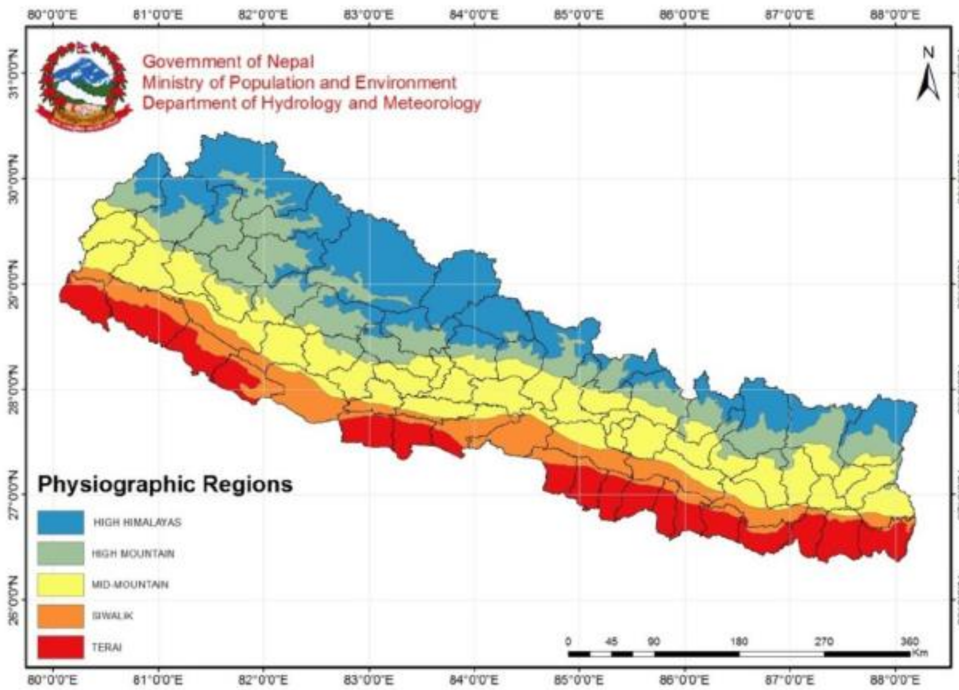

Figure 5 Physiographic regions of Nepal (Gilani et al., 2017)

3.4. Climate of Nepal

Temperature

Nepal's climate is influenced by elevation as well as by its location, varying from subtropical monsoon conditions to temperate and alpine climates. The temperature decreases from the lowlands, Terai (northern part of the Ganges plain) to the high Himalayan region. The spatial variation of mean annual temperature is influenced by the physiographic setting of the country. In general, temperature decreases gradually from south to north with the increasing altitude. The winter season (December to February) is the coldest season. Maximum temperatures of the year occur in May or early June. With the withdrawal of the monsoon, the temperature starts declining throughout the country. The extreme temperatures recorded show that in Lomangtang (Mustang district) located at an elevation of 3,705 m, the minimum temperature was -14.6°C in 1987, while in Dhangadhi (Kailali district) located at an elevation of 170 m, the maximum temperature was 44°C in 1987. Precipitation falls as snow at elevations above 5,100 m in summer and 3,000 m in winter. Temperature is a constraint on crop production in the Himalayas and the mountain region where only a single crop can be grown in a year. On the other hand, in the Terai, three crops a year are common where the water supply is adequate. Single rice cropping is possible up to elevations of 2,300 m while double rice cropping is limited to areas below 800 m.

Rainfall

The extremely varied topography of Nepal within a small width, ranging from 145 to 241 km, influences the weather and climate of the country. The mean annual rainfall is 1,500 mm, with a maximum annual rainfall record of 5,581 mm in 1990 at Lumle in Kaski district (elevation 1,740 m) in the mountain region and a minimum record of 116 mm in 1988 at Jomsom in Mustang district, located at 2,744 m in the Kaligandi river valley near the Annapurna Himalayan range. There are two rainy seasons: one in the summer (June to September), when the southwest monsoon brings more than 75% of the total rainfall, and the other in winter (December to February), accounting for less than 25% of the total. With the summer monsoon, rain first falls in the southeast and gradually moves to the west with diminishing intensity. Thus, more rain naturally occurs in the east. On the other hand, during winter, rain occurs as a result of westerly disturbances. This rain first enters Nepal through the west and gradually moves towards the east with diminishing intensity (FAO, 2011b).

3.5. Geography of Sri Lanka

Sri Lanka is an island in the Indian Ocean, located at the tip of the Indian sub-continent. There is no land mass located between the southern tip of Sri Lanka and Antarctica. The island covers a total area of 65,610 km^2 including 2,905 km^2 of inland water bodies. The maximum extent from west to east is 240 km while from a north-south direction, it is 435 km. Located between 50° 55'N to 90° 50' N and 79° 42'E to 81° 53' E, the island has extensive faulting and erosion over time which have resulted in a wide range of topographic features. There are three distinguishable elevation zones within the island: the Central Highlands, the Plains and the Coastal Belt. In the south-central part of Sri Lanka, the rugged Central Highlands span around 65 km in a north-south direction with a peak elevation at 2,524 m, forming the hydrologic heart of the country (Figure 6). All major, perennial rivers originate from the Central Highlands, spreading in a cart-wheel fashion from the centre towards the coast. Most of the island's surface consists of plains located between 30 and 200 m above mean sea level. In the south-west, ridges and valleys rise gradually to merge with the Central Highlands, giving a dissected appearance to the plain. The coastal belt around the country, extending up to about 30 m above mean sea level, consists of scenic sandy beaches indented by bays and lagoons (Punyawardena et al., 2013). For administrative purposes, the country is divided into nine provinces: Central, Eastern, North Central, Northern, North Western, Sabaragamuwa, Southern, Uva and Western, with Colombo as the capital.

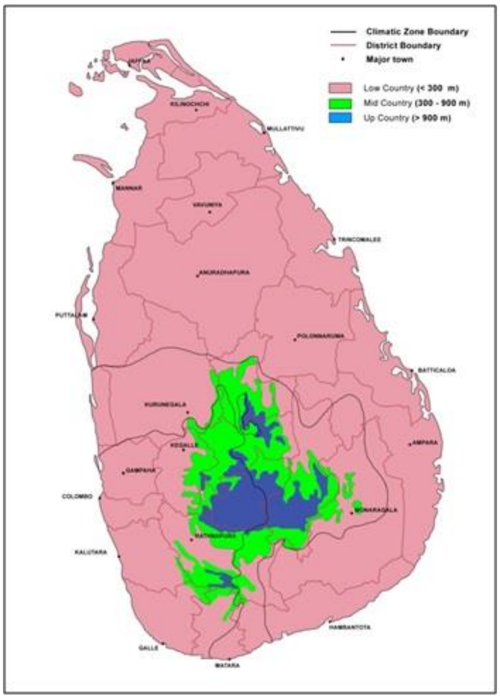

Figure 6 Elevation map of Sri Lanka (Source: Department of Agriculture, Sri Lanka)

The total cultivated area is approximately 2.17 million ha of which, 1.20 million ha are for annual crops such as rice, Kurrakkan, maize, green gram, green chilies and cowpea and 0.97 million ha of permanent crops such as fruits, tea, rubber, sugarcane and coconut.

3.6. Climate of Sri Lanka

Rainfall

Despite its relatively small size, the Sri Lankan landmass incorporates a variety of climatic conditions depending on geographical setting and elevation. In general, the climate of Sri Lanka is one of tropical monsoons with a marked seasonal variation of rainfall. Rainfall in Sri Lanka has multiple origins. Monsoonal, convectional and the formation of 'Weather Systems' in the Bay of Bengal account for a major share of the annual rainfall. The average annual rainfall of the island varies from about 900 mm at the south-eastern part of the Dry Zone (for example: Maha Lewaya, Hambantota) to over 5,500 mm on the south-western slopes of Central Highlands (for example: Kenilworth Estate, Ginigathhena). It is generally accepted that there are four rainfall seasons in Sri Lanka:

March - April → First Inter Monsoon (FIM) rains

May - September → South West Monsoon (SWM) rains

October - November → Second Inter Monsoon (SIM) rains

November - February → North East Monsoon (NEM) rains

Out of these four rainfall seasons, two consecutive rainy seasons make up the predominant growing periods of Sri Lanka, namely the Yala and Maha seasons. Generally, the Yala season is the combination of FIM and SWM rains, and is considered as the minor growing season, being short in length and with a comparatively small amount of cumulative seasonal rainfall. The major growing season of the country is the Maha season in terms of its length and amount of cumulative seasonal rainfall, which begins with the arrival of SIM rains in mid-September/October and continues up to late January/February with the NEM rains (Punyawardena, 2010).

The Sri Lankan climate has traditionally been generalized into three zones based largely on annual rainfall. The Wet Zone in the south-western region includes the south-western slopes of the central hills. The Dry Zone predominantly covers the plains in the northern, north central, south-eastern and eastern parts of the country and an Intermediate Zone skirts the Central Highlands except in the south-west. Important factors in differentiating these climatic zones, other than annual rainfall are: a) contribution of southwest monsoon rains, b) type of soils, c) land use patterns, d) terrain and e) vegetation types. The Wet Zone receives a relatively high average annual rainfall over 2,500 mm without pronounced dry periods. The Dry Zone receives a mean annual rainfall of less than 1,750 mm with a distinct dry season from May to September. The Intermediate Zone receives a mean annual rainfall between 1,750 to 2,500 mm, with a short and less prominent dry season from May to September.

Temperature

Being located in the low latitudes between 5°N and 10°N and surrounded by the Indian Ocean, Sri Lanka has a very typical, maritime-tropical temperature regime. These conditions are characterized by greater daily than annual temperature ranges and moderate average temperatures in comparison with the more continental tropics. Meanwhile, regional differences, observed in the air temperature over Sri Lanka, are mainly due to variations of altitude as opposed to the difference in latitude which is marginal. Mean monthly temperatures differ slightly depending on the seasonal movements of the sun and limited, seasonal modifications caused by rainfall, especially monsoonal winds. The mean annual temperature in Sri Lanka is largely homogeneous in the lowlands and decreases rapidly as elevation increases towards the highlands. In the lowlands, up to an altitude of 100 to 150 m, the mean annual temperature varies between 26.5°C to 28.5°C while in the highlands, temperature falls quickly as the altitude increases due to atmospheric lapse rate. The average temperature of the highest town, Nuwara Eliya, at about 1,800 m above sea level, is 15°C where even frost could occur for several days during winter months. The coldest month of the country, with respect to average monthly temperature, is January; the warmest months are April and August (Punyawardena, 2010). Temperature conditions in Sri Lanka are also characterized by a significant temperature increase with descending southwest monsoon winds over the Central Hills towards the leeward side (eastern half of the island along with south-eastern, north-eastern, north-western and northern regions) where the wind gets warm adiabatically, causing ambient temperatures to increase along with a decrease in humidity called the Föhn effect, during May to September (Punyawardena, 2007).

4. Salient Features of Climate Change in Asia, with Special Reference to Thailand, Nepal and Sri Lanka

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has revealed that warming of the climate is unequivocal, and that rapid climate change over the past 50 years is anthropogenic-driven (IPCC, 2007). Recent studies have indicated a significant increase in global average temperature, widespread snow and ice melting, associated changes in wind patterns and cyclone activity (IPCC, 2014). The IPCC Special Report, 2018, on the impacts of global warming of 1.5°C above pre-industrial levels, indicates an increase of: mean temperature in most land and ocean regions (high confidence); hot extremes in most inhabited regions (high confidence); heavy precipitation in several regions (medium confidence) and the probability of drought and precipitation deficits in some regions (medium confidence). Observational evidence shows that many parts of the globe have already experienced its adverse impacts and projections from IPCC suggest that such impacts will become even more intense in the future (IPCC, 2014; UNFCCC, 2007). Similarly, climate change has already affected both South and Southeast Asia with rising temperature, decreasing rainfall, rising sea levels and increasing frequency and intensity of extreme events.

Temperature

It is very likely that the mean annual temperature has increased over the past century over most of Asia. As per the IPCC (2014) report, the number of cold days and nights has decreased and the number of warm days and nights has increased across most of Asia since 1950. Heat wave frequency has also increased since the middle of the 20th century in large parts of Asia. A significant warming trend (>2°C per 50 years) in the second half of the 20th century has also been observed in the northern Asian sector. Over the period 1901–2009, the warming trend has been particularly strong in the cold season between November and March, with an increase of 2.4°C in the mid-latitude, semi-arid area of Asia. Increasing annual mean temperature trends on a country scale in East and South Asia have also been observed during the 20th century. In West Asia, upward temperature trends are notable and significant in recent decades. Across South-east Asia, temperature has been increasing at a rate of 0.14°C to 0.20°C per decade since the 1960s, coupled with a rising number of hot days and warm nights and a decline in cooler weather.

Precipitation/Rainfall

Precipitation trends, including extremes, are characterized by strong variability, with both increasing and decreasing trends observed in different parts and seasons of Asia. In Northern Asia, the observations indicate some increasing trends of heavy precipitation events but in Central Asia, no spatially coherent trends were found. Both the East Asian summer and winter monsoon circulations have experienced an inter-decadal scale weakening after the 1970s, leading to deficient mean precipitation. In West Asia, a weak, but non-significant, downward trend in mean precipitation was observed in recent decades, although with an increase in intense weather events. In South Asia, seasonal mean rainfall shows inter-decadal variability, noticeably, a declining trend with more frequent deficit. For example, over India, the increase in the number of monsoon break days and the decline in the number of monsoon depressions are consistent with the overall decrease in seasonal mean rainfall. However, an increase in extreme rainfall events occurred at the expense of weaker rainfall events over the central Indian region and in many other areas. In South Asia, the frequency of heavy precipitation events is increasing, while light rain events are decreasing. In Southeast Asia, annual total wet-day rainfall has increased by 22 mm per decade, while rainfall from extreme rain days has increased by 10 mm per decade. However, climate variability and trends differ vastly across the region and between seasons. In Southeast Asia, between 1955 and 2005, the ratio of rainfall in the wet to dry seasons increased. While an increasing frequency of extreme events has been reported in the northern parts of Southeast Asia, decreasing trends in such events are reported in Myanmar. In Peninsular Malaya, during the southwest monsoon season, total rainfall and the frequency of wet days decreased but rainfall intensity increased in much of the region. On the other hand, during the northeast monsoon, total rainfall, the frequency of extreme rainfall events and rainfall intensity, all increased over the peninsula (IPCC, 2014).

4.1. Projected Climate Change in Asia

Christensen et al. (2007) showed that warming is very likely in the 21st century in Asia and that assessment still holds for all land areas of Asia by the mid and late 21st century. Ensemble-mean changes in mean annual temperature exceed 2°C above the late 20th-century baseline over most land areas by the mid-21st century under RCP8.5, and range from greater than 3°C over South and Southeast Asia to greater than 6°C over high latitudes by the late 21st century. However, the ensemble-mean changes are less than 2°C above the late 20th century baseline in both the mid and late 21st century under RCP2.6, with the exception of changes between 2°C and 3°C over the highest latitudes (IPCC, 2014).

Projections of future annual precipitation change are qualitatively similar to those assessed in the AR4 (Christensen et al., 2007). Precipitation increases are very likely at higher latitudes by the mid-21st century under the RCP8.5 scenario and over eastern and southern areas by the late 21st century. Under the RCP 2.6 scenario, increases are likely at high latitudes by the mid-21st century while it is likely that changes at low latitudes will not substantially exceed natural variability (IPCC, 2014).

Future increases in precipitation extremes related to the monsoon are very likely in East, South and Southeast Asia. More than 85% of CMIP5 (Coupled Model Inter-comparison Project Phase 5) models show an increase in mean precipitation in the East Asian summer monsoons while more than 95% of models project an increase in heavy precipitation. All models and all scenarios project an increase in both the mean and extreme precipitation in the Indian summer monsoon (IPCC, 2014).

4.2. Climate Change in Thailand

The long time series of temperature records dramatically explain why Thailand is experiencing climate change. An analysis of daily temperature records in Thailand has indicated that the mean states and their associated extreme indices showed remarkable changes over the 1970 – 2006 period. Trends in temperature indices reflect an increase in both maximum and minimum temperatures and are consistent with general warming trends observed on global and regional time scales. Linear trends analysis in annual time series of daily maximum, mean and minimum temperatures, have revealed that annual means of these three variables exhibited widespread increases in the range of 0.12-0.59, 0.10-0.40 and 0.11-0.55 °C/decade, respectively. The annual series of warm days and nights analysed through the TX90p and TN90p (daily maximum or daily minimum temperature above its 90th percentile) significantly increased by 3.4 days/decade and 3.5 days/decade, respectively (Limsakul et al., 2011).

During the past decade, rainfall in Thailand has fluctuated, resulting in severe droughts or severe floods, impacting both residential and agricultural areas significantly. Recorded flood events average at 11 events a year in Thailand, resulting in a number of deaths; 150 per year on average, with the exception of 2011, when more than 400 deaths occurred. Both drought and flood events are more frequently spread over the last 20 years (Bhatikul, 2012). Annual rainfall records of Thailand for the period 1951-2005, revealed a decreasing trend of average annual rainfall in Thailand (Archevarahuprok, 2015). A recent study, based on quality-controlled, daily rainfall data to ascertain long-term trends and the variability of total and extreme rainfall indices in Thailand during 1955–

2014, have revealed that while extreme rainfall events have been less frequent across most parts of Thailand, they have become more intense. Moreover, the indices measuring the magnitude of intense rainfall events indicate a trend towards wetter conditions, with heavy rainfall contributing a greater fraction to annual totals. One consequence of this change is the increased frequency and severity of flash floods as recently evidenced in many parts of Thailand (Limsakul and Singhruck, 2016).

A recent climate projection study conducted by Chinvanno (2013) has shown that Southeast Asia, especially Thailand, will be slightly warmer at the turn of the century but the hot area will have a wider extent. The hot period of the year will be much warmer and longer while the summertime will extend into winter. Higher rainfall, with increasing intensity, will be observed though the length of the rainy season and will tend to be more or less the same, with a higher risk of floods in years to come.

4.3. Climate Change in Nepal

A study on observed climate trends (1971-2014) of Nepal (DHM, 2017) showed that, in maximum temperature, there were positive trends annually and seasonally while the minimum temperature showed a positive trend only in the monsoon season. In the precipitation analysis, no significant trend was observed in precipitation during any season. All Nepal's annual maximum temperature trends are significantly positive (0.056°C/yr). All Nepal's annual minimum temperature trends are also positive (0.002°C/yr) but insignificant. The other salient features of the study are as follows:

Precipitation Trends

At district level, pre-monsoon and monsoon precipitation shows significant trends only in a few districts while winter and post-monsoon precipitation trends are insignificant in most of the districts. The significantly highest positive rainfall trend is observed in Syangja and Parbat districts in the monsoon season. Only pre-monsoon precipitation shows a significant negative trend in the High-Himalayan region. In other seasons, precipitation trends are insignificant in all physiographic regions.

Both at district and physiographic level, three coherent but insignificant patterns are observed: 1) insignificant positive precipitation trend in the southern districts of the Far Western Development Region (FWDR) in three seasons (winter, pre-monsoon and monsoon); 2) insignificant decrease in monsoon precipitation in the majority of districts east of 84°E longitude; 3) insignificant highest decreasing rainfall trend in all seasons in the High Mountains and insignificant positive trend in all seasons, except post-monsoon, in Tarai. These coherent but insignificant patterns might be associated with short-term variability in atmospheric phenomena. Further analysis/longer period data is necessary to understand these patterns. Since these patterns are not significant, these results should be viewed very cautiously.

Maximum Temperature Trend

The positive trend in maximum temperature is highly significant in the majority of districts (more than 90% of the districts) and in all physiographic regions in all seasons, except in the majority of the Tarai districts in winter. At the district level, the highest significant positive trend (0.12°C/yr) is observed in Manang district in the winter season. All five physiographic regions show a significant positive trend in all seasons, except in Tarai in winter and pre-monsoon, and in Siwaliks in winter. In High Mountains and High Himalayas, the highest positive trend is observed in the winter season and in Tarai, Siwaliks and Middle Mountains, the highest positive trend is observed in the monsoon season. Both at district and physiographic levels, seasonal and annual maximum temperature trends demonstrate a pattern in relation to altitude with negative trends or small positive trends in lower altitude districts/regions and larger positive trends in higher altitude districts/regions.

Minimum Temperature Trend

The minimum temperature shows a significant negative trend in most of the north-western districts in the winter and post-monsoon seasons while positive minimum temperature trends are significant in the majority of southern (Tarai to Middle Mountains) districts in the Eastern Development Region (EDR), Central Development Region (CDR) and Western Development Region (WDR) in all seasons.

Seasonal and annual minimum temperature trends, although the majority are insignificant both at district and physiographic levels, show positive trends in lower elevations and negative in higher elevations. Since these patterns are not significant, but might be associated with short-term variability in atmospheric phenomena, these results should be viewed very cautiously.

At the district level, the significantly highest positive trend (0.046°C/yr) is observed in Dolpa district in the monsoon and the significantly highest negative trend (-0.076°C/yr) in Humla district in winter. At the physiographic level, Terai and Siwaliks show significant increasing trends in most of the seasons. The decreasing trend is significant only in the winter season in the High Himalayas.

Extreme Precipitation Trends

The number of rainy days is increasing significantly, mainly in the north-western districts. Very wet days and extremely wet days are decreasing significantly, mainly in the northern districts. Consecutively dry days are decreasing significantly, mainly in the north western districts of the mid-western Development Region (MWDR) while consecutive wet days are increasing significantly in the northern districts of MWDR and central parts of WDR and EDR.

Extreme Temperature Trends

Trends of warm days and warm nights are significantly increasing in the majority of the districts. Warm spell duration is also increasing significantly in the majority of the districts. Cool days are decreasing in the majority of the districts while cool nights are increasing in a few north-western and northern districts and decreasing in a few south-eastern districts significantly. Cold spell duration is also increasing significantly but only in the Far Western Development Region (FWDR). It is noteworthy that maximum temperature trends are higher than minimum temperature trends in all seasons. The significant test shows maximum temperature trends are more robust than minimum temperature and precipitation trends (DHM, 2017).

In the recent study carried out by the Ministry of Forest and Environment, Government of Nepal (MOFE, 2019), a future scenario has been prepared for precipitation and temperature, considering the years 2016 to 2045 as medium-term and the period 2036 to 2065 as long-term, corresponding to the 2030s and 2050s respectively, with respect to the reference period (1981- 2010). Its findings suggest that temperature is expected to increase continuously throughout the 21st century. Mean temperature could rise by 0.9°C – 1.1°C in the medium-term period and 1.3°C – 1.8°C in the long-term period. Subsequently, extreme climate events are likely to be more frequent and severe. Average annual precipitation is likely to increase in both the medium-term and long-term periods. Average annual precipitation is likely to increase by 2–6% in the medium-term period and by 8–12% in the long-term period. Both the average annual mean temperature and the average annual precipitation are projected to increase until the end of the century. Precipitation could increase by 11–23%, and mean temperature might increase by 1.7°C – 3.6°C by 2100.

The temperature is projected to increase for all seasons. The highest rates of mean temperature increase are expected for the post-monsoon season (1.3°C – 1.4°C in the medium-term period, and 1.8°C – 2.4°C in the long-term period) and the winter season (1.0°C – 1.2°C in the medium-term period, and 1.5°C – 2.0°C in the long-term period).

Precipitation is projected to increase in all seasons, except the pre-monsoon season, which is likely to see a decrease of 4–5% in the medium-term period. The post-monsoon season might have the highest increase in precipitation with respect to the reference period, possibly going up by 6–19% in the medium-term and 19–20% in the long-term.

There will always be an uncertainty factor when using the models for the projection of climatic parameters. The uncertainty in temperature projections in the study carried out by MOFE is less than that in precipitation. Agreement between different climate models is greater for temperature as compared to precipitation, suggesting that projections regarding temperature-related changes are more certain than the projected changes in precipitation.

The changes in climatic extremes for air temperature and precipitation were evaluated by considering the Expert Team on Climate Change Detection and Indices (ETCCDI). Intense precipitation events are likely to increase in frequency and the number of rainy days is likely to decrease in the future which probably indicates the occurrence of more water-related hazards in the future.

Both warm days and warm nights are likely to increase in the future whilst both cold days and cold nights are likely to decrease. The duration of warm spells, of at least six days of high maximum temperatures, is likely to increase sharply in the future under both RCP4.5 and RCP8.5 scenarios. The duration of cold spells is likely to decrease in the future as indicated by the cold spell duration index under both RCP4.5 and RCP8.5. This is in conjunction with the increasing temperature trends and decreasing cold days of future periods.

This recent projection suggests that in general, the climate in all of Nepal will be significantly warmer and wetter in the future, except for a decrease in precipitation during the pre-monsoon season. At the same time, climate extremes, related to temperature and precipitation, suggest that more extreme events are likely in the future. All these scenarios indicate that different developmental sectors, relating to water resources in particular, will be significantly affected and so a deeper understanding of these changes will help the design of better adaptation strategies and their implementation in a more sustainable manner.

4.4. Climate Change in Sri Lanka

Sri Lanka possesses an established series of historical climatic data, especially rainfall and temperature, starting in the 1860s. Recent analysis of these data has shown that the country's average temperature is significantly increasing at a rate of 0.01°C to 0.03 °C per year (Fernando and Chandrapala, 1995; Nissanka et al., 2011) with an increased occurrence of more warm days and nights (Premalal and Punyawardena, 2013). The increase is more pronounced in night-time minimum temperature than in the daytime maximum temperature (Marambe et al., 2012). Data indicates that increases in night-time minimum air temperature contribute more to average increases in annual temperature than that of daytime maximum air temperatures (Basnayake, 2007). Moreover, Premalal and Punyawardena (2013) have clearly shown that both the number of days with cold nights and cold days is significantly decreasing in most areas of the country. Meanwhile, a significantly increasing trend has also been observed in the number of days with warm days and warm nights. All these clearly signal a warming trend as regards the temperature regime in Sri Lanka.

However, there are no discernible significant trends in seasonal and annual rainfall (Nissanka et al., 2011, Marambe et al., 2012), except for a few locations among over 400 rain gauging stations in the country. The same is true in terms of variability of cumulative annual and seasonal rainfall during the same period. Nevertheless, it has been observed that the variability of seasonal rainfall during the most recent decade (2001 – 2010) has increased compared to the previous decade (1991 – 2000) in most of the island, across all three climatic zones, with the occurrence of more frequent drought and flood conditions.

Recent studies focused on the occurrence of extreme, positive rainfall anomalies in the dry zone and Central Hills of the country. These have shown that contrary to common belief, there is no significant increase of heavy and very heavy rainfall events in the region but there has been an apparent increase of such events during the period of 2006 – 2010, evident in the Central Hills (Abeysekara et al., 2015) and the Dry Zone (Premalal and Punyawardena, 2013).

Climate change projections, also referred to as climate scenarios, are widely used for assessments of the potential impact of climate change on natural processes and human activities, including assessments conducted at the local/regional level. The southwest monsoon rainfall anomaly is positive and increasing in both moderate and high emission scenarios, with an increasing anomaly which is significant in the wet zone (Figure 7).

The northeast monsoon rainfall anomaly is negative for short-term, medium-term and long-term projections and the negative trend is observed under moderate emission scenarios. The northeast monsoon rainfall anomaly is slightly positive in short-term projections, 2020-2040, and negative thereafter for medium-term and long-term projections under high emission scenarios. A negative trend is observed for a high emission scenario. A decreasing anomaly is significant over the Dry Zone (Figure 7).

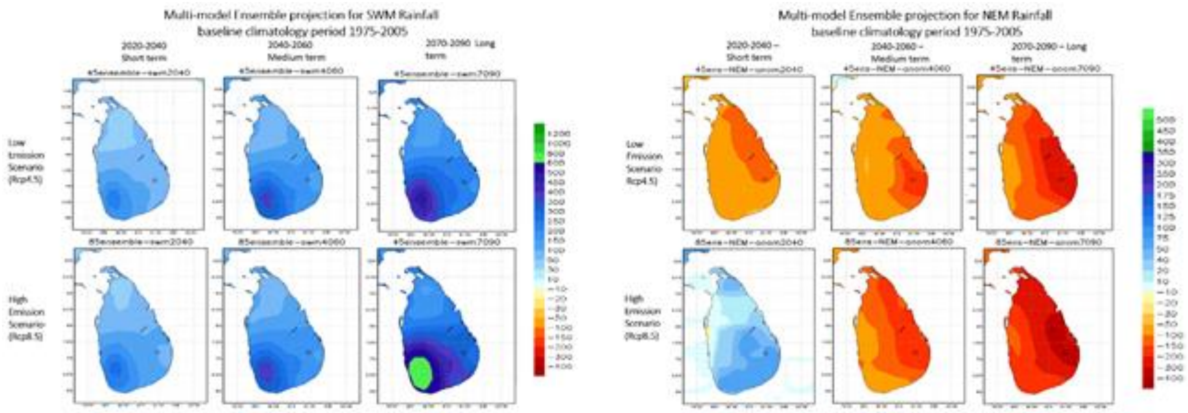

Figure 7 Multi model ensemble of change in Southwest-Monsoon rainfall (left) and Northeast - Monsoon Rainfall (right), relative to 1975-2005 for moderate emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060) and (2070-2090).

The First Inter Monsoon rainfall anomaly is negative in 2020-2040, slightly negative in 2040-2060 and positive in 2070-90 except for north-eastern parts under moderate emission scenarios. The First Inter Monsoon rainfall anomaly is negative in all three time frames with no significant trend under high emission scenarios (Figure 8).

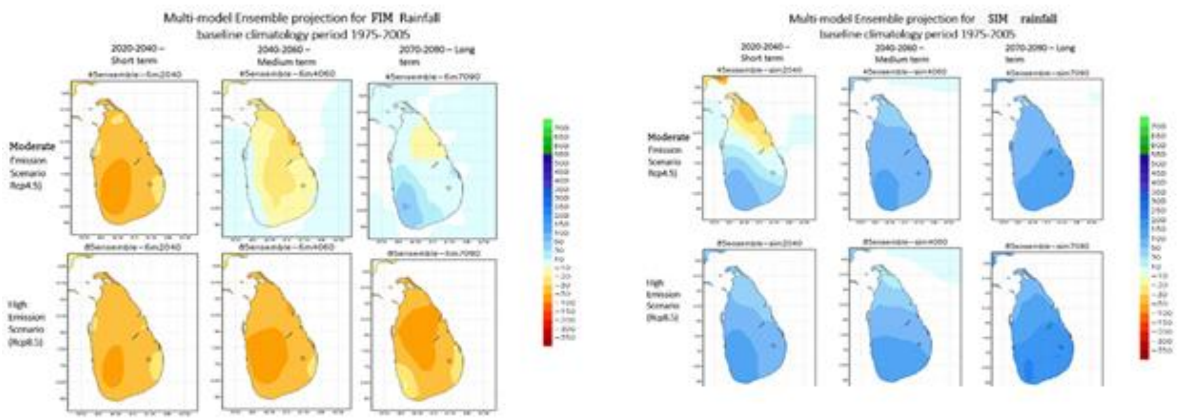

Figure 8 Multi model ensemble of change in First Inter-monsoon rainfall (left) and Second Inter-monsoon rainfall (right), relative to 1975-2005 for moderate emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060) and (2070-2090).

The Second Inter Monsoon rainfall anomaly is negative in north-eastern parts and positive in southwestern parts in 2020-2040. The Second Inter Monsoon rainfall anomaly is positive and increasing under high scenarios with a significant increase of positive rainfall anomaly over the southwestern and south-eastern parts (Figure 8).

Future projections indicate that the annual rainfall anomaly is negative in north-eastern parts and positive in southwestern parts in 2020-2040, while the annual rainfall anomaly is positive and increasing thereafter under moderate emission scenarios. The annual rainfall anomaly is positive and increasing under high emission scenarios with an increasing anomaly which is significant in the wet zone (Figure 9).

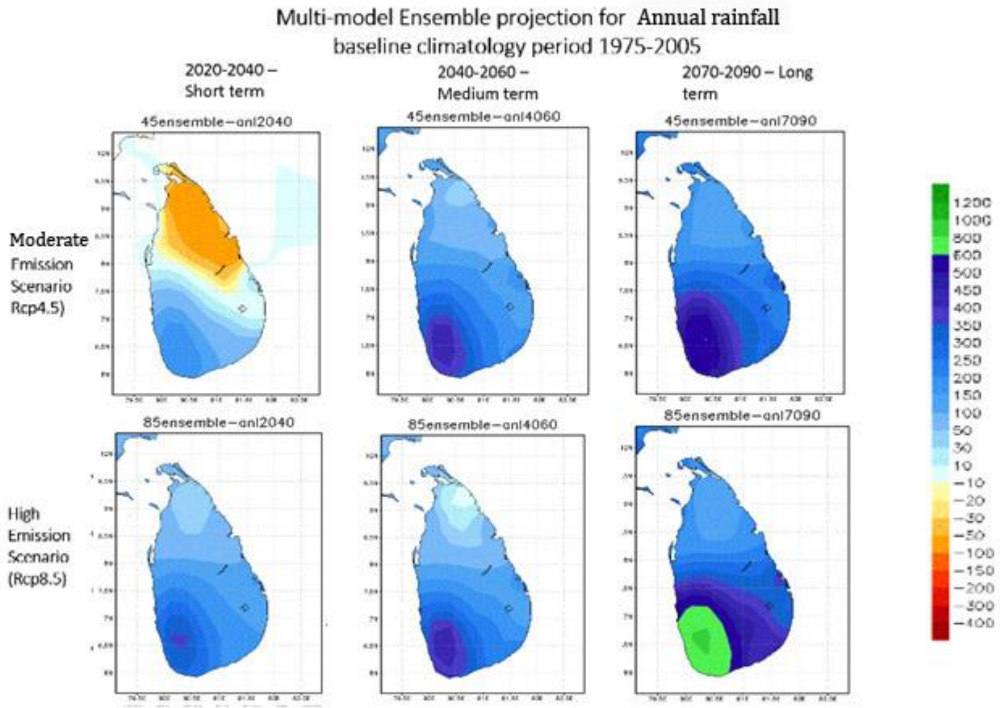

Figure 9 Multi model ensemble of change in Annual rainfall, relative to 1975-2005 for moderate emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040)(left), (2040-2060)(middle), (2070-2090)(right)

The Multi Model Ensemble prediction indicates an increase in maximum and minimum temperatures for all three time periods in 2020-2040, 2040-2060 and 2070-2090, for both moderate emission and high emission scenarios. The IPCC studies have also projected an increased incidence of extreme weather events for the South Asian region that may include heat waves and intense precipitation events (Cruz et al., 2007). Coastal disasters have also been projected to rise with increased incidences of tropical cyclones by 10–20% (Cruz et al., 2007). This is likely to impact Sri Lanka.

According to the Department of Meteorology, Government of Sri Lanka, Multi Model Ensemble (MME), the prediction indicates an increase in maximum and minimum temperatures for all three time periods in 2020-2040, 2040-2060 and 2070-2090, for both moderate emission (RCP 4.5) and high emission scenarios. For moderate emission scenarios, the Multi Model Ensemble prediction indicates that an increase of minimum and maximum temperature of 0.7°C– 1.2°C, 1.0°C-1.6°C and 1.5°C-2.3°C can be expected during 2020-2040, 2040-2060 and 2070-2090 respectively. For high emission scenarios, the Multi Model Ensemble prediction indicates that an increase in minimum temperature of 1.1°C – 1.5°C, 1.6°C - 2.5°C, and 2.4°C - 3.5°C and an increase in maximum temperature of 1.0°C – 1.5°C, 1.4°C - 2.3°C and 2.2°C - 3.2°C can be expected in the time periods of 2020-2040, 2040-2060 and 2070-2090 respectively.

A very recent study (2018), undertaken by the Department of Meteorology, Sri Lanka, with multi-model ensemble projections (composite products of six global climate models) has revealed that Sri Lanka's temperature will continue to rise in years to come (by 2080) with more warm days and nights and fewer cold days and nights. In terms of seasonal rainfall, the cumulative seasonal rainfall of the First Inter Monsoon (FIM) will decrease. The increased cumulative rainfall in the South West Monsoon (SWM) rainfall will result in the wetter parts of the country becoming even wetter from March to August, when both the FIM and SWM are most active, leading to frequent and intense flood hazards. In contrast, the rainfall of the Second Inter Monsoon (SIM) season will increase across all parts of the country while the North East Monsoon (NEM) will become drier in semi-arid areas. Hence, the prevalence of drought conditions during Maha seasons in the Dry Zone of Sri Lanka will probably become a common feature in future; a serious situation to consider in terms of national food security as the Dry Zone is the national food basket of the country.

5. Climate Related Natural Hazards in Asia with Special Reference to Flood Hazard

Natural disasters are extreme, sudden events caused by environmental factors which impact the population of the area and often result in destruction of the physical, biological and social environment of the affected area and its communities. Natural disasters can be classified into hydro-meteorological disasters such as climate induced hazards like flood, drought, heat/cold wave and geologically induced disasters which include earthquakes, tsunamis and volcanic eruptions. It has been projected that global warming is expected to make the climate warmer, wetter and more extreme. Hence, it can be expected that such changes in climate regime will increase the severity and frequency of climate induced natural disasters like floods, droughts, cyclones, storm surges, heat and cold waves, landslides and lightning strikes.

According to the United Nations' Global Humanitarian Overview Report – 2019, in the period between 2014 and 2017, 870 million people from 160 countries of the world, either lost their lives, their livelihoods or were displaced from their homes because of disasters caused by natural hazards. The same report also reveals that floods, severe storms, droughts and other climate-related extremes are responsible for over 90% of global disasters and affect the most people. The cost of damage caused by natural disasters around the world has skyrocketed, from an estimated $47 billion in 2009, to $340 billion in 2017. These extremes occur in all parts of the world but some regions are impacted more than others, as, for example, the Asian region. The countries in the Asia-Pacific region experience more climate-related natural disasters than any other region in the world. Between 2014 and 2017, countries in this region were affected by 217 storms and cyclones and 236 cases of severe flooding, impacting 650 million people and causing 33,000 deaths (UNOCHA, 2019). This clearly suggests that vulnerability to disasters is not solely a matter of where a person lives but also depends on the way they live. Many Asian countries share common characteristics such as large, growing populations with a high proportion of people living below the poverty line.

Floods are the most destructive form of natural hazard in both Asian and global contexts, leading to damage of crops and property, as well as loss of life, and finally ending up with economic and environmental loss. Flooding occurs when flows in a river, stream or any other water body surpass their carrying capacity, causing the overflow of water to the adjacent lands, leading to inundation

(WMO, 2006). Physically, flooding occurs when the total inflow of water at a locality becomes higher than the total outflow. The increased inflow may be caused by runoff from rainfall or discharge from a reservoir or a tank or a river.

Similarly, communities and farms near coastal regions, often lack the resources to build adequate sea defence structures and nor do their local authorities or national government, leaving them exposed to monsoon rains and storms. Thus, strong winds and storm surges along the coast lead to flooding, resulting in not only the destruction of homes, livestock and crops, but also, polluting fresh water supplies and cutting off emergency food and medicine supply routes. For example, when one of the deadliest tropical cyclones hit the Chittagong region of south eastern Bangladesh in April, 1991, it killed over 135,000 people and left an estimated 10 million homeless. Poor communications and lack of preparedness meant that villagers received no warning of the coming storm (UNOCHA, 2019).

In addition, in many of the Asian countries, rapid industrialization and urbanization are leading to high concentrations of the population living in unplanned, crowded cities. Rapid urbanization, without adequate planning, make densely populated, urban areas more vulnerable to floods and storm surges, particularly near coastal regions and along the banks of large rivers. Due to the unplanned expansion of urban areas, the Asian region also suffers from high rates of environmental degradation. Besides urbanization, logging and land clearances for farming activities in catchment areas have caused dramatic loss of tree cover, depleting natural barriers and increasing the risk of landslides and flash floods. Additionally, poverty makes communities more vulnerable to climate induced natural disasters as a result of having less coping capacity as well as the political and economic instability prevailing in some Asian countries.

Though floods are considered as hazards, they also have a number of beneficial aspects. Floods replenish groundwater aquifers and sustain groundwater supplies. Floods help to maintain wetland systems which play a vital role in ecology, providing habitats for a rich bio-diversity. Floods lead to increased fertility of the floodplains by regularly depositing rich silt on the riparian lands. Without the build-up of these alluvial deposits, riparian cultivators would have to spend significant amounts on chemical fertilizers for their lands to maintain the fertility (such as in Thailand, Bangladesh, Myanmar, Vietnam). However, unmanaged eco-systems and unplanned anthropogenic interventions result in the negative impact of floods.

5.1. Floods in Thailand

Thailand is a flood-prone country. The monsoon is the main contributor of rainfall in Thailand but other weather systems can also increase rainfall during the monsoon months. Tropical cyclones, for example, can generate copious amounts of rainfall long after strong winds have diminished. Although Thailand is rarely impacted by typhoon winds, the remnants of storms crossing Vietnam, Cambodia and Laos from the east generate heavy precipitation in Thailand on a near-annual basis (Anon, 2016) which may lead to flooding.

The impact of floods in Thailand is the result of both natural and anthropogenic factors. The first factor is the copious amount of monsoonal rains which will often be augmented by approaching storms from the east. The second is the terrain of the region. Due to the gentle slope of the downstream parts of the Nan and Yom Rivers (the tributaries of the Chao Phraya River system) a high volume of discharge flows into the lower part of the watershed from the narrow, upstream section of the river system. In addition, the Chao Phraya River has a modest bank full capacity, particularly in the downstream section, which results in it being flood-prone (Komori, 2012). The third factor is the land use/landcover downstream of the Chao Phraya River including Bangkok metro area which is located on the former floodplains of the river. The natural drainage and wetlands have been replaced with urban structures. The same applies for the surrounding, mega industrial parks, located out of the Bangkok metropolitan area as well (Engkagul, 1993). In addition, land subsidence in Bangkok, due to over extraction of ground water for industries, might have also worsened flood damage, given that the elevation of Bangkok is 0.5 m to1.5 m above mean sea level (ADB, 1994) leading to localized water logging. Another factor is the lack of reliable seasonal weather forecasts with a reasonable lead time. If such forecasts were available, an optimum reservoir operation strategy could be drawn up to meet two competing objectives that confound reservoir operations, namely, storing water for use during the dry season and minimizing flooding during the wet season (Lebel et al., 2011). In addition, high tides from the sea and low efficiency of the drainage systems are also contributing factors. As the population and number of exposed properties will continue to grow in Thailand, losses from this peril will continue to rise, especially under a changing and variable climate, since floods will be more frequent and intense in this region in future.

5.2. Floods in Nepal

Nepal is traversed by numerous rivers and rivulets with mainly four major river basins (Figure 10), namely, the Koshi river basin in the east and to the west, Gandaki and Karnali and Mahakali to the far west of Nepal. In addition, there are smaller catchments of river systems which are not snow-fed and originate from the mid hills of the country.

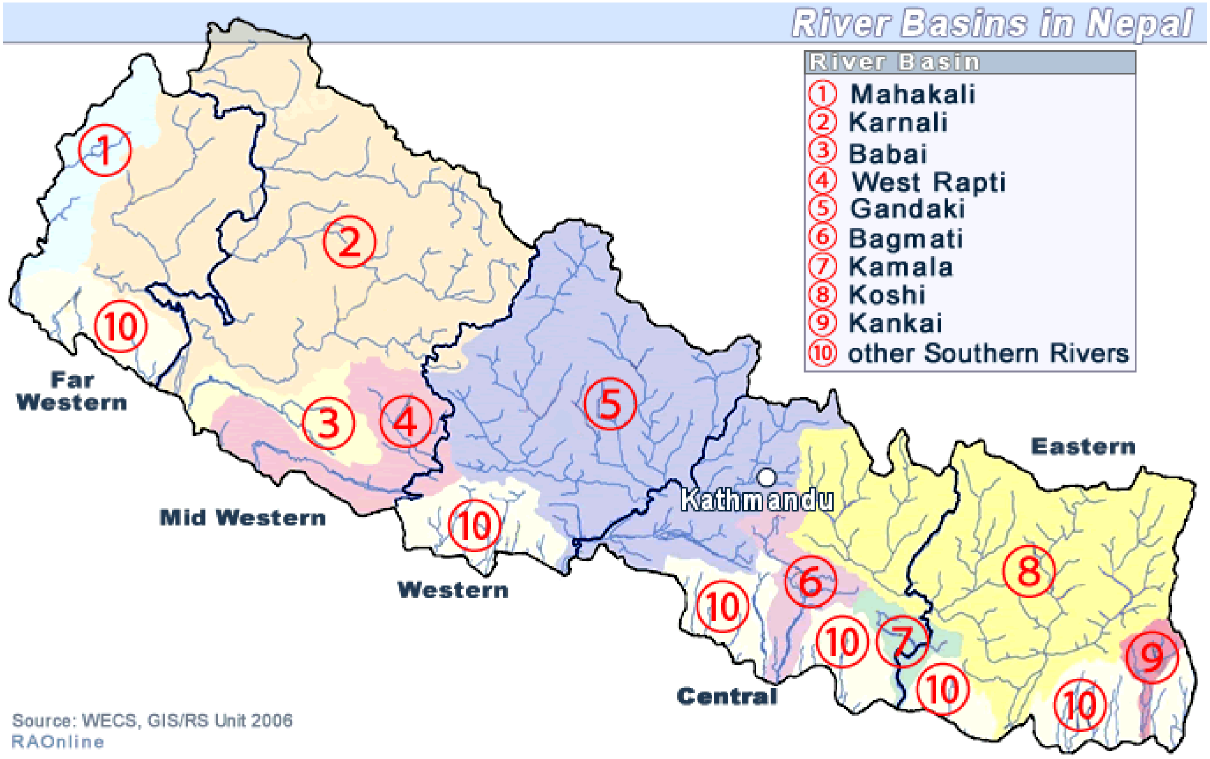

Figure 10 River basins of Nepal (Source: WECS, GIS/RS Unit, 2006)

The characteristics of the river system in Nepal are presented Table 1.

Table 1 Hydrological character of rivers of Nepal

River Basin	Estimated catchment area in Nepal (km^2) #	Average discharge (m^3/s)	Annual discharge (km^3/year)
Rivers originating at Himalayas			
Koshi	27,863	1409	45
Gandaki/Narayani	31,464	1600	50
Karnali	41,058	1397	44
Mahakali	5,188	573	18
Rivers originating at Middle Mountains and Hills	17,000	461	14.5
Rivers originating at Siwalik zone	23,150	1682	53
Total	145,723	7122	224.5

Total catchment area of each river basin is larger than shown in the table. Areas of the basins excluded in the table lies either in China or India.
Source: Water and Energy Commission Secretariat, 2005

Floods significantly impact Nepal in terms of the number of affected people and frequency of events. For example, data on the number of people affected by various types of natural disaster that occurred in Nepal during the period 1971-2006, reveal that 68.3% of the total affected people were impacted by floods (NSET, 2007). Nepal's three biggest river systems, Koshi, Gandaki and Karnali, which originate in the high mountain glaciers, flow through the country and then enter India through the state of Bihar. During the monsoon season, these river systems often get flooded due to heavy rains/landslides in Nepal which then create floods in India's most flood-prone state, Bihar. About 76% of the population in northern Bihar live with the threat of floods due to these river systems and a total of 73.1% of the total geographical area of Bihar is flood affected, mostly during the monsoon season (Anon, 2015).

Nepal is ranked the 30th country in the world in respect of relative vulnerability to floods, according to a study conducted by the UNDP (UNDP/BCPR, 2004). There are more than 6,000 rivers and streams in Nepal. Most of them flow from north to south, generally, with a high velocity due to the high gradient. Most of the large rivers are snow-fed and originate from the Himalayan glaciers which are covered by perpetual snow. Hence, the melting snow maintains a considerable base flow which swells very quickly with a very high intensity of rainfall during the monsoon season causing floods. The monsoonal rainfall which falls mostly during June and September every year, contributes to about 80% of the annual rainfall (Chalise et al., 1995) and thus, extreme floods occur during this period, mostly due to concentrated spells of heavy rainfall (Shakya, 1998). The filling of natural wetlands, the rapid urbanization across the countryside and many other human interventions/land use changes, have reduced infiltration and subsequent percolation, leading to more stagnating water which results in higher floods, even with a minor positive anomaly of rainfall (Shakya et al., 2006). In the Himalayan region of Nepal, glacier lakes are common. A total of 159 glacial lakes have been found in the Koshi basin and 229 in the Tibetan Arun basin. Among them, 24 were found to be potentially dangerous and located in areas like Upper Barun, Lower Barun, Chamlangtsho, Tsho Rolpa, Sabou, DudhKunda, Majang, Inja and Thulari. These lakes contain huge volumes of water in unstable conditions and, as a result, could burst at any time. Catastrophic floods might occur, resulting in considerable loss of life and physical property (Alton et al., 2019; Chhetri, 1999).

Nepal has been identified as one of the most sensitive countries in terms of climate hazard. Nepal's altitude varies from 60 m to 8848 m within the average width of 193 km. There are more than 600 rivers and rivulets flowing from north to south. 80% of the annual rainfall occurs in the monsoon season (June to September). This variation of altitude within a short distance, the rainfall pattern and the number of rivers and rivulets, provide an overview of the flood hazards in Nepal. Rain induced flood hazards, GLOF, avalanches which occur due to an increase in the average temperature, are all major factors which constitute flood hazards in Nepal. Historical data shows that from 1971-2013, 3953 major flood events were recorded in Nepal. The remarkable series of flood events, with more than 100 events in a single year, are presented in the Table 2.

Table 2 Annual floods in Nepal with years having more than 100 recorded events

Year	No of Flood Events	Year	No of Flood events
1993	269	1998	130
2000	179	2001	205
2002	425	2003	147
2004	186	2007	125
2008	280	2009	183
2010	282	2009	183
2011	299	2012	105
2013	115		

The data shows that the number of flood events in recent years is increasing. In the period 2007 to 2013, each year, more than 100 flood events were recorded. During this period, more than 6 billion USD of economic loss were caused by floods alone (DesInventar, 2018).

GLOF is also one of the climate induced hazards in Nepal. As per the information available, there were at least 24 GLOF events in Nepal, of which, 14 were believed to have occurred in Nepal and 10 occurred in China. Data obtained in 2010 shows that about 3,808 glaciers have been identified in the Nepal Himalayas, covering an area of 4,212 sq.km. This area was only 3252 sq.km in 2001. This shows the potential threat of GLOF events in Nepal (Mool et al., 2011).

5.3. Floods in Sri Lanka

In Sri Lanka, floods are more common than any other natural hazards. There are three types of floods mainly affecting Sri Lanka (Meegastenna, n.d.) :

1. Riverine floods: this is an alternative term to identify river floods. When any river/stream reaches its carrying capacity/flood stage, the swollen flow overflows the banks of the river/stream and inundates low-lying areas and levees on either side.

2. Urban floods: these types of flood occur in a relatively short space of time and can inundate an area with several feet of water due to intense rains, inadequate drainage provision, the blockage of drains with debris and irrational land use such as the filling of wetlands and blocking of natural drainage.
3. Reservoir induced floods: these types of flood occur downstream of a reservoir due to spillage during intense or prolonged rains or the breaching of dams due to extensive rainfall in the upper catchment.

The major floods of Sri Lanka are associated with two monsoon seasons:

- South west monsoon season (May to September) in the south western part of the country, especially the Sabaragamuwa provinces, also termed the 'Wet Zone' of the country.
- North east monsoon season (December to February) in eastern, northern and north-central provinces of the country; the 'Dry Zone' of the country.

In addition, the months from October to December are considered as the 'stormy months' of Sri Lanka, due to the frequent formation of weather systems in the Bay of Bengal on account of the position of the Inter Tropical Convergence Zone (ITCZ) on, or near to, Sri Lanka. Heavy rainfall receipt from these weather systems can cause floods in any part of Sri Lanka depending on the relative position of the weather system in the Bay of Bengal.

Moreover, when the usual north east monsoonal flow changes its trajectory over the Bay of Bengal from north-east to a northerly direction (due to easterly waves coming all the way from the Pacific Ocean and eastern Indian Ocean) this may also lead to heavy downpours and associated floods in most parts of the island, especially in the eastern region. This kind of weather condition usually occurs in the last few weeks of the year or in January, once or twice per season.

During the month of April, in any given year, when the country is experiencing intense convectional activity due to the sun's position being directly overhead, this leads to localized, high intensity thunderstorms, even exceeding 100 mm/hr rainfall. There may be flash floods or urban floods due to insufficient drainage provision in built up areas and the blocking of drainage and small streams with debris and waste materials in rural and semi-urban areas.

6. Climate Smart Disaster Risk Management with Special Reference to Agriculture in Asia

Significant changes are observed in the global climate due to global warming; Asia is no exception, resulting in changes to weather patterns. The effect of these changes is likely to be worse in the least developed and developing economies in the region due to their low coping capacity and lack of awareness on the issue. Agrarian communities, living in monsoonal, tropical, sub-tropical and coastal regions of Asia, are currently dealing with extreme weather conditions; the dry areas are experiencing drier weather while the flood-prone areas are experiencing increases in flood frequency, leading to considerable impacts on the agricultural sector. Furthermore, climate change will lead to greater uncertainty, meaning that traditional knowledge of previous extreme weather patterns will be insufficient to predict the future as before. For instance, a 100 year return period flood or drought may become a 30 year return period flood or drought, indicating that severe events could happen more frequently in the future. Thus, a major shift in the paradigm of managing disaster risk is needed urgently to avoid disasters and to mitigate them so that the communities in Asia do not experience worse. This paradigm shift in climate-related, disaster risk reduction has been termed as Climate Smart Disaster Risk Management (CDSRM). CDSRM is an integrated social development and disaster risk management approach that aims simultaneously to tackle changing disaster risks, enhance adaptive capacity, address poverty, exposure, vulnerability and their structural causes, and promote environmentally sustainable development in a changing climate (Mitchell, 2010).

One of the major shortfalls of conventional disaster management strategies is the lack of climatic information on the nature of future climate risks and post-disaster reconstruction processes or modalities, which eventually lead to an increased risk of disaster rather than a decrease (Mitchell, 2010). Thus, inclusion of both climate predictions and projections provides opportunities to increase the lead times of early warnings. For instance, seasonal climate outlooks help governments to predict and manage excessive (flood) or deficient (drought) rainfall and thereby, minimize the risk associated with it. Similarly, climate forecasts, through seasonal to decadal time scales, can help inform decisions on long-term investments and strategic planning for example, riparian zone management, development of new building codes and the retrofitting of infrastructure, like levees, to withstand more frequent and severe flood hazards. Short-term responses to disaster events can support the immediate needs of the affected people but a long-term solution, embedded in development planning, gives not only hope for potentially vulnerable people, but also, a sustainable solution to reducing their vulnerability and exposure to such climate related risks.

6.1. Climate-related Disasters and Agriculture

During the period of 1980-2014, a notable rise in climate induced, hydro-meteorological disasters worldwide was recorded, especially events such as droughts, floods and storms. With this rise, there were associated economic losses (FAO, 2016). The increase in climate-related events is of special significance to the Asian region where agriculture is the main livelihood. With it being an open system, it is highly dependent on the prevailing weather conditions and is highly sensitive to rainfall extremes, both droughts and floods. It has also been observed that increased, climate-related disasters in the world are associated with increases in loss and damage during recent times (Table 1). FAO (2016) has also found that the share of climate-related disaster damage and loss, absorbed by agriculture in developing countries during the period 2003-2013, is about 17% and 31%, respectively.

The world's agricultural sector is affected to different degrees and scales by climate induced disasters depending on the geographical position of the respective country across the world's agro-climatic zones. Crops tend to be significantly affected by floods and storms; livestock is overwhelmingly affected by droughts and to some extent, during flash floods; the fisheries and aquaculture sector is also considerably affected by storms, including hurricanes and cyclones, while most of the economic impacts to the forestry sector are caused by storms and wild fires with no significant impact from droughts. According to FAO (2016), amongst various climate induced disasters, the contribution to agricultural losses in Asia was 86% due to floods, 10% due to drought and 4% due to storms. However, figures for individual countries may differ significantly across the region, especially between droughts and floods (Table 3 & Table 4).

Table 3 Annual occurrence of climate related disasters and associated economic damage (Adapted from FAO, 2016)

Period	Average No. of annual climate related disasters	Average annual climate related losses - UD$ Billion	Increase (per cent)
1980 - 1990	149	332	123
2004 - 2014	14	100	614

Table 4 Damage and Losses to agricultural sectors by climate-related disasters (FAO, 2016)

Sectors	Disasters		
	Droughts	Floods	Storms
Crops	14.9	59.1	26.0
Livestock	87.6	8.6	3.8
Fisheries & Aquaculture	9.8	31.3	59.0
Forestry	-	5.3	94.7

Climate-related disasters create several negative impacts beyond physical damage to the agricultural sector. They impact the agricultural production and productivity, with potential negative cascading effects along the value chain, including on industrial output in sectors that depend on agriculture. In medium and large scale disasters, high production losses can have negative consequences for the balance of payment of the country and affect sectoral and national economic growth (FAO, 2016). As a consequence, disasters may weaken the efforts of governments and international donors to eradicate hunger, food insecurity and poverty and also undermine achieving the sustainable development goals of the United Nations by the year 2030 (Figure 11).

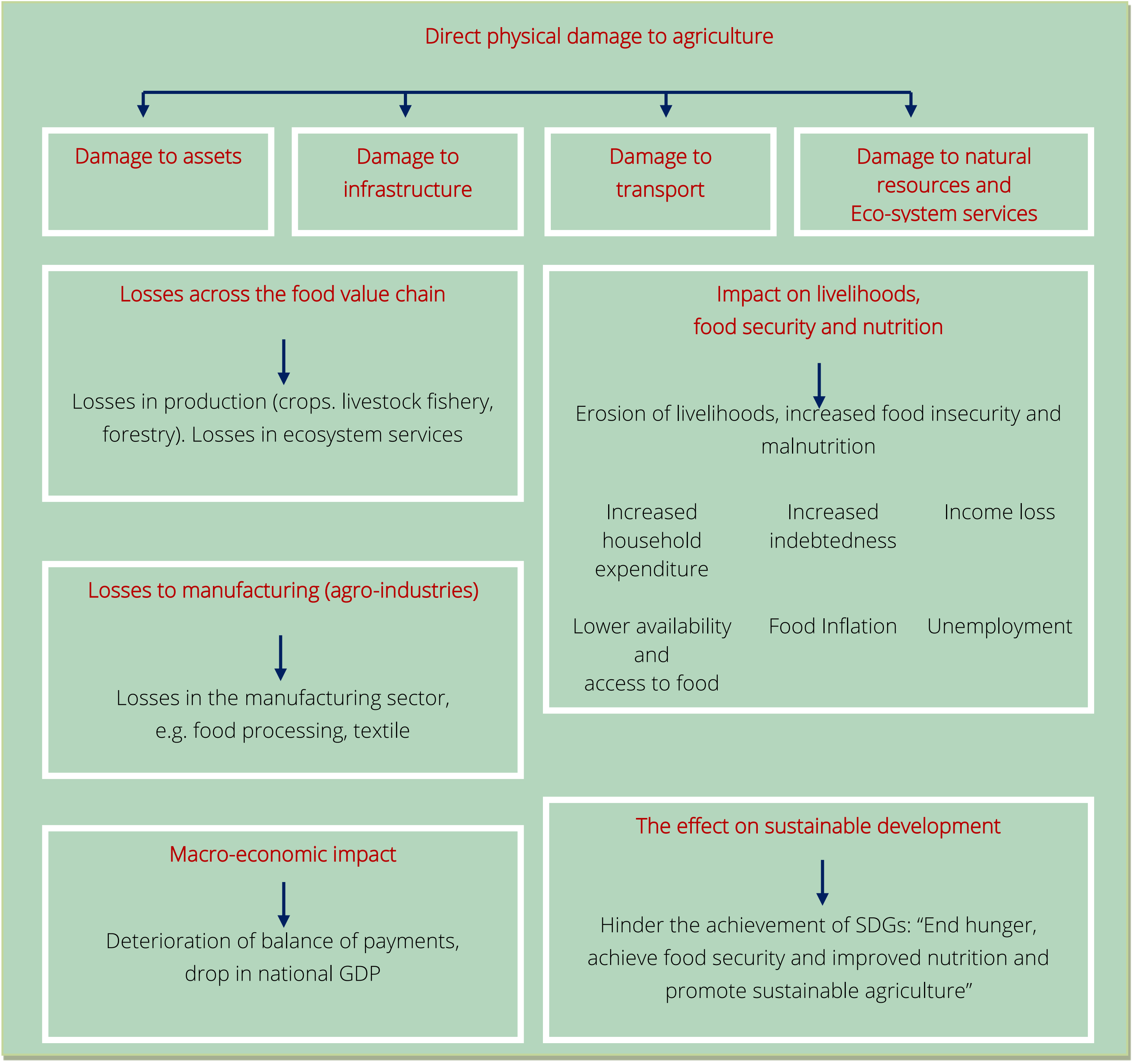

Figure 11 Direct and indirect impacts and consequences of natural disasters on the agriculture sector (Adapted from FAO, 2016)

6.1.1. Climate related disasters and likely effect to agriculture sector - Thailand

Frequently occurring climate induced natural disasters in Thailand include floods, droughts, tropical storms and forest fires. The occurrence of flood is the most frequent in Thailand, especially during the monsoon season from June to September, causing damage to property and livelihoods, especially in the agricultural sector and more than any other type of disaster. In July, 2011, Thailand experienced its worst flood over the last half a century, with landfall of a tropical storm which resulted in 815 deaths, economic losses totalling about US$ 45.7 billion and 8,100 square miles of damage to farmland which was unusable until January of the following year. During this event, flooding spread to 65 provinces, affecting 13.6 million people and was particularly intense in the central and northern parts of the country (Anon, 2016a).

Droughts annually occur in the dry season during March to April and they have become more intense in recent years. The problem has been exacerbated by unprecedented demands for water to the agricultural, industrial and service sectors, owing to the increase in population and economic development, along with heavy deforestation in catchment areas.

Tropical storms, resulting in heavy floods, occur in Thailand during June to November, including the monsoon months. On average, four storms cross Thailand every year. The whole country is vulnerable to tropical storms but the peninsular southern region is the most vulnerable area.

6.1.2. Climate related disasters and likely effects on agriculture sector - Nepal

Globally, Nepal ranks 4th in terms of its relative vulnerability to climate change (MoHA 2015). The country is also amongst the 20 most disaster-prone countries in the world, both natural and human induced. More than 80% of the total population of Nepal is at risk of natural hazards such as floods, landslides, windstorms, hailstorms, fires, earthquakes and Glacial Lake Outburst Floods (GLOFs). Amongst the above, floods and associated landslides are the most destructive hazards in Nepal and are most common during the monsoon season, between June and September, when 80% of the annual precipitation falls, coinciding with snowmelt in the mountains (MoHA, 2015). It is estimated that more than 6,000 rivers and rivulets criss-cross Nepal, flowing from north to south. Among these snow fed rivers in Nepal, the Koshi, Narayani, Karnali and Mahakali present flood-risks during the monsoon period of June to September (DRRP, 2019). Increased glacial melt in Nepal during the monsoon period is also contributing to Glacial Lakes Outburst Floods (GLOFs) resulting in catastrophic floods downstream. Out of 2,315 glacial lakes, about 15 have been found to be substantially dangerous in Nepal with the potential for GLOF (DRRP, 2019). To mitigate the risk, there have been programmes to lower glacial lake levels in two cases, namely the Tsho Rolpa glacial lake and the Imja glacial lake in Nepal. However, such programmes in the high Himalayas are very expensive because of the rugged and high altitude topography. This is one climate change effect Nepal has to bear, in spite of the fact that the contribution of Nepal to the total global emission of Greenhouse Gases (GHGs) is almost negligible.

Data from the last three decades show that climate-related disasters accounted for almost 25% of deaths with 84% of the population being adversely affected, causing economic losses of 76%. Thus, it is clear from these numbers that proactive Disaster Risk Reduction (DRR) strategies and policies are important and must receive high priority in national level policy making. The agricultural sector of the country is predominantly made up of small holder farms which are mainly rain fed. Historically, the agricultural sector has been heavily affected by floods and erratic rainfall, although there have also been droughts in recent years under a changing and variable climate regime (MoSTE, 2014).

Droughts are a frequent occurrence in Nepal and are generally caused by uneven and irregular low monsoon rainfall in the summer. Some parts of Terai, mid-land and Trans-Himalayan belts of Nepal are prone to drought (DRRP, 2019). Dry spells also usually occur between November and May and these dry-spells have become more frequent, longer, more intense and more severe recently (Practical Action, 2010)

6.1.3. Climate related disasters and likely effects on agriculture sector - Sri Lanka

In Sri Lanka, climate related natural disasters and associated losses due to damage to housing, infrastructure and agriculture, as well as the amount of relief distributed, are estimated to be about LKR 50 billion (approx. USD 327 million). The highest annual expected losses are from floods (LKR 32 billion), cyclones or high winds (LKR 11 billion), droughts (LKR 5.2 billion) and landslides (LKR 1.8 billion). This is equivalent to 0.4 % of GDP or 2.1% of government expenditure (Pswarayi-Riddihough, 2017). The worst floods and landslides in recent history, in May 2016, caused damage amounting to US$572 million. These numbers are likely to rise as droughts and floods, triggered by climate change, may become more frequent and severe in years to come (Punyawardena et al., 2013). Out of 21 natural and human induced disasters which pose serious threats to the island nation, flood, droughts and landslides are considered as the most significant as they can affect the country's population, the livelihood of the people, the infrastructure and environment (Punyawardena and De Silva, 2012).

Besides riverine floods, flash floods and urban floods, flood occurrence due to reservoir operations and floods caused by dam breaching are of special importance to Sri Lanka. In Sri Lanka, areas vulnerable to floods share some common characteristics. They tend to be in high rainfall receiving areas, low in elevation and close to stream or sea. However, the presence of any, or all, of these characteristics does not make an area necessarily flood-prone. Similarly, their absence does not guarantee that an area is free from the occurrence of flood (Punyawardena and De Silva, 2012).

Even though Sri Lanka has a tropical monsoon climate according to the world's climatic nomenclature, with a high rainfall regime ranging from 900 to over 5,500 mm annually, drought is still a common feature of the Sri Lankan landscape. Drought, or extreme negative rainfall anomalies, are experienced in Sri Lanka in three major meteorological situations. One situation arises when the air stream over the island comes from a northern hemisphere high pressure system and travels over the dry mainland of India immediately before reaching Sri Lanka during the northeast monsoon season, December to February. A marked decrease in formation of weather systems (low-level disturbances, depressions and cyclones) in the Bay of Bengal, also creates below normal rainfall during October to January. Such droughts and dry spells can affect most regions of the island. Rains during mid-March to early May, generally occur due to convection under local thermal conditions and the influence of the Inter Tropical Convergence Zone (ITCZ). However, activity of the ITCZ during this period is highly variable and thus, it is common to experience below normal rainfall in most regions of the country, especially in the Dry Zone. The third situation may occur during the southwest monsoon months of May to September when the prevailing air stream of the monsoon is relatively dry due to deviation in the flow direction from its usual path. Under such situations, dry conditions are likely to occur in agro-ecological regions that lie across even Wet and Intermediate Zones. Thus, it is apparent that almost all locations of the island carry the potential threat of drought occurrence (Chitranayana and Punyawardena, 2008).

Many of the natural hill slopes that have stood safe for centuries are now frequently subject to landslides. This is mainly due to anthropogenic activities and irrational land use practices on vulnerable hill slopes. The situation will be further aggravated as the frequency of intense rainfall will be more likely under a changing and variable climate regime. Nearly 13,00 km^2, (20% of the total extent of the island) covering 10 administrative districts (out of 25) such as Badulla, Nuwara Eliya, Matara, Kandy, Kegalle, Ratnapura, Kalutara, Galle, Matara and Hambantota, are considered as highly vulnerable to landslides (Bandara et al., 2012).

7. Climate Smart Flood Mitigation Interventions for Agriculture in Thailand, Nepal and Sri Lanka

A changing climate is expected to lead to changes in the frequency, intensity, spatial extent, duration and timing of weather and climate extremes, especially in the rainfall and temperature regimes of respective countries. These impacts are expected to disproportionately affect the welfare of the poor in rural areas who are dependent on agriculture for their livelihoods, including female headed households and those with limited access to land. They will also impact modern agricultural inputs, infrastructure and education, especially in the developing countries of the Asian region. Moreover, these impacts are seen as additional, and severe, further stresses on countries currently facing the problems of already losing sustainability. Meanwhile, the three countries under review are especially vulnerable to climate-related disasters because they have a comparatively higher degree of exposure to such hazards as previously explained.

To mitigate the threats posed by climate change on global food security and sustainable development, the Food and Agriculture Organization (FAO) of the UN came up with the concept of Climate Smart Agriculture (CSA). This integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges and is composed of three main pillars, or goals, namely:

- Sustainably increasing agricultural productivity to support equitable increases in incomes, food security and development.
- Food security and increased sustainable agricultural production.
- Adapting and building resilience to climate change from the farm to national levels.
- Adaptation to climate change.
- Reducing and/or removing greenhouse gas emissions (GHG), where possible.
- Climate change mitigation.

International institutions such as the UN, IFAD, the World Bank and CGIAR, are in agreement that this is an approach which ensures a way forward for achieving global food security and sustainable development under a changing and variable climate (SIDA, 2017). Thus, CSA can be integrated with disaster risk reduction measures for minimizing the impacts of flood hazard on agriculture in the three countries under review.

Since ancient times, human civilizations have prospered on the floodplains of large rivers, taking advantage of the benefits of floods, which are much more than just a hazard. This remains true to the present day: Bangkok in Thailand along the Chao Praya river, Colombo in Sri Lanka on the bank of the Kelani river and Kathmandu in Nepal on the banks of the Bagmati river. The flood plains generally encompass habitation together with economic activities. These zones often represent a major source of income, livelihood and housing for thousands of communities, while floods play a key role in these processes (WMO and GWP, 2006).

Until the early 1900s, the main flood mitigation practices were mainly structural, by means of the construction of levees only, followed by reservoir constructions in large river basins. The concept of Non- Structural Measures (NSMs) was first used in the context of flood control in the late 1970s, as a means to reduce the ever- increasing damage by floods, without unduly expanding the costly infrastructure. NSMs were perceived more as complementary additions to the essentially structural solutions to flood hazard, in order to reduce costs and enhance efficiency (Watanabe et al., 2018). This concept has further evolved during the last few decades in the agriculture sector with the introduction of new approaches in line with the CSA approaches. These can be implemented hand-in-hand with conventional and novel structural approaches in flood management to improve the effectiveness of the interventions. The following sections discuss such potential interventions which can be implemented in Thailand, Nepal and Sri Lanka, depending on the physical settings of river basins in the respective countries.

7.1. Floodplain Management Plans

Floodplain management is a good starting point to reduce the risk from floods on agriculture in the river basins. Preparing a floodplain management plan enables strategic decisions about where, what and how to develop the floodplain for agricultural activities while reducing the flood risk (for example, land at high elevations within the floodplain landscape to be exclusively reserved for agricultural use in the master plan). In this context, local authorities can play a vital role by referring only to the overarching floodplain management plan without letting local communities or government and private sector agencies violate the conditions laid out in the master plan (lands reserved for agriculture will not be allowed for settlements or industries by any means). This kind of zoning will not only protect the agricultural land from flood risks, but other development initiatives in the plain as well, including community dwellings and properties. Leaving lands which will not be subject to inundation for agriculture, also facilitates the building of critical facilities such as emergency hospitals and flood-free evacuation areas when there are no other practical alternatives during a flood.

7.2. Flood Modification Measures

Flood modification measures aim to change the behaviour of floods by reducing flood levels, velocities or flows, or by excluding floodwaters from areas under threat up to their designed capacity. They are a common and proven structural means of reducing damage to existing agricultural areas and other properties downstream under threat from flooding. They tend to be more expensive than NSMs, but will often essentially protect vast areas of agricultural lands and their associated properties, sometimes including entire value chains of agricultural produce downstream.

One such measure is flood mitigation dams that can reduce downstream flow velocity and flood levels by temporarily storing and later, releasing, floodwaters. Most of these dams can be used for supplying water to the community or irrigation for agricultural lands during dry spells and hydropower generation. However, they are successful only up to their design capacity, beyond which, occasionally, it might be more hazardous due to structural failures, especially under conditions where a proper reservoir operation plan is not in place. Under these circumstances, it is more advisable to construct several detention basins of small size which can collectively arrest a large volume of runoff water in the catchment at a given time. This minimizes the downstream flood risk while water collected in the basin will act as a recharge structure for ground water, maintaining a good base flow of streams in the catchment during dry seasons.

Levees are generally raised embankments built to eliminate inundation on either side of river banks. During larger floods, levees can be overtopped with water flooding into lowlands, basically meant for rice-based cropping systems, inundating areas protected in smaller events. Levees trap local storm-water without entering the waterway. Thus, unless flood gates and pumps are provided, they may cause additional risks of inundation of lowland agricultural lands. On the other hand, levees, whether temporary or permanent, can increase flood levels in the upstream, causing inundation in unprotected lowlands, even with a minor flood.

Waterway modifications such as widening, deepening, re-aligning or desilting rivers and flow paths, can enhance the velocity of floodwaters downstream and reduce the likelihood of blockage resulting in inundation of lowland or adjacent agricultural land uses. However, increased velocities can lead to river bank erosion and other adverse environmental impacts. It should also be noted that the benefits of desilting and clearing are only a temporary measure unless there is regular maintenance which can be easily entrusted to Farmers' Self Help Groups or other civil society organizations in those areas.

Other structures, such as roads, railways and embankments, also have a positive impact on flood risk management in flood plain agricultural lands because they can alter flood flows and behaviour, if properly designed for the purpose. Floodgates can also be used to prevent backflow from river systems into primary and secondary drainage systems, subsequently, inundating lowlands in the back swamp where usually, agriculturally-related land use exists.

Sometimes, emergency dykes, or levees, are built following a flood forecast. Although they may be effective for the emergency situation, they should not be considered as permanent flood protection measures. Dykes, levees and walls that possess enough protection against all floods cannot feasibly be built in an emergency situation and the consequences of their overtopping and failure during a future major flood may be catastrophic. However, the removal of emergency measures often does not occur because of cost and lack of interest by the community after the hazard is over. Hence, priority should be given to dismantle such temporary structures on the floodplain immediately after the danger period is over, based on available weather forecast information.

It should also be borne in mind that unless accompanied by appropriate non-structural measures, the structural measures could lead to a false sense of security and encourage floodplain agricultural land owners to use their lands inappropriately which will aggravate their flood risk. For this reason, some form of agricultural land use regulation should be imposed in the floodplain lands to reduce the flood damage to agriculture.

For the completeness and comprehensiveness of the above discussion, it should be noted that structural works require a periodic and systematic inspection, rehabilitation and maintenance programme to ensure that design capabilities are maintained. For example, levees may be subject to weakening due to erosion during a past flood event, by the actions of burrowing animals or the construction of utility lines through the levee. Of particular importance is an inspection programme and responsibilities assigned for rehabilitation and maintenance. Structures, such as dams, should be subject to a dam safety programme, usually at the national level, to ensure that the specialized expertise required is available for the inspection of all structures. Dam safety programmes are carried out in many countries and standards or guidelines are readily available (UN, 2002).

7.3. Land Treatment Measures

Land treatment measures modify floods by increasing infiltration and decreasing the amount and rate of runoff. Well drained soil can absorb huge quantities of rainwater, preventing it from running into rivers (Grant, 2015). These measures may also be viewed as modifying susceptibility to flood damage. They include vegetative cover, runoff interceptors and diversions, small detention and erosion control structures, terraces and crop management practices (which also serve to modify susceptibility to flood damage). Wetland drainage in upper river basins is also such a measure. Wetland pockets in upper river basins are already saturated and thus, they do not possess any great potential for the storage of water in flood risk events. Drainage networks act to lower the water table, hence, increasing soil moisture deficit and increasing the water storage in heavy rainfall events, lowering the downstream flood risk. In order to avoid any environmental degradation by lowering the water table, this kind of intervention should be carried out with the utmost care along with a continuous, monitoring programme. Nevertheless, this type of intervention may not be feasible for a country where adequate capital is not available to spend on investment and with a comparatively short pay-back period.

These land treatment measures are generally effective in small headwater areas and function in combination with other measures to ameliorate flood conditions in larger watersheds. In most respects, land treatment measures produce changes in the broad range of flooding effects, although they become less effective as flood size increases. They can be especially important in reducing erosion and the resulting amount of sediment and pollutants carried downstream (Grant, 2015; UN, 2002).

7.4. Integrated Water Resources Management (IWRM)

This is an alternative to the dominant sector-by-sector, top-down management style of the old, conventional flood management approach. The IWRM concept aims at: a) integrating management of water resources at the basin or watershed scale, integrating both supply-side and demand-side approaches; b) taking an inter-sectoral approach to decision-making; c) improving and integrating policy, regulatory and institutional frameworks; d) promoting equitable access to water resources through participatory and transparent governance. While ensuring water security for multiple users, including agricultural users, of a river basin, this approach also leads to the mitigation of reducing flood risk downstream in the long run (UN, 2002).

7.5. Agronomic Measures

7.5.1. Seed Sowing and Seedling Transplanting

As the lowlands of floodplains are usually cultivated with rice in these three countries, peak monsoon rains always pose flood threats to the newly established rice seedlings. Hence, if broadcasting is the preferred establishment method, sowing should be carried out in the early monsoon period so that when flooding occurs during monsoon peak time, seedlings are well established and can withstand minor floods for a few days.

If the lowlands are highly prone to floods, the best option is seedling transplantation. Under these circumstances, the selection of relatively taller and vigorous seedlings ensures the good establishment of the crop, even if it is subjected to flooding during the vegetative phase. Meanwhile, if floods are the most recurrent threat in lowland rice cultivations during monsoon periods, it is always advisable to look for recommended long-age varieties. Relatively older seedlings, with good root systems which cluster, should be planted so that reduced tillering can be offset while withstanding the threat of flood with the required plant density for a good yield. Under these circumstances, application of an additional dose of fertilizer to the seedling nursery is recommended to improve the vigour of the seedlings. These seedling nurseries should be established in a location which is not vulnerable to flooding.

7.5.2. Nutrient Management

Flood-prone lowlands of the floodplains are generally rich in N, P, K, S, Ca, Mg, Fe, Mn, Zn and B to some extent through regular deposition silts. The only potentially deficient plant nutrient could be Nitrogen but adopting the usual recommendation for the region might lead to over fertilization with a chain of associated impacts and a waste of costly resources. Thus, soil test base or Leaf Colour Chart based (LCC) N fertilizer application for rice cultivation should be practised.

7.5.3. Weed Control

Lowlands in flood plains are always subject to invasion by floating weeds, resulting in heavy yield losses in rice cultivation. Manual weeding is not a cost-effective control measure in rice cultivation in all three countries. Directly seeded rice fields (more than 90% of the total extent in Sri Lanka) do not allow for machine weeding. Thus, in order to arrest the floating weeds in floods, a protective fence (trash collector) can be erected around the rice fields which are subject to frequent flooding.

7.5.4. Drainage Management

In most cases during the monsoon in Asia, the threat of flood to agriculture is aggravated due to mismanagement and negligence of natural drainage ways, leading to flash floods and prolonged inundation in riverine floods. Thus, priority should be given to desilting both irrigation and drainage ways before the start of the season with collective voluntary participation through Farmers' Self Help Groups (SHOs). These institutional arrangements should introduce a penalty system for those who do not undertake the voluntary work to maintain the irrigation and drainage network of the floodplain.

7.5.5. Adoption of the Sorjan System

One of the other alternatives available for lowlands which are subject to frequent minor floods or prolonged inundation, is the 'raising land' concept, widely known as the Sorjan system. It was first developed by Indonesian farmers and is a system which constructs alternate deep sinks and raised beds. Its features can adapt to both dry and wet seasons in most of the Asian countries where flood or inundation is a recurrent threat in floodplains (Figure 12).

In the flood-prone or swampy areas, the sink impounds more water and can tame the flow. Meanwhile, the raised beds and bunds constructed in making the sink, allow farmers to plant highland crops such as vegetables and cash crops. The sink with the impounded water can be used for rice and fish production. The water stored in the sink can later be used for irrigation in the dry season. With Sorjan, the production can support the family's daily food requirements and expenses thus, saving the income from later rice production as capital for other, income generating endeavours (Pasiona, 2016)

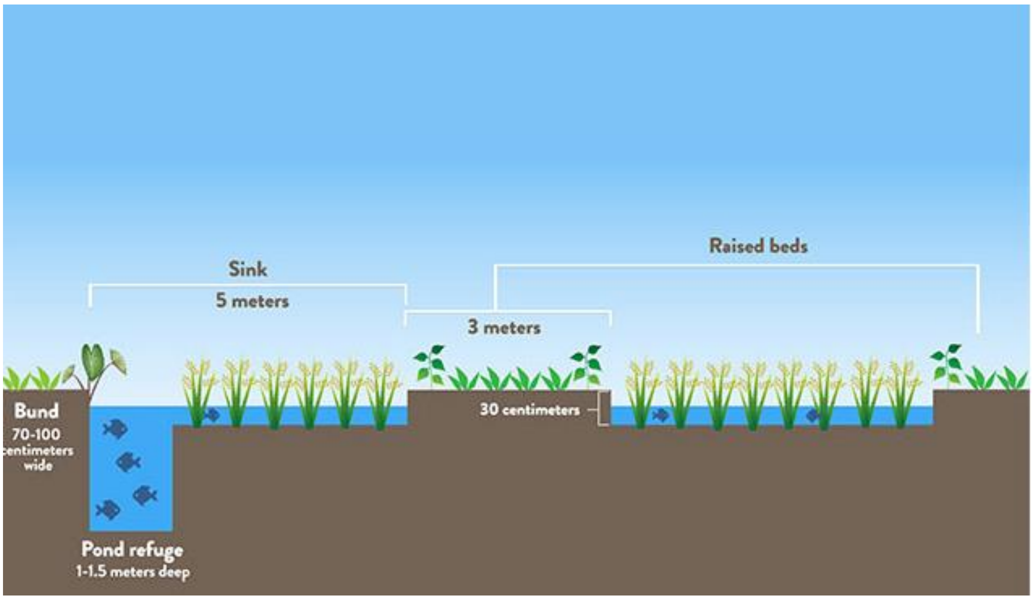

Figure 12 Schematic diagram of Sorjan system in flood prone areas

(Source: Philippines Rice Research Institute, Philippines)

7.5.6. Use of flood tolerant rice varieties

During flooding, the rice plant elongates its leaves and stems to escape submergence. Deepwater rice varieties are able to do this rapidly enough to survive. High-yielding, modern varieties cannot elongate enough. If floods last for a couple of days, the rice varieties are unable to recover. Plant breeders at the International Rice Research Institute, Philippines, have discovered that a single gene, the SUB1 gene, confers resistance to submergence of up to 14 days (IRRI, 2018). Improved varieties incorporated with the SUB1 gene have shown a yield advantage of 1–3 tons following flooding for 10–15 days. Flood-tolerant varieties which have been released and are now being planted include Swarna Sub1 in India, Samba Mahsuri in Bangladesh and IR64-Sub1 in the Philippines. These three varieties can be introduced to flood-prone, rice-based cropping systems in Thailand, Nepal and Sri Lanka to improve their productivity under a changing and variable climate.

7.5.7. Use of deep-water rice varieties

Rice production in Asia is being carried out in different rice eco-systems, namely: irrigated lowland, irrigated upland, rainfed lowland, rainfed upland and deep water or floating ecosystems. Rice is the only cereal which can withstand water submergence and has the ability to survive in water depths of more than 50 cm for at least one month (Catling, 1992). 'Deepwater' areas are those with a depth of flooding of more than 1 m during the peak of the monsoon season and 'intermediate deep water' areas are lands with a flooding depth from 30 to 100 cm (Yamuna and Ashwini, 2016). Rice is the only cereal crop plant adapted to aquatic environments because of its well-developed aerenchyma tissues which facilitate oxygen diffusion through continuous air spaces from shoot to root. It avoids anoxia development in the roots and has the capacity for rapid elongation when the plants become partially covered by floodwaters. Almost all the deep water cultivars are strongly photoperiod sensitive. Photosensitivity fixes flowering time at a favourable point in the flooding period, enabling the plant to escape the adverse effects of low temperature in the reproductive phase which usually ensures crop maturity as soon as floods have receded. However, yields of deep water rice are comparatively low whereas yields of modern rice cultivars average about 6 t/ha; the average yield of deep water rice is only 2 t/ha (Catling, 1992). Nevertheless, it still plays a vital role in stabilizing household food security in heavily and frequently flood-prone floodplains where other forms of livelihoods are beyond possibility in Thailand, Nepal and Sri Lanka.

8. Land Use Planning and Watershed Management

Figure 13, depicted below, clearly reveals that changes in the land use type, from natural forest to an urban landscape in a river basin, leads to increase in surface runoff. This additional runoff increases the delivery rate to the channel and the network of natural waterways downstream, thereby leading to the modification of flood regimes. As a result, the peak discharges, volume and frequency of flood in the floodplain affect the land mostly used for agriculture in the three countries under review.

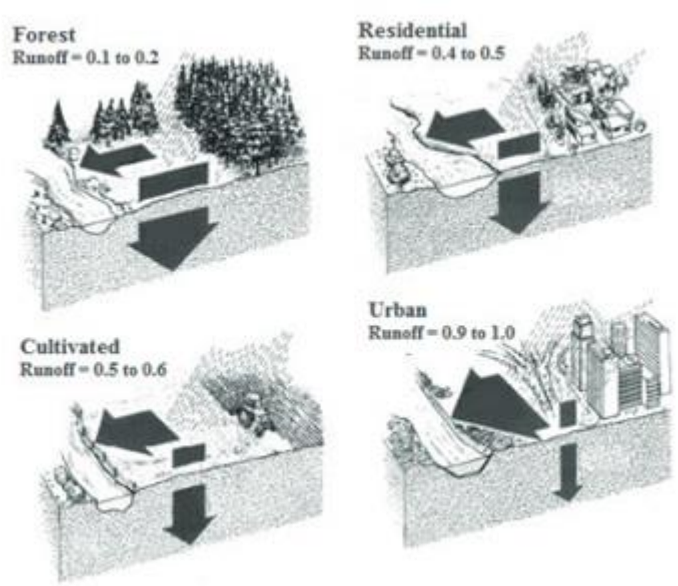

Figure 13 Modification of runoff generation depending on land use
(Adapted from WMO, 2016 – Page15)

Hydrological responses to rainfall depend strongly on local characteristics of the soil, such as water storage capacity and infiltration rates. The type and density of vegetation cover and land use characteristics have an impact on the responsiveness of an area to a given rainfall event.

For example, the water storage effect on vegetation, soil, shallow groundwater, wetlands and drainage has a direct impact on the flood level in downstream areas. Each of these storage media retain certain quantities of water for various periods of time and can influence the timing of tributary flows and hence, their contribution to a flood event. Saturated conditions, or conditions leading to quick saturation during a rainfall event, inhibit the infiltration of rainwater. The consequences are more abrupt and dangerous for high intensity rainfall over small, steep basins. Hence, areas upstream of such flood-prone river basins should be afforested, or have a similar land use, by means of scientific land use planning and watershed management approaches. These include reforestation, agro-forestry, adoption of soil and water conservation measures of relevance, lock and spill drains, stone bunds, Sloping Agriculture Land Technology (SALT), minimizing soil compaction through minimum tillage concepts and reducing the use of heavy machines. Other measures include contour planting, the structure stability of soil through organic manuring, cover cropping, mulching and switching from annual crop farming to perennial crops such as horticulture crops, filling gaps between tree plantations and plantation crops as quickly as possible, uprooting and timber felling of commercial plantations only during long, dry periods and conversion of abandoned croplands to grasslands for intensive livestock management. It should be borne in mind that of all the aforesaid interventions, afforestation and reforestation deserve special consideration in any given watershed as more moisture transpires to the atmosphere at a greater rate than replacement crops or grasses. This reduces the antecedent moisture of soil, enabling the absorption of more infiltrated rain water with consequently less runoff (UN, 2002). However, suitable practices for a particular watershed depend on its terrain, climate, vegetation and social environment. Hence, a methodical and holistic approach should be chosen through a participatory approach of all relevant stakeholders. In addition, legal enforcement of acts and ordnances of relevance to environmental conservation should be in place uniformly across the entire basin. Legal provisions on land, forest, river and streams, coastal eco-systems, waste disposal and wetland conservation, or their overarching policies, should be given high priority.

9. Planning for Potential Sea Level Rise and Storm Surge

Sea level rise due to climate change will result in decreased river slopes in reaches above the point where the river enters the ocean, thereby reducing the capacity of the waterways to pass flood flows. This increases the elevation of floods in coastal cities and villages. While the rate of sea level rise is slow, most protective works, or floodplain delineation exercises, are sufficiently long-term in scope to warrant consideration of the predicted rise, giving ample time for mitigation measures. Meanwhile, coastal farming communities must also be ready to deal with the implications of potential sea level rise on their present, coastal, arable lands for increased flood incidences and salinity intrusions.

10. Use of Climatic Information Systems and Strengthening Flood Early Warning/Monitoring Systems

Climatological forecasting, or seasonal forecasting, has now advanced to the point of being a useful tool in reducing the risk of flooding. Extreme rainfall events are generally correlated to major changes in atmospheric and ocean circulation patterns. Climatological forecasting, or weather forecasting, can be integrated into hydrological models to enhance the existing Flood Early Warning/ Monitoring System for better preparedness of the emergency response by relevant agencies. The existing flood early warning system can be strengthened to provide early warnings in the short-term/medium-term/ extended medium-term. Modern weather forecasting tools, such as Numerical Weather Predictions (NWPs), models and information received from meteorological satellites can be used to forecast the degree and spatial extent of storm activity and chances of extreme rainfall events which may eventually lead to flooding. A framework for flood forecasting, proposed by ESCAP, 2016, gives an overview of integrating modelling and satellite sensor technology for greater lead times in flood forecasting (Figure 14).

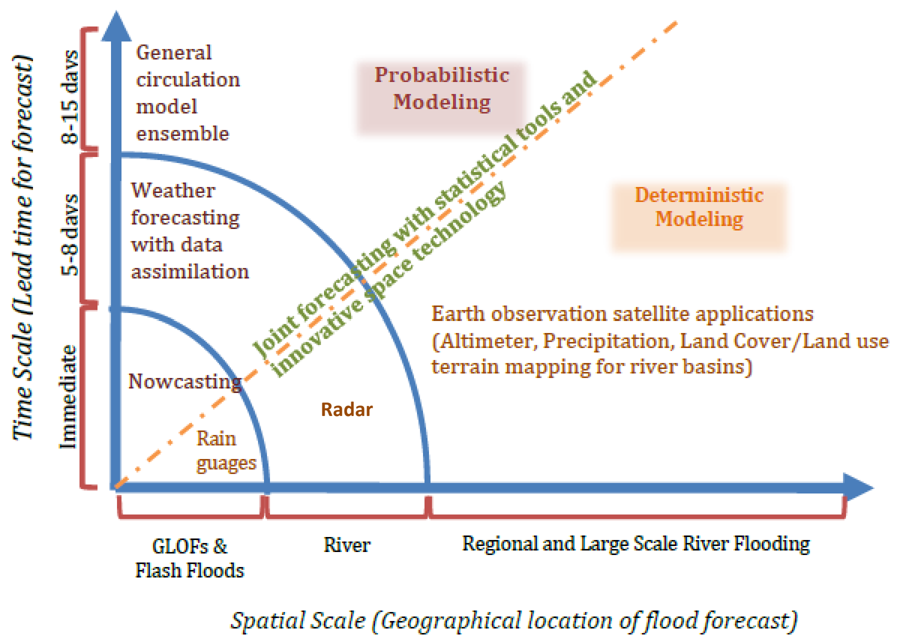

Figure 14 Integration of modelling and space technology for longer lead time for flood early warning (Source: ESCAP 2016)

10.1. Strengthening Flood Early Warning (Short-Term Scale)

Agriculture is an open system and saving cultivated areas from extreme flood events is difficult but a short-term, early warning system, based on watershed level flood modelling, would be helpful for the farming community in certain cases. Short range weather forecasts can be useful in regulating upstream reservoir operations to minimize the degree of flood damage in downstream agricultural lands in certain cases. By informing farmers about rainfall events leading to potential floods a few days in advance (< 5 days) and regulating upstream reservoir and controlled water release, downstream farmers can be made aware, enabling farm water management, nutrient or other agro-chemical application. In some other cases, evacuation of stored materials and moving livestock and stored fodder and foods to safer places are also possible based on short-term flood forecasting. To enable such short-term forecasting, the forecasting tools should be supported with enhanced ground-based information. This can be achieved by establishing a considerably dense network of automatic weather stations and automatic rain gauges, water level gauges at the upstream reservoirs and a community based, end-to-end early warning system for enhanced lead time for preparedness and response by the farming community. Warning of extreme event generated floods will only help the farming community in evacuation of family and belongings, reducing losses to a certain extent.

10.2. Strengthening Flood Early Warning (Medium/Seasonal Scale)

On the other hand, medium (5-10 days) and extended medium (10-15 days) or seasonal level weather forecasts and the possibility of forecasting flood-like situations, will enable critical farm decision-making such as changing the entire cropping pattern or planting early varieties, changing planting dates and transplanting, instead of direct sowing. All of these measures can reduce the effect caused by the severity of flooding, if it occurs. If the probability of the extreme flooding event is greater than normal, then activities such as the stockpiling of sandbags, emergency food and water supplies can be undertaken. In some cases, emergency measures, such as the temporary raising of flood protection works, may also be carried out.

However, we have to take into consideration the fact that a longer lead time is inversely proportional to the forecast quality as well as its reliability. Thus, a longer lead time forecast needs to be complemented by a shorter range forecast. The flood early warning can be strengthened by identifying proper flood warning thresholds as well as rainfall thresholds to be used as an input to a near, real time automatic alert system. Additionally, forecast accuracy and forecast reliability will also act as factors for an enhanced flood early warning system. Thus, while establishing a short-term/medium-term flood forecasting system, the above factors need to be taken into consideration for better accuracy and reliability of the alert generated from the system for the farming community.

Many countries have recognized the importance of Climate Early Warning Systems (CEWS) by enhancing their hydro–meteorological warning services combined with improving their emergency plans and operations to better prepare for climate-related hazards, especially floods. Countries which have successfully built these systems have benefited from a reduction in fatal and non-fatal human casualties and property loss and damages related to flood hazards, along with various additional benefits to their economies. However, the most vulnerable countries to flood hazards, including the three countries under review, are yet to realize the full benefits of CEWS for several reasons: a) poorly functioning national hydro-meteorological services; b) weak or non-existence of appropriate dissemination systems; c) lack of effective emergency planning and preparedness interventions. Most possible causative factors for the said weaknesses in the systems are related to under-funding, low visibility of impacts from interventions, high reliance on reactive responses, environmental and legal barriers and even, civil conflicts in certain areas within the respective countries. Meanwhile, a cursory examination of available climate information related literature in these three countries also reveals that hydro-meteorological observation networks have deteriorated over time. Technology is outdated, modern equipment and forecasting methods are lacking, the quality of demand-driven services is poor, support for research and development from the general budget is insufficient. The poor credibility of past climatic information has resulted in reluctance to accept these factors, along with the adamant attitudes of users adhering to centuries old weather laws. Workforces of trained specialists have also been eroded during recent times, looking for 'Green Pastures' (Anon, 2015a).

The importance of advancements in weather forecasting beyond the short-term, medium-term and seasonal term (to provide flood warnings with longer lead times, enabling people and authorities to protect their property and infrastructure while reducing loss and damage) is very well understood by the relevant authorities in Thailand, Sri Lanka and Nepal. However, there are still some gaps and challenges which hinder achieving anticipated goals in building resilience for flood hazards in these countries in a sustainable manner. Some of these gaps and challenges are of high priority and can be identified as four categories:

1. **Risk Knowledge**
    a. Inadequate availability and accessibility of flood-related information for public use.
    b. Lack of quality controlled historical time-series on flood hazards with related attributes such as magnitude, location, duration and timing.
2. **Monitoring and Warning service**
    a. Lack of continuously updated data for flood modelling and recording of associated losses and damage.
    b. Limitation in trans-boundary information sharing.
    c. Lack of policy and legal frameworks to ascertain authority and accountability of flood related hazards.
3. **Dissemination and communication**
    a. Warning services either: i) do not exist; ii) exist but people have limited access; iii) exist and are accessible but messages are not understood/trusted.
    b. Coverage not well co-ordinated (local to national level and multi-agency co-ordination).
    c. Insufficient communication coverage in remote locations.
    d. Weak feedback and verification mechanisms.
4. **Response capability**
    a. No consistent review, update or practice preparedness plans linked to warning systems.
    b. Lack of specific information for tailored emergency planning geared to risk management in sensitive sectors and locations.
    c. General insufficiency of financial resources for sustainable operation of public meteorological, hydrological and Disaster Relief Management agencies.
    d. Divided political will and support.
    e. Lack of transparency and corruption.

Although efforts are underway to reduce the risks arising from flood hazards in the three countries explored herein, climate change is increasing the frequency and intensity of rainfall events. The resulting floods have become a common feature of the climates in the three respective countries. In this context, low-income countries and small islands and their rural communities (whose main livelihood is agriculture on the floodplain and urban dwellers in floodplains and low-lying areas) are the most endangered communities. Meanwhile, environmental degradation and socio-economic factors like poverty and urban population growth, contribute additionality to the vulnerability of communities regarding flood hazards in these three countries; Flood Early Warning Systems could make a paradigm shift in community resilience for flood hazards.

11. Agriculture Insurance as a Risk Transfer Mechanism for Flood Hazard in Agriculture

As we know, in the three countries of interest, the agriculture sector is greatly exposed to natural hazards, especially floods, leading to significant crop damage and even, the complete loss of crops. Globally, farmers use a range of strategies to manage risk in agriculture by 'informal' modalities such as sale of assets, borrowing from relatives and food crop sharing and so forth (FAO, 2011c) where the risk is not fully absorbed or transferred in a comprehensive manner. In these circumstances, insurance can provide beneficial protection to vulnerable farming communities. Agricultural insurance schemes are currently available, either in a pilot form or a fully mature, national level programme, in only 20 out of the 44 countries in the Asian region, except China. No other countries have fully comprehensive coverage for loss and damage to agriculture due to flood hazards. This is owing to the non-availability of accurate estimations covering the extent of the damaged land caused by each flood event. For example, both Thailand and Nepal cover only the food crop sector through their agricultural insurance programme while Sri Lanka covers crops, livestock and plantation sectors (Mia et al., 2015). Meanwhile, the corporate insurance sector is not willing to extend their product to the agriculture sector owing to inherently high risks associated with agricultural endeavours. Researchers have also shown that the existence of state programmes in crop insurance in developing countries cannot survive without government subsidies (Skees et al., 1999).

Hence, in the light of the increased occurrence of intense flood events in these countries under changing and variable climate regimes, further research and the use of remote sensing technology are urgently needed to assess the losses and damage in the agriculture sector more accurately. This would provide guidelines and recommendations to policy-makers to promote sound and effective insurance programmes, with the emphasis on hydro-meteorological hazards, such as floods. In this aspect, climate information systems can play a vital role by computing weather-based indices to determine the premiums and compensations. This will create a conducive environment for the corporate sector to enter the market through agricultural insurance products, especially for hydro-meteorological hazards.

12. Institutional and Governance

Reduction of losses due to flood events will benefit a number of government agencies and the private sector, as they are the likely users of the floodplains for agriculture activity. Therefore, development of a common agenda, objectives and the definition of a clear role for each of the participants is required. This should include aspects pertaining to land-use planning, farming, input suppliers, buyers, traders, policy makers, disaster management agencies, health authorities, local authorities and essential utility suppliers (such as power and water). The Meteorological Office must be an integral part of providing the solutions. Normally, some form of inter-agency body would need to be established and the leadership role should be assigned to the agency with the greatest involvement or to a capable, central agency. There is probably no ideal model for such a structure, as circumstances are quite different between countries and regions. Under this scenario, an autonomous agency is a viable option but in general, it is probably better to try and build on the strengths of existing agencies so that supportive resources can be delivered quickly in case of extreme events. However, within this diverse model, it is imperative that one agency be given the overall lead and that agency to be held accountable for the overall process.

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