Climate change impact on the built environment in coastal regions

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April 2021

Co-funded by the Erasmus+ Programme of the European Union

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1 Introduction

Climate change is "a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (IPCC, 2018, 544). It is the increase in global temperatures due to the greenhouse effect caused by the increasing emission of greenhouse gasses, mainly through anthropogenic activities. It is a contemporary crisis that is highlighted through many policy debates including the Intergovernmental Panel on Climate Change (IPCC). An IPCC special report confirms that climate change is already affecting people, ecosystems and livelihoods around the world (IPCC, 2018). According to the Global Risk report 2021, the risk associated with climate change is ranked as 2^{nd} by both likelihood and impact(World Economic Forum, 2021).

Coastal areas are argued to be more vulnerable because they are impacted by Sea-Level Rise (SLR) which accelerate coastal erosion and inundate coastal regions. Impacts associated with SLR include salinity of coastal groundwater, increased flooding and damage to infrastructure, and damage to coastal ecosystems (IPCC, 2018). The impacts of storms are predicted to be amplified by SLR leading to substantial challenges, especially for cities, deltas and small island states (IPCC, 2018). The intensity of tropical cyclones across the world's oceans has already said to have increased, although the frequency remains the same or has decreased (Elsner et al., 2008; Holland and Bruyère, 2014, as cited in IPCC, 2018). The intensity changes are associated with increases in maximum wind speed, wave height and the inundation levels, leading to increased exposure to related impacts, such as flooding, reduced water quality and sediment runoff (Brodie et al., 2012; Wong et al., 2014; Anthony, 2016, as cited in IPCC, 2018).These impacts can increases the risks of physical damage to coastal communities and to ecosystems (Long et al., 2016; Primavera et al., 2016; Villamayor et al., 2016; Cheal et al., 2017, as cited in IPCC, 2018). The built environment of coastal regions are also vulnerable to be damage from flooding, erosion and intensifying hazards. Hence one could argue that there is a need for strengthening the coastal built environment with an effective level of resilience to withstand predicted climate change impacts.

There is little research undertaken in the field of SLR and its impacts on the coastal communities in Sri Lanka (Gopalakrishnan, Kumar & Hasan, 2020). There is little study on physical and environmental changes that are already manifest in the coastal areas. This report makes and attempt to review the climate change impact on the built environment in coastal regions of Sri Lanka to make an assessment of adaptation needs to reach a fully resilient and sustainable built environment. The aim and objectives of the report are as follows,

Aim: -

Review existing literature and identify the climate change impacts and associated disaster risks on the coastal built environment in the Sri Lankan context.

Objectives: -

1. To identify the climate change evidence in the coastal belt in Sri Lanka
2. To identify disaster risk and vulnerabilities associated with climate change
3. To review potential impacts on coastal regions
4. To review potential impacts on the built environment

2 Background

Sri Lanka is an island surrounded by the Indian Ocean and located at the tip of the Indian Subcontinent. As a tropical nation, is extremely vulnerable to climate change. The IPCC predicts that the small islands, low-lying coastal areas and deltas will be especially exposed to the risks associated with SLR caused by increasing temperatures including increased saltwater intrusion, flooding and damage to infrastructure (IPCC, 2018). Greenhouse Gases (GHG) from human activities are the most significant driver of observed climate change. Figure 2.1 shows GHG emission in Sri Lanka during 1990-2018. As it can be noted Energy, Transportation and Electricity/Heat sectors are major GHG emitters in Sri Lanka and have an increasing trend over the observed period. Thus, it is obvious that the climate is going to change dramatically in Sri Lanka. According to the Global Climate Risk Index 2019, Sri Lanka was ranked second among the countries most impacted by climate change in 2017(Eckstein et al., 2018). Furthermore, Sri Lanka is considered vulnerable to climate change impacts due to a variety of political, geographic, and social factors, ranking 100th out of 181 countries in the 2017 ND-GAIN Index (The World Bank Group & The Asian Development Bank, 2020). The ND-GAIN Index assigns a ranking to 181 countries based on their vulnerability to climate change and other global threats, as well as their readiness to boost resilience.

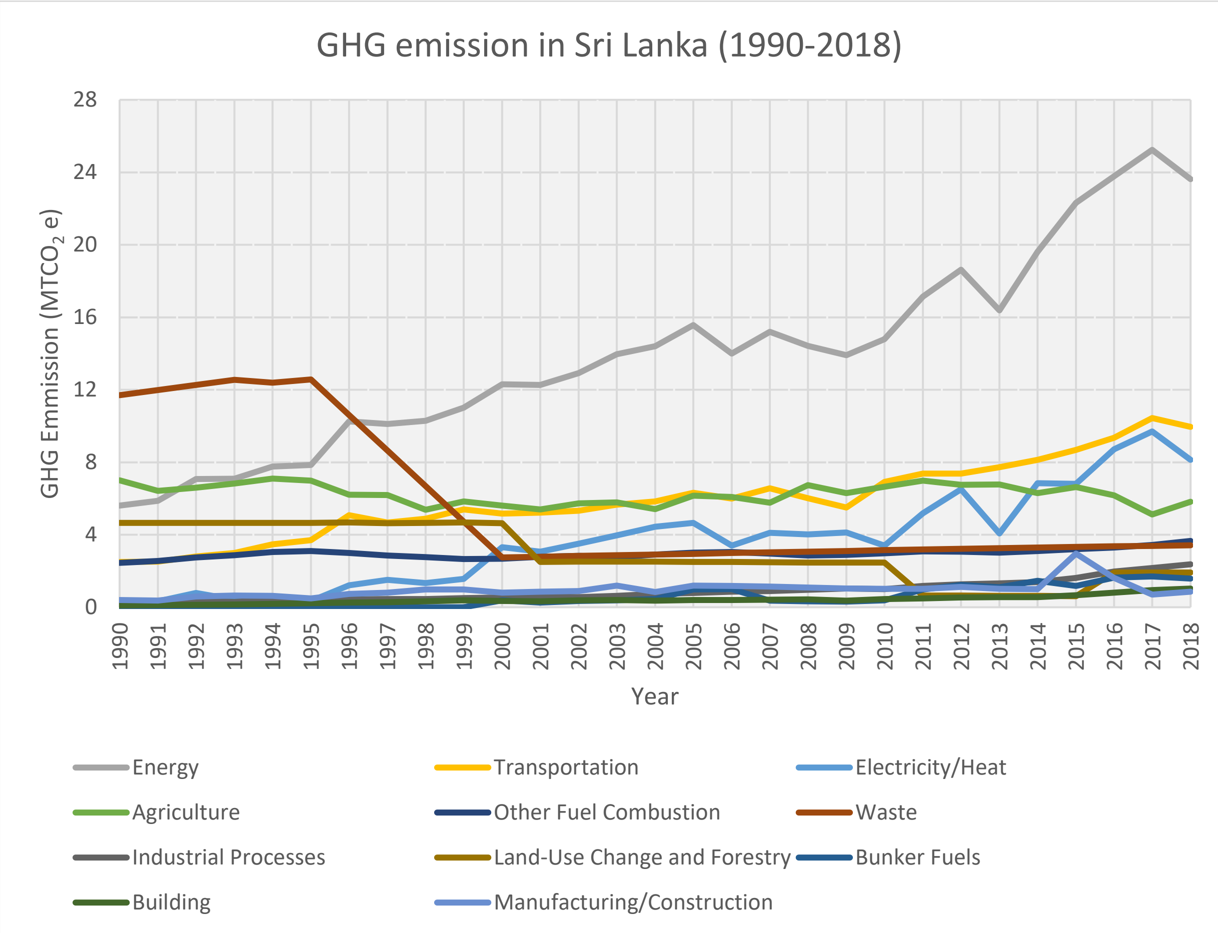

*Figure 2.1 GHG emission in Sri Lanka (1990-2018)(*Data Explorer | Climate Watch*, 2020)*

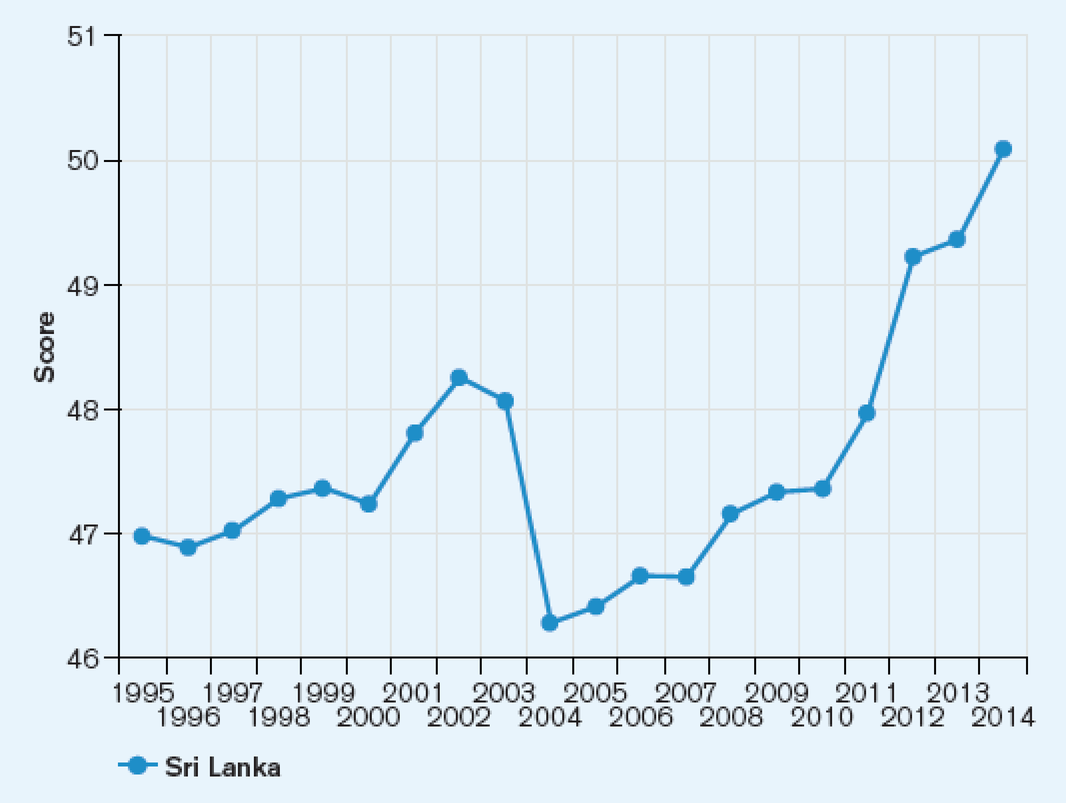

Figure 2.2 The ND-GAIN index of Sri Lanka(The World Bank Group and the Asian Development Bank, 2020)

Figure 2.2 shows the ND-GAIN index of Sri Lanka over the past years. The ND-GAIN Index sums up a country's vulnerability to climate change and other global threats, as well as its willingness to boost resilience. It aims to assist companies and the public sector in better prioritizing investments in order to respond more quickly to the immediate global challenges that lie ahead (University of Notre Dame, 2020). Sri Lanka has been experiencing disasters over the past years. It faces a moderate disaster risk level. Table 2.1 shows the selected indicators from the INFORM 2019 Index. Sri Lanka has moderate exposure to flooding, some slightly lower exposure to tropical cyclones and drought. These figures show that how the country's risk due to climate change-related disaster.

Table 2.1 Selected indicators from the INFORM 2019 index (European Commission, 2019)

Flood (0-10)	Tropical Cyclone (0-10)	Drought (0-10)	Vulnerability (0-10)	Lack of coping capacity(0-10)	Overall inform Risk Level (0-10)	Rank (1-191)
6.1	3.6	3.6	3.4	4.1	3.6	97

Indeed, for a small island like Sri Lanka, the coastal zone is an obvious feature of the landscape. Development activities in the fisheries sector and along the coast are critical to the country's economy. As a result, the coastal belt offers limitless advantages to coastal residents over a broad spectrum (Abeykoon et al., 2021; Climate Change Secretariat, 2016; Gopalakrishnan et al., 2020; Rajarathna & Nianthi, 2019). For management and conservation purposes of the coastal environment, the coastline is defined by the coastal management act 1981 as the,

"the area lying within a limit of 300m landward of the mean high water level and a limit of 2 km seaward of the mean low water level. In the case of rivers, streams, lagoons or any other body of water connected to the sea either permanently or periodically the landward boundary extends to a limit of 2km measured perpendicular to the straight base line drawn between the natural entrance points. Thereof and includes the waters of such rivers, streams and lagoons or any other body of water so connected to the sea. (Parliament of the Democratic Socialist Republic of Sri Lanka, 1981)"

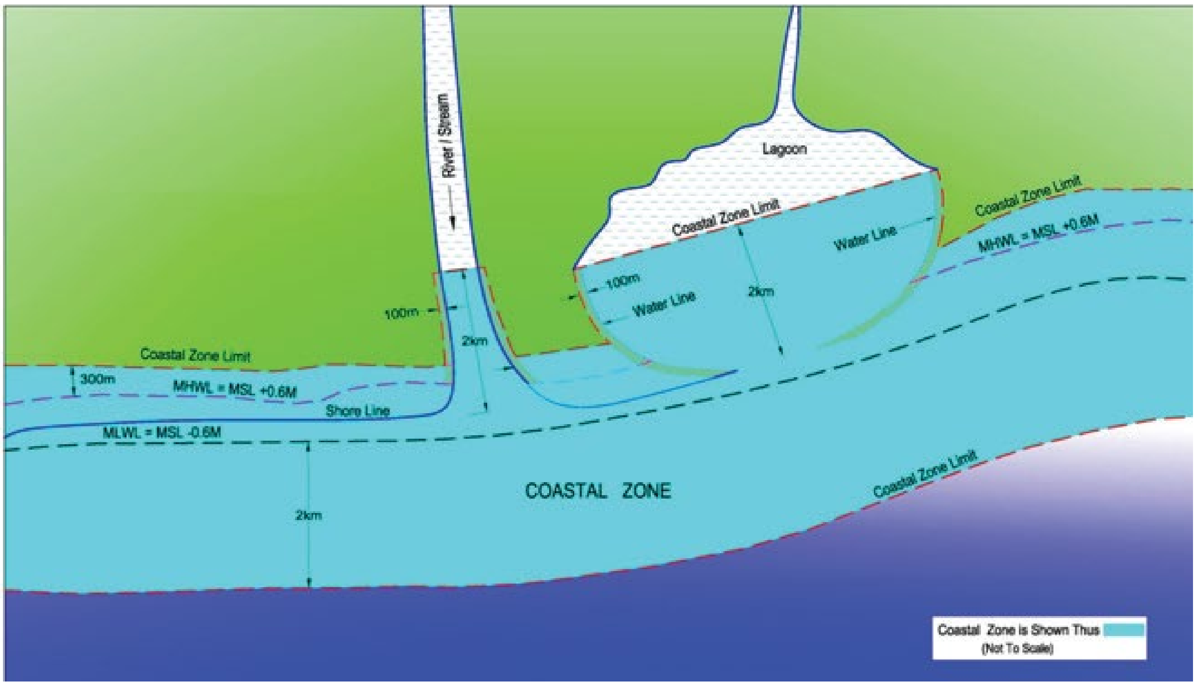

Figure 2.3 Graphical representation of Coastal zone in Sri Lanka(Minister of Mahaweli Development and Environment., 2018)

Figure 2.3 shows the limits of the coastal zone in Sri Lanka which is described in the coastal conservation act, 2018. The coastal region is the lowest of the three peneplains that make up the island, and it consists mostly of flat coastal plains with an average elevation of fewer than 100 feet (30 m) (Coastal Conservation Department, 2004). The continental shelf extends outward from the island as the lowest peneplain, covering the coastal plains, for a width of 5-25 miles (about 8-40 km) in most areas, and at an average depth of 216 feet (about 65 m) below sea level. (Minister of Mahaweli Development and Environment., 2018). Sri Lankan coastline is about 1,620 km that covers the shoreline of bays and inlets but excludes lagoons. It can be many features along the coastal zone(Minister of Mahaweli Development and Environment., 2018; World Bank, 2017). Figure 2.4 shows the land coverage alone in the coastal belt. The Tsunami that struck on 26th December 2004 was probably the worst natural disaster in Sri Lankan history and showed how coastal habitats are vulnerable to disasters. The Tsunami left more than 38,000 people dead and another 7,100 missing and causing 208.2 billion USD damages to livelihood and other sectors(Coastal Conservation Department, 2004; Minister of Mahaweli Development and Environment., 2018; World Bank, 2017). According to Government figures, more than one million people were affected(Coastal Conservation Department, 2004; Koralagama, 2008). Drinking water sources have been severely damaged due to the tsunami in the coastal region. Table 2.2 shows sector vice damages in Sri Lanka caused by the 2004 Indian Ocean Tsunami. The coastline of Sri Lanka is a vital lifeline for the country's social and economic growth. Food, livelihoods, and shelter are all dependent on coastal natural resources for the majority of the coastal population. The coastal zone covers 24 percent of Sri Lanka's total land area and is home to 33 percent of the country's population. Sixty-five percent of the country's urbanized areas are located along the coast, and 45 percent of the coastal population lives in these areas. Overall, the coastal zone contributes 40% of Sri Lanka's GDP, houses half of the country's developed infrastructure, and produces 90% of the country's manufacturing and fish(World Bank, 2017).

Table 2.2 Damage to the livelihood and other sectors (Nayananada, 2007)

Sector	Damage (USD billion)
Livelihood	0.7
Education	27
Housing	48.5
Power	10
Water Supply, Sanitation and Transport	44
Railway	15
Roads	63
Total	208.2

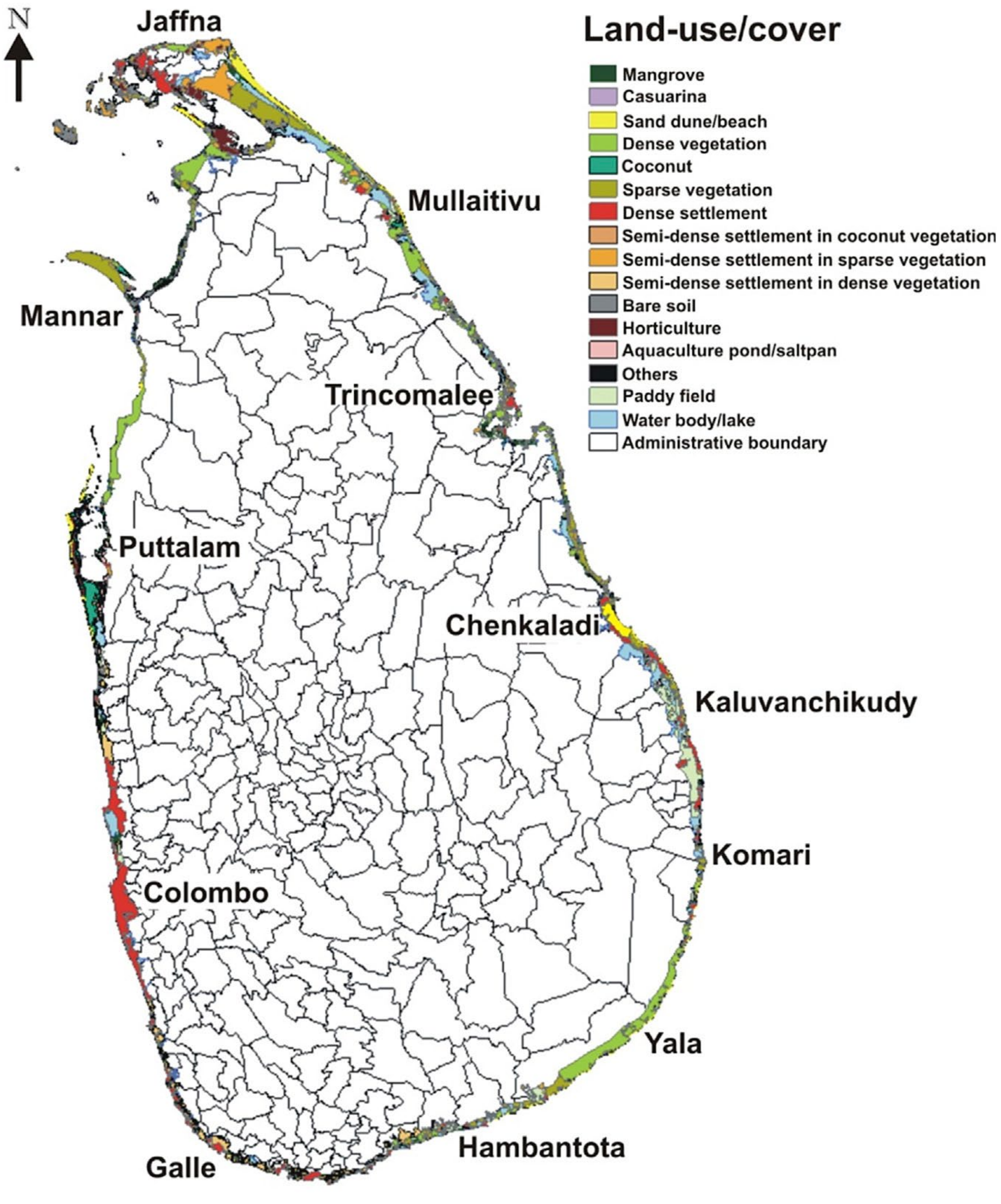

Figure 2.4 Land use/cover in coastal belt(Satyanarayana et al., 2017)

Few scholars, including Desprats et al. (2010) and Mahanama et al. (2014) have looked to delineate the exposed areas, including human resettlements, by using the general administrative division-based household census data and the global mean SLR projections (Gopalakrishnan, Kumar & Hasan, 2020). A study conducted by Bakker (2018) to assess the coastline recession along the Sri Lankan coast showed that a significant number of beaches in Sri Lanka are at risk of disappearing by 2100 (Gopalakrishnan, Kumar & Hasan, 2020). potential SLR impacts include elevated tidal inundation, accelerated coastal erosion, increased saltwater intrusion in groundwater, rising water tables, and changes in coastal ecosystems (Cazenave and Le Cozannet, 2014; Nicholls and Cazenave, 2010, as cited in Gopalakrishnan, Kumar & Hasan, 2020). Saltwater intrusion can have negative impacts on ecosystems, agricultural land, pastures and create scarcity of fresh water. The humans that depend on and make a livelihood from these eco systems and land will suffer from economic and health costs. Especially communities engaged in agriculture and fisheries are expected to be vulnerable. Besides that, there are several studies carried out in Sri Lanka on identifying gaps and barriers for the enabling coastal community disaster resilience(Hippola et al., 2018; G. P. Jayasiri, Randil, et al., 2018; G. P. Jayasiri, Siriwardena, et al., 2018a, 2018b; Jayasooriya et al., 2018; C. Perera et al., 2020; Rathnayake et al., 2020).

Climate change is predicted to increase the frequency and intensity of existing hazards (Hettiarachchi, 2013). Climate change is seen as the main factor behind the recent increase in incidences of climate-related hazards and disasters. Direct hazards such as drought, floods, hurricanes, storms and heatwaves, can cause loss of lives, property, infrastructure and livelihood. Besides infrastructure failure resulting from the initial hazard could exacerbate losses and disrupt services (Little, 2002). Little (2002) has elaborated how the initial disaster could cause simultaneous failures in the water and natural gas systems, causing fires and more destruction. Destruction of telecommunication and transport networks could leave communities to become isolated and make aid and assistance unreachable. Long term impacts such as food scarcity due to the impact of variations of climate on food production, the increasing spread of diseases, water scarcity and desertification of land, can also negatively affect the socio-economic and physical wellbeing of residents and locals. Poverty could be alleviated because of loss of livelihood and resources. Disasters and hazards have a negative impact on the overall economies of countries. Basic services and facilities can be destroyed or disrupted with infrastructure. Human health and socio-economic conditions would deteriorate due to all of these reasons. Therefore, research on possible risks and methods of adaptation to climate change within the context of the built environment is crucial.

3 Climate change evidence in coastal regions

Sri Lanka is a tropical country, which has two main seasons called Maha season and Yala season. The Maha season (September–March) is associated with the northeast monsoon, while the Yala season (May-August) is associated with the southwest monsoon. Sri Lanka is one of the hottest countries on the planet, with an average temperature of around 27°C–28°C. Colombo, Sri Lanka's commercial capital, has average temperatures of 28°C–29°C and, like most of the rest of the world, little monthly temperature variation (The World Bank Group and the Asian Development Bank, 2020). Throughout the year, daily maximum temperatures average about 31°C. Altitude is the most important factor influencing temperature fluctuations in Sri Lanka, with significantly lower temperatures in the country's south-central mountain ranges. The topography of Sri Lanka produces unusual rainfall patterns, with significant spatial variance for a country of its size. The wet zone, intermediate zone, and dry zone are the three areas that makeup Sri Lanka's precipitation regime. The wet zone in the southwest receives an average annual rainfall of over 2,500 millimetres (mm), with the southwest monsoon playing a significant role (Climate Change Secretariat, 2016). This section provides evidence for climate change in Sri Lanka. Dry areas in the south and northwest receive less than 1,750 mm of rainfall. The northeast monsoon brings between 1,750 mm and 2,500 mm to the intermediate zones in the eastern and central regions. Annual rainfall can vary by more than 1,000–2,000 mm over distances of less than 100 km in areas of the southwestern slopes of the central hills, and annual rainfall can vary by more than 1,000–2,000 mm over distances of less than 100 km (Climate Change Secretariat, 2016; Department of meteorology Sri Lanka, n.d.; The World Bank Group and the Asian Development Bank, 2020). During the inter-monsoon seasons, all regions receive consistent rainfall. The climate profile in Sri Lanka has been changing over the recent few decades. The main climate change evidence, includes the Sea Level Rise (SLR), changing weather patterns, temperature variations and precipitation changes. The evidence for the above has been broadly discussed in the latter of this section.

3.1 Sea Level Rise (SLR)

The warming since 1900 has been slower in oceans than over land surfaces. Since 1961, oceans have absorbed 80% of the extra heat energy retained by the earth-atmosphere system thus causing the sea level to rise because of thermal expansion. Besides, the melting of polar ice, glaciers and snow-caps under warmer temperatures contributes to SLR. The global SLR of 3.1 (±0.7) mm per year during 1993-2003 was higher than the corresponding rate of 1.8 (±0.5) mm per year during 1961-2003. Sri Lanka, as a tropical nation, is extremely vulnerable to climate change. Sri Lanka's coastal area is vulnerable to increases in sea level since it is a small island in the Indian Ocean. The tsunami of 2004 demonstrated that low-lying coastal plains would be vulnerable to potential SLRs(Climate Change Secretariat, 2016).

The findings from the Palamakumbure et.al. (Palamakumbure et al., 2020) shows that there will be significant SLR south and southwest coastal area in Sri Lanka. The data collected within the period of 2006-2017 shows that the sea level has increased with the rate of 0.288± 0.118 mm / month in Sri Lanka. Also, DEMs based on LiDAR data suggested that south and southwest coasts are a risk of future sea-level inundation (height = 0.1–0.2m during next 50 years and about 0.7m in height during next

200 years, and distance = about 3.5–15.0m from the present sea level towards the inland)(Palamakumbure et al., 2020).

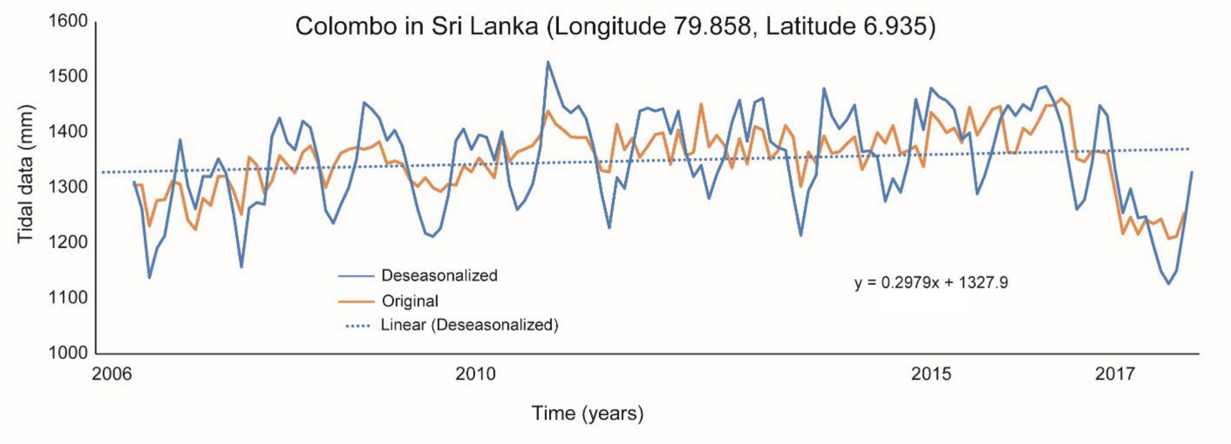

Figure 3.1 Tidal data of Colombo, Sri Lanka over the period of 2006-2016 (Palamakumbure et al., 2020)

From Figure 3.1 it can be noted that the sea level in Colombo has increased throughout 2006-2017 and it is continuing which is an indication for the change in sea level.

3.2 Changing weather patterns

Sri Lanka has two main seasons named Maha and Yala season. The Maha season is mainly associated with the northeast Monsoon (September-March) where the Yala season associated with the southwest monsoon (May-August). Sri Lanka becomes one of the hottest countries, with an average temperature of around 27 ^{0}C - 28 ^{0}C. A unique pattern of rainfall is received due to Sri Lankan topography and with the notable spatial variation for a country of its size(The World Bank Group & The Asian Development Bank, 2020). Sri Lanka can be divided mainly into three climatic zones, Wet zone, intermediate zone and dry zone. Figure 3.2 illustrates the average monthly temperature and rainfall in Sri Lanka during the period of 1901-2016.

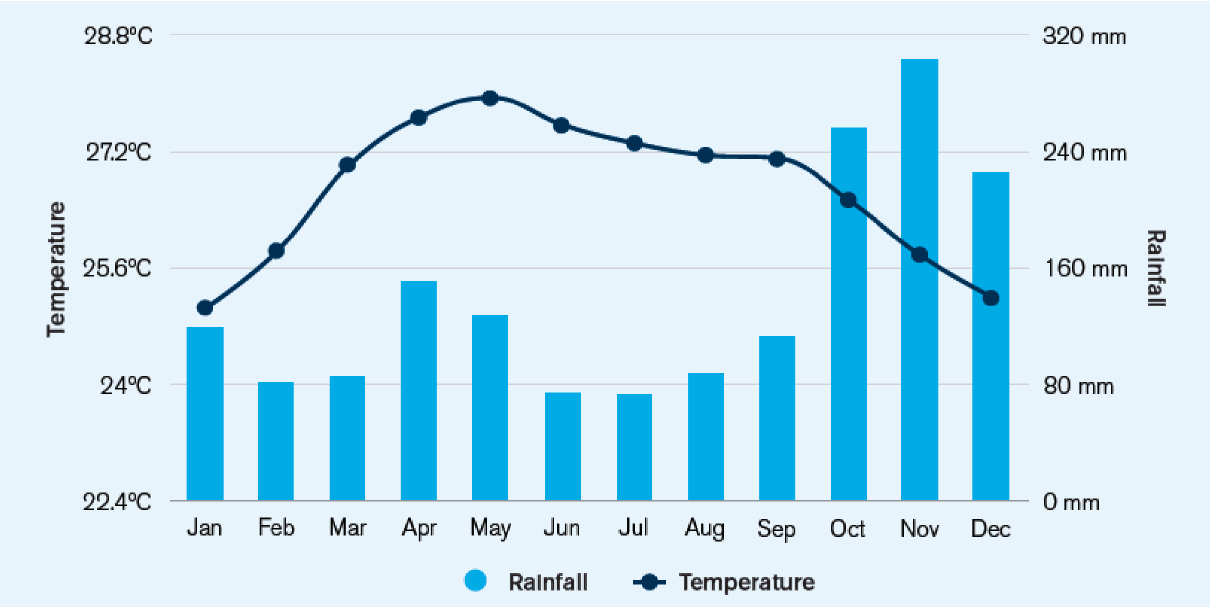

Figure 3.2 Average monthly temperature and rain fall in Sri Lanka (1901-2016)(World Bank, n.d.)

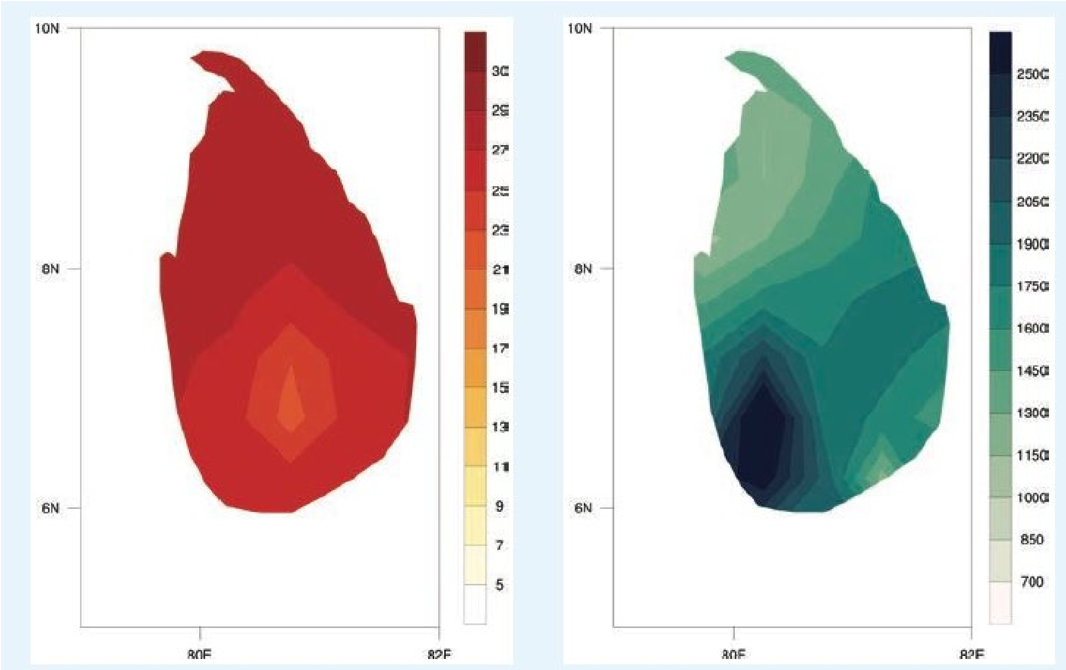

Figure 3.3 Spatial distribution of annual mean temperature and annual mean rainfall (mm) in Sri Lanka (1901-2019) (World Bank, n.d.)

Figure 3.3 demonstrates clearly how the temperature and precipitation are changing with the geographical location of the country.

But, Due to climate change, the Sri Lankan weather profile has changed over the last few decades. Specially, the precipitation level in Sri Lanka shows a complex and spatial variability over the past years, which makes estimation of change over time difficult. Several studies have attempted to identify the key trends in precipitation level, and these are broadly discussed in Section 3.4. From those studies, it is observed that the number of consecutive wet days has reduced and the number of consecutive dry days experienced has increased over the 20^{th} century (Eriyagama & Smakhtin, 2010; The World Bank Group & The Asian Development Bank, 2020). On the other hand, due to climate change, the frequency of extreme events has been increasing over the past years(Esham & Garforth, 2013). Also, it can be experienced higher intensity rainfall events within a short time period. Specially, with the occurrence of the EL Nino events, typically precipitation which is associated with northeast monsoon is increasing(Zubair, 2003). Also, the other thing that is to be noticed related to the weather is temperature. The recent studies have shown that the annually-averaged mean minimum temperatures are increasing across most of Sri Lanka and the difference between maximum and minimum temperatures, diurnal temperature range is decreasing indicating that the minimum temperatures are increasing faster than the maximum temperature(Jayawardena et al., 2018). A significant decrease in the annual occurrence of cold nights and an increase in the annual occurrence of warm nights are also obvious(Jayawardena et al., 2018). The evidence for the changes of the precipitation level and temperature have further discussed in section 3.3 and 3.4.

3.3 Temperature variations

Climate change is usually quantified in terms of easily measurable variables such as air temperature and precipitation. Sustained long-term increase in global mean surface temperature, T_a (i.e. the average of near-surface air temperature over land, and sea surface temperature) popularly termed 'global warming', is the most widely used parameter of climate change. The Third Assessment Report (TAR) of the IPCC (Watson & Albritton, 2001) estimated that the measured T_a increased by 0.6 (± 0.2) ^{0}C during the 140 years up to 2000. The 100-year linear trend of 0.74 (± 0.18) ^{0}C from 1906 to 2005 given in the Fourth Assessment Report (Pachauri & Reisinger, 2008) showed a greater rate of warming than that given in the TAR. This was owing to 11 of the 12 years from 1995 to 2006 being among the 12 warmest years since air temperature measurements began in 1850.

As air temperature is a primary indicator of climate change, several studies have analysed the annual and monthly mean air temperatures to provide evidence for climate change. A study that has been carried out by De costa, in 2008 (De Costa, 2008) provide great evidence for the change of the temperature as an indication of the climate change in Sri Lanka. Findings from this study have shown that decadal mean air temperatures of all selected locations except Kandy, are a highly significant and linear increase over 1869-2007. Apart from that, in all locations, including Kandy, almost continuous decadal warming has occurred during the last 6-10 decades. The rates of continuous warming in all locations except Rathnapura exceeded, by a substantial margin, the global mean during the period from 1906-2005. Also, the analysis of the frequency distributions of annual mean air temperatures showed that the above increases have occurred because of a shift in the entire distribution of temperatures over time rather than due to a few extremely warm years (De Costa, 2008). Table 3.1 shows the rates of increase of decadal mean air temperatures during the total period considered and during the period of almost continuous warming of the selected locations in Sri Lanka.

Table 3.1 Rates of increase of decadal mean air temperatures during the study period and during the period of almost continuous warming, for the selected locations of Sri Lanka (De Costa, 2008)

	Total period (1869-2007)		Period of almost continuous warming		
	Rate of increase of decadal mean T_a	R^2 value of linear regression	Rate of increase of decadal mean T_a	R^2 value of linear regression	Period
Anuradhapura	0.078± 0.019	0.58	0.195 ± 0.021	0.94	1930-2007
Kurunegala	0.053 ± 0.012	0.63	0.104 ± 0.015	0.89	1930-2007
Kandy	No significant relationship	-	0.096 ± 0.019	0.86	1950-2007
Rathnapura	0.049± 0.015	0.47	0.065 ± 0.013	0.75	1910-2007
Badulla	0.086 ± 0.018	0.66	0.191 ± 0.021	0.94	1930-2007
Nuwara Eliya	0.106 ± 0.008	0.93	0.141± 0.014	0.94	1930-2007
Colombo	0.040 ± 0.018	0.30	0.154 ± 0.018	0.93	1930-2007

Also, the major conclusion (i.e. mean air temperature is linear increasing with the years) from the previous studies have been further verified by several studies (Chandrapala, 1996; Naveendrakumar et al., 2018; Rasmusson & Carpenter, 1983; Zubair, 2003). The study that has been carried out by the Naveendrakumar et al., 2018 used the statistical data of the daily maximum temperature (T_{max}) and minimum temperature (T_{min}) of the 55 years (1961-2015) from 20 stations and were analyzed using non-parametric Mann-Kendall test and Sen- Thell regression. The results from the statistical tests showed a remarkable increase in the annual average temperature T_{min} and T_{max} in the 70% and 55% of the stations (Naveendrakumar et al., 2018). Furthermore, 80% of the stations demonstrated increasing in T_{min} during June and July month (Naveendrakumar et al., 2018). Fonseka et.al, 2019 have studied the impacts on land surface temperature from the urban expansion utilizing a case study from Sri Lanka. The findings from the study have shown that there was a noticeable increase in the mean land surface temperature of 5.24 ^{0}C for water surfaces; 5.92 ^{0}C for vegetation; 8.62 ^{0}C for bare land and 8.94 ^{0}C for urban areas (Fonseka et al., 2019). Overall, all the studies have shown that there is an increase in the temperature with time which can provide good evidence for climate change in Sri Lanka.

3.4 Precipitation changes

Precipitation in Sri Lanka is caused by a variety of factors. The annual rainfall is dominated by monsoonal, convectional and depressional rain. The precipitation in Sri Lanka is highly influenced by monsoon winds in the Indian Ocean and depressions and cyclones in the Bay of Bengal (Zubair, 2003). Based on fluctuations of the precipitation in Sri Lanka over few decades, various studies have introduced four rainy seasons (Alahacoon & Edirisinghe, 2021; Wickramagamage, 2010). The rainy seasons are the first inter monsoon (FIM) from March to April and the Second Inter Monsoon (SIM) from October to November, while the North Eastern Monsoon (NEM) occurs from December to February and the Southwestern monsoon (SWM) occurs from May to September(Malmgren et al., 2003). The Indian Ocean monsoon system is highly affected by the El Nino and La Nina hence changing the country's rainfall and temperature. In the events of El Nino, Walker circulation weakens as the eastern Pacific warms abnormally, and sinks in the western Pacific, extending into the mid-Indian Ocean region during summer (Chandimala & Zubair, 2007; Geethalakshmi et al., 2009; Zubair et al., 2008). Thus, in general, the rainfall in Sri Lanka decreases from July to August from January to March, while the north-eastern monsoon receives more rainfall during the period from October to December due to the movement of the Indian Ocean Walker cell to the east(Alahacoon & Edirisinghe, 2021).

Wet zone, intermediate zone, dry zone and semi-arid zone are four major climatic zones in Sri Lanka(Gunda et al., 2016). The country's "wet zone" covers the wester face of the mountain range and the southwest windy slopes(Department of meteorology Sri Lanka, n.d.). Generally, these areas receive an average annual rainfall of 2500mm. The dry zone of Sri Lanka receives between 1200 and 1900mm of rainfall, predominantly from the northeast monsoon while the semi-arid zone (i.e. north-western and south-eastern coasts) receives the lowest rainfall, which is between 800 and 1200mm (Alahacoon & Edirisinghe, 2021).

The findings from the recent studies have shown how the rainfall has been changed temporarily and spatially manner. A recent study showed that the eastern, southeastern, northern, and north-central part of Sri Lanka has been experiencing an increase in rainfall over the past 31 years (1987-2017) and that there has been a decrease in the trend of rainfall in the western, northwestern and central parts of the country.

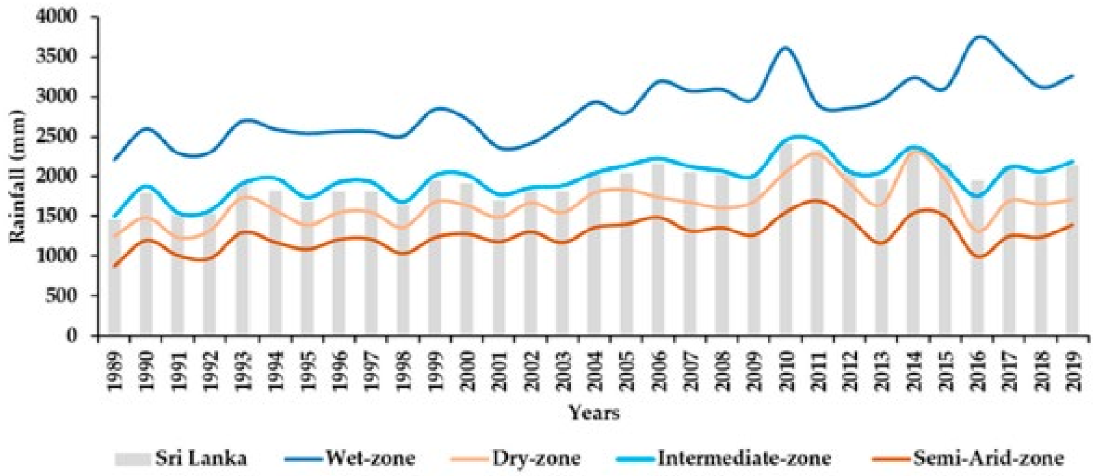

Figure 3.4 Annual average rainfall distribution in wet, dry, intermediate, semi-arid zones and Sri Lanka from 1989 to 2019(Alahacoon & Edirisinghe, 2021)

Figure 3.4 shows the annual average rainfall distribution in major climatic zones of Sri Lanka. Furthermore, the spatial and temporal variability of rainfall can be identified, all of which usually show a variety of variance patterns, but overall, there is a tendency for rainfall to increase. Considering only the average annual rainfall of Sri Lanka, the maximum rainfall was received in 2010, 2011, and 2014. During these three years, the country experienced major floods. The 2010 and 2014 floods occurred in the wet zone, and 2011 in the dry zone. Despite the heavy rains that accompanied the catastrophic floods of 2016 and 2017 in the wet zone, Sri Lanka's overall rainfall declined during those two years. The main reason for this is the decline in rainfall in the dry zone during the period of 2016–2018.

The other notable feature is the decrease in the total rainfall in Sri Lanka from 2015 to 2019. However, in 2016 and 2017, the wet zone received the highest recorded rainfall in its 30-year history. In contrast to the wet zone, the dry zone showed relatively low rainfall from 2015 to 2019, resulting in drought/dry conditions during the "Maha" season from 2016 to 2018. Therefore, the rainfall variation is very close to the terrestrial reality when viewed at the country or region level, as shown in Figure 3.4. Table 1 shows the descriptive statistical parameters called mean, maximum, minimum, standard deviation, median, and coefficient of variance of the annual rainfall at the district level. The highest average annual rainfall between 1989 and 2019 was recorded in the Kalutara district (3340.2 mm), and the lowest was recorded in the Kilinochchi district (1109.7 mm). The observed speciality of the analysis of the maximum and minimum rainfall time series is that the maximum average rainfall value of 4489.4 mm was recorded in the year 2019 in the Kalutara district. Further study shows that the lowest maximum, 1619.8 mm in the Jaffna district, was observed in 1993, which is almost three times lower than the peak recorded in the Kalutara district in 2019.

Table 3.2 summarizes the recent studies that have been carried out to identify the rainfall trends in Sri Lanka. From the findings of the studies, it can be concluded that there is a significant variation in the precipitation level in Sri Lanka during recent years. Also, it should be noted that rainfall patterns are varied spatially and temporally significantly. On the other hand, this could lead to the change of the margins of the climatic zones of Sri Lanka as shown in Figure 3.5. However, the main point of the findings and conclusions of the recent studies is that these would provide evidence for changing the precipitation over time and space.

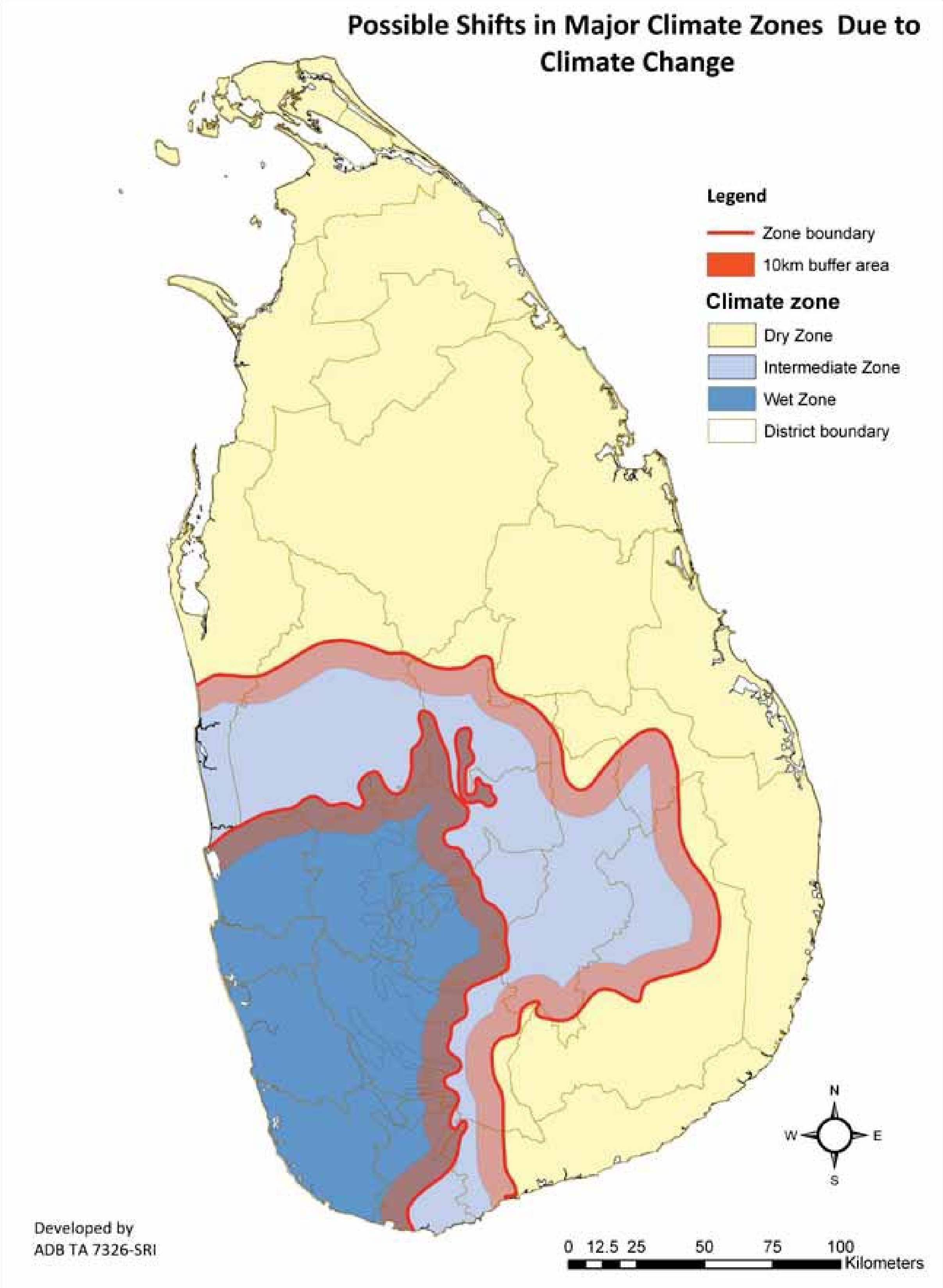

Figure 3.5 Predicted changes to the climate zones in Sri Lanka (Source: Climate change vulnerability data book(Ministry of Environment, Sri Lanka, 2011))

Table 3.2 Recent Studies that have been carried out in identifying rainfall trends in Sri Lanka

Reference	Title	Time	The major evidence for change of precipitation level	Study Area	Key Indicators to measure climate change
(Ratnayake & Herath, 2005)	Changing Rainfall and its Impact on Landslides in Sri Lanka	1960-2001	• Analysis of rainfall time series shows a trend of increased lengths of dry periods along with an increasing trend of rainfall intensity, especially after the late seventies	Covering all climatic zone in Sri Lanka	• Length of the dry period • Rainfall intensity
(Manawadu & Fernando, 2008)	Climate changes in Sri Lanka	1961-2002	• The study finds that the number of rainy days has decreased • However, the total annual rainfall has not decreased in all stations which could indicate that the intensity of rainfall events may have increased together with the increased durations of dry spells. • The 2000mm isohyet-demarcating the wet zone of the country has shrunk •	22 meteorological stations	• Number of rainy days • Annual rainfall • The intensity of rainfall events • Change in isohyet maps
(Wickramagamage, 2016)	Spatial and temporal variation of rainfall trends of Sri Lanka	1981-2010	• The regression coefficients showed spatially and seasonally variable positive and negative trends of annual and seasonal rainfall • The Central Highlands and Northern Sri Lanka have clearly shown the negative trends in the annual and seasonal mean pentad rainfall. • Results have shown rainfall patterns have significantly changed spatially and temporally over the study period.	48 stations	• Trends of annual rainfall • Trends of seasonal rainfall
(Jayawardena et al., 2018)	Recent Trends in Climate Extreme	1980-2015	• The annual total precipitation has indicated a significant increase over the period. • The trends in extreme precipitation events such as maximum one-day precipitation, maximum five-day precipitation and total precipitation on extreme	Includes 19 weather stations in Sri Lanka covering all	• Annual total precipitation level • Rainfall intensity

	Indices over Sri Lanka		rainfall days are increasing at most locations, indicating that the intensity of the rainfall is increasing. • An increase of precipitation extreme trends indicates that the occurrence of extreme rainfall events notably influences total annual precipitation in Sri Lanka.	major climatic zones.	
(Naveendrakumar et al., 2018)	Five decadal Trends in Averages and Extremes of Rainfall and temperature in Sri Lanka	1961-2015	• The results show that 15% of the stations showed a significant decrease in wet days, which may be due to the delayed southwest monsoon to Sri Lanka	20 weather stations	• Number of wet days
(Nisansala et al., 2020)	Recent rainfall trend over Sri Lanka	1987-2017	• The results from the Mann-Kendall (MK) and Innovative Trend Analysis (ITA) of the study has shown that increasing trends in annual rainfall in 65% and 67% weather stations respectively while decreasing trends in the rest. • Furthermore, MK test results for the seasonal rainfall indicated an increasing trend at 76%, 51%, 32% and 86% of stations during First Inter Monsoon (FIM), Second Inter Monsoon (SIM), South West Monsoon (SWM) and North East Monsoon (NEM) seasons respectively. Also, results from the ITA showed the same trends in seasonal trends in Sri Lanka • In general, the eastern, south eastern, north and north-central regions of the country showed increasing rainfall trend over the study period while the western part of the north western and central part of the country indicated decreasing rainfall trend.		• Trends in annual and seasonal rainfall data

(Jayasinghe et al., 2021)	Investigation of the Variation of Annual and Seasonal Rainfall patterns in Rathnapura District, Sri Lanka	1989-2018- Long term 2005-2019- Short term	Positive rainfall trend in Rathnapura area	14 meteorological stations covering the Rathnapura district	• Annual rainfall data
(Alahacoon & Edirisinghe, 2021)	Spatial variability of rainfall trends in Sri Lanka from 1989-2019 as an Indication of climate change	1989-2019	• Annual rainfall has been increased significantly over the study period in all climatic zones. • The wet zone has recorded a maximum increase whereas the semi-arid zone recorded the minimum increase. • Severe drought will be experienced in eastern and south eastern districts due to the declining rainfall trend in NEM whereas southern and western provinces experienced severe flood	33 stations	• Annual rainfall data

3.5 Projections on climate change

Projections on future climate provide good evidence for climate change in Sri Lanka. General circulation models (GCM), regional climatic models (RCM), and statistically downscaled GCM models have all been used to forecast climate change in Sri Lanka (Eriyagama & Smakhtin, 2010). The projections for Asia in the IPCC's fourth and fifth assessments reports (AR4 and AR5) are key global projections that apply to Sri Lanka. The consensus among these forecasts is that South Asia will become steadily warmer. South Asia is expected to warm faster than the rest of the world (Cruz et al., 2007; Hijoka et al., 2014). Some of the high-confidence (very likely) forecasts for South Asia include: a rise in mean annual temperature of more than 3 ^{0}C; an increase in precipitation by the mid-twentieth century; increased precipitation extremes due to monsoons; and warmer seas in tropical Asia(Hijoka et al., 2014).

Table 3.3 Precipitation and Temperature projections under different scenarios specified by IPCC Assessment report,2001(Ahmed & Suphachalasai, 2014)

Parameter	2030			2050			2080		
	A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Precipitation (%)	7.4	11.0	3.6	15.8	25.0	16.5	39.6	35.5	31.3
Temperature (^{0}C)	1.0	1.1	1.0	1.8	1.5	1.3	3.6	3.3	2.3

Projections are less certain about shifts in rainfall patterns, just as they are less certain about observed changes. Ahmed and Supachalasai (2014) expect increases in precipitation of 39.6%, 35.5%, and 31.3% by 2080 under the A2, A1B, and B1 scenarios, respectively. on the other hand, Locally downscaled models forecast changes in precipitation in both directions—increasing and decreasing mean annual rainfall (Eriyagama & Smakhtin, 2010).

Furthermore, Coupled Model Inter-comparison Project Phase 5 (CMIP5) models project climate change under Four Representative Concentration Pathways (RCPs) (i.e RCP2.6, RCP4.5, RCP6.0, and RCP8.5) RCP is a GHGs concentration trajectory which is adopted by IPCC fifth assessment report and it is meant to serve as input for climate and atmospheric chemistry modelling. Figure 3.6 and Figure 3.7 show projected average temperature and average precipitation in Sri Lanka for four RCP scenarios. It should be noted that despite the scenario average temperature is going to increase while precipitation is highly varying as described previously(Climate Change Secretariat, 2016; The World Bank Group and the Asian Development Bank, 2020).

However, overall it can be concluded major key points on climate change from these models as follows,

- Air temperature is increasing with the time
- Although precipitation shows high variability, it is evident that the intensity of sub-daily extreme rainfall events appears to be increasing.

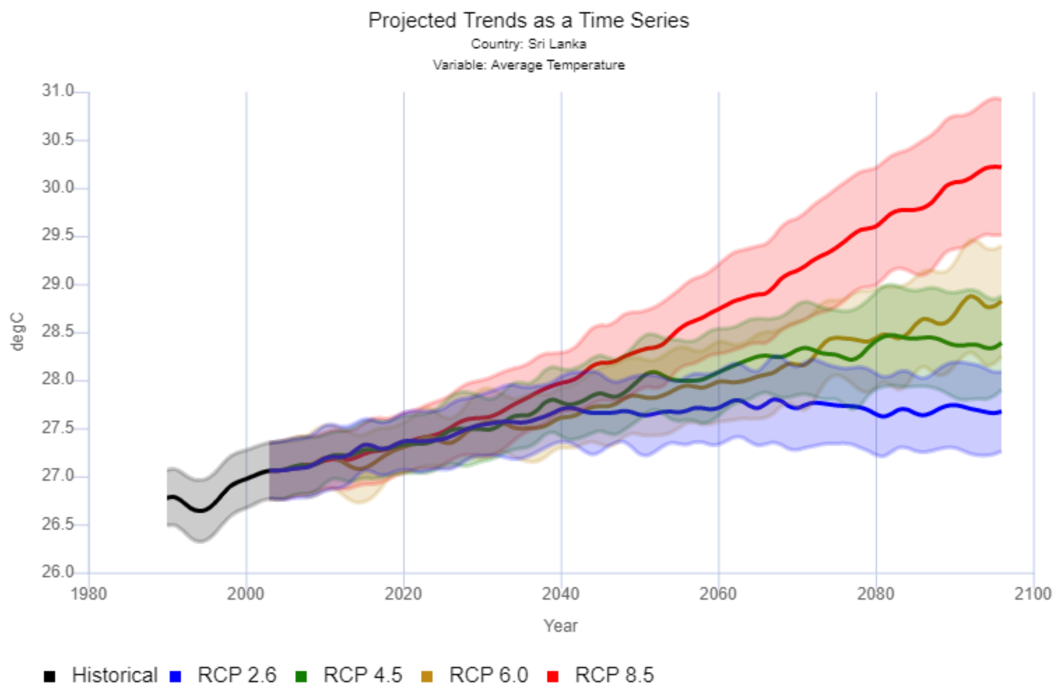

Figure 3.6 Projected change in Average temperature in Sri Lanka under four RCP scenarios(Crops and Land Management - Agriculture - CRMePortal*, n.d.)*

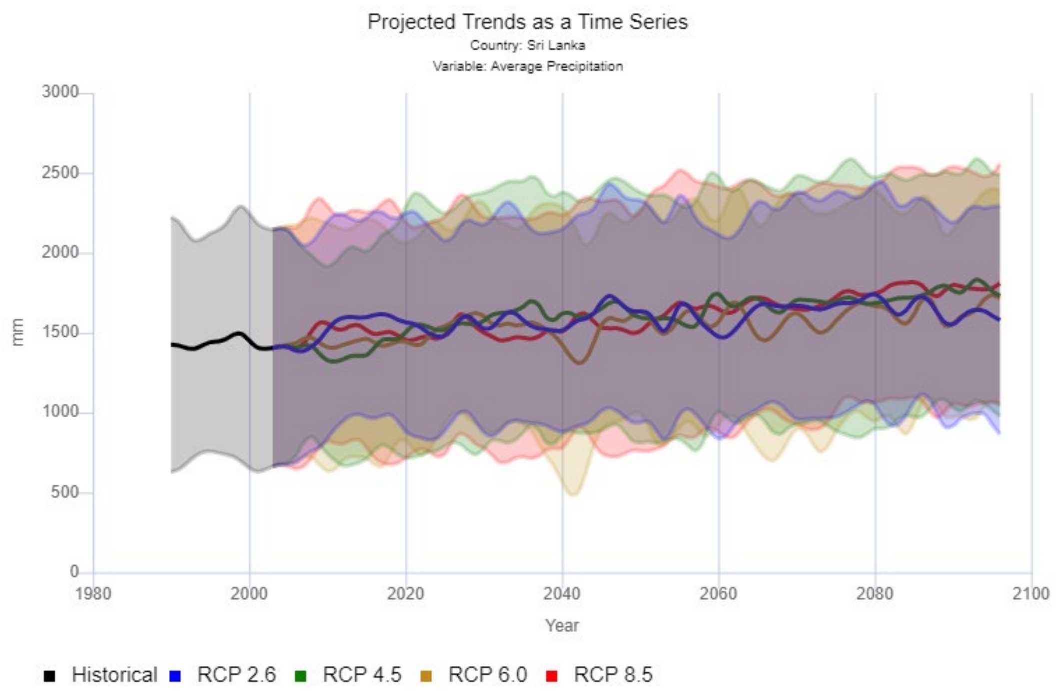

Figure 3.7 Projected change in Average precipitation in Sri Lanka under four RCP scenarios(Crops and Land Management - Agriculture - CRMePortal*, n.d.)*

4 Disaster Risk and climate change

Disasters resulting from both natural and human causes have become an inherent part of our lives. Climate change is predicted to increase the frequency and magnitude of existing hazards, and exacerbate coastal erosion (Hettiarachchi, 2013). Hettiarachchi (2013) recognized that irrespective of the source of the hazard, the underlying principles of protection against flooding and erosion protection are similar, but that it is important that the protective measure taken should match the magnitude of the impact. Similarly, scholars have noted the necessity to integrate the concepts of Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA), as both are used to reduce vulnerability and thereby contribute to the creation of a resilient environment (Dias, Dilanthi, & Haigh, 2018; Dias et al., 2019). IPCC too has suggested that sustainable development has the potential to significantly reduce systemic vulnerabilities, enhance adaptive capacities, and promote livelihood security for poor and disadvantaged populations (IPCC, 2018).

4.1 Hazard

IPCC defines hazard as the potential occurrence of a natural or human-induced physical event or trend that could cause deaths, injury, adverse health impacts to humans and cause damage and loss of property, infrastructure, livelihoods, services, ecosystems, and environmental resources (IPCC, 2018). Some scholars have highlighted that hazards should be identified as basic elements of environments and as constructed features of human systems rather than as extreme and unpredictable events, as they were traditionally perceived (Oliver-Smith, 1996). Oliver-Smith has noted that hazards and disasters viewed as integral parts of environmental and human systems become a test of societal adaptation and sustainability (Oliver-Smith, 1996).

IPCC defines risk as to the potential for adverse consequences to human and natural systems from climate-related hazards, resulting from the interactions between the three aspects of hazard, vulnerability and exposure (IPCC, 2018). Hazard risk is argued to be a contentious issue (Oliver-Smith, 1996). Oliver-Smith (1996) argues that risk is problematic because it is subject to differential construction by the various parties involved. Scientific discourse on climate change has highlighted that small islands are at risk (IPCC, 2018) and it remains for local actors to validate that risk with local experiences, engagements and lived realities. Sri Lanka has experienced climate-related hazards including droughts, heatwaves and cyclones. Cyclones can result in flood and landslide situations. According to Wijetunge and Marasinghe (2015), Sri Lanka is vulnerable to cyclones generated mostly in the Southern part of the Bay of Bengal (Chandrasekara et al., 2018). In May 2017, the arrival of the precursor system to Cyclone Mora with the depression at the Bay of Bengal worsened flooding due to the southwest monsoon in 15 out of 25 administrative district in Sri Lanka (Chandrasekara et al., 2018). Ensuing floods and landslides claimed nearly 212 lives and left 79 people missing (International Organization for Migration, Sri Lanka, 2017; Wikipedia, 2017, as cited in Chandrasekara et al., 2018). The Disaster Management Center, Government of Sri Lanka, documented that approximately 0.58 million people were affected, and 30,000 houses were destroyed (International Organization for Migration, Sri Lanka, 2017, as cited in Chandrasekara et al., 2018). It also resulted in a Dengue outbreak in the flooded areas (Chandrasekara et al., 2018). Hence the hazard risks of climate-related disasters are experienced and evident, in Sri Lanka. Flood events that occurred in the past years prove that the country is getting affected by climate change (Jayasiri et al., 2019).

Sri Lanka has developed a Hazard profile for the country and has a functioning Early Warning Dissemination System (Jayasiri et al., 2018). The country has also oriented its national policies and action plans with the post-2015 global standards such as the Sendai Framework for Disaster Risk Reduction (SFDRR), Sustainable Development Goals (SDGs) (Jayasiri et al., 2018), United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. Sri Lanka has also partnered with regional initiatives for early warnings, such as the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) and the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)(Jayasiri et al., 2018). However, scholars have pointed at certain gaps in Early Warning, mitigation and mechanisms to build the resilience of coastal communities (Jayasiri et al., 2018; Perera et al., 2020; Hettiarachchi et al., 2018). Studies and surveys have revealed that the communication networks and mechanisms of Early Warning are poor, gaining less trust of the people (Perera et al., 2020) There has only been one more multiphase assessment conducted on the island, which is supposed outdated now (Hettiarachchi et al., 2018). Factors related to climate change such as climate-induced floods caused by the release of dams resulting in sudden additions of water to coastal areas, ocean acidification, and temperature need to be added to Multi-Hazard Early Warning systems (Hettiarachchi et al., 2018). Some scholars suggest Community Based Early Warning Systems (CBEWS) overcome gaps (Perera et al., 2020).

4.2 Vulnerability

IPCC defines vulnerability as the propensity or predisposition to be adversely affected (IPCC, 2018). "Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2018, 560). Sri Lanka is already considered highly vulnerable to many natural hazards (Chandrasekara et al., 2018). According to the Berkeley Earth dataset, Sri Lanka experienced warming of around 0.8°C, over the 20th century (World Bank Group & the Asian Development Bank, 2020). Sri Lanka also has been identified as having a moderate level of vulnerability to slow-onset SLR impacts, and high vulnerability to the combined impacts of storm surge and SLR (World Bank Group & the Asian Development Bank, 2020).

Developing countries are expected to face the most adverse effects of climate change because there are high amounts of populations living in conditions of low socio-economic development (Demel et al., 2019). The Jaffna Peninsula has been identified as the most vulnerable region in Sri Lanka to changing climate in terms of living standards by the World Bank report (Mani et al., 2018, as cited in Gopalakrishnan, Kumar & Hasan, 2020). Sea-water intrusion has already become a pressing issue in coastal areas of the Jaffna Peninsula (Gopalakrishnan, Kumar & Hasan, 2020) because the community depends on groundwater for their livelihoods as there are no perennial rivers or permanent water supply systems in the Jaffna Peninsula. The coastal areas of Sri Lanka which are vulnerable to coastal intrusion are densely populated, with much of the urban cities including the capital city of Colombo located there (Nianthi & Shaw, 2015; Baba, 2010). The coastal areas also contain many industries and industrial hubs that could be destroyed by extreme climatic events and coastal intrusion (Nianthi & Shaw, 2015), thus increasing vulnerability. Studies have identified coastal cities and communities to be more vulnerable to negative impacts of climate change (Hettiarachchi et al., 2018; Jayasiri et al., 2018).

Furthermore, vulnerabilities of the coastal community to hazards and extreme events that are associated with climate change are exacerbated by many various factors in Sri Lanka as follows,

(Hippola et al., 2018; G. P. Jayasiri, Siriwardena, et al., 2018b, 2018a; Jayasooriya et al., 2018; C. Perera et al., 2020; Rathnayake et al., 2020)

- Lack of trust in authorities who disseminate Early Warning
- Limited knowledge of evacuation routes and shelters in residential areas
- Lack of efficient and sustainable resilience mechanisms focused on the coastal communities
- Lack of efficiencies and effectiveness of national policies and frameworks related to coastal hazards and lack of alignment with the post-2015 global standards.
- Lack of capacity and preparedness of the coastal communities
- Lack of exposures and awareness to the modern technology
- The administration process also disregarding indigenous knowledge regarding the EW mechanism
- Lack of interest of the coastal communities in evacuation planning and safety drill

Furthermore, a study by Jayasiri et, al. 2018, pointed out the role of social media in disseminating the Early Warnings (EWs) and applicability of social media into the Multi Hazards Early Warnings (MHEW) mechanism(G. P. Jayasiri, Randil, et al., 2018). Also, another study by Jayasiri et, al. shows Sri Lanka is lacking in efficient and sustainable resilience mechanism which focused on the coastal community (G. P. Jayasiri, Siriwardena, et al., 2018a). Furthermore, it is stressed out that training and public awareness campaigns, efficient funds, properly maintained hierarchy, and concern to the coastal ecosystems will enable the building coastal resilience and thereby reduce the vulnerability. Also, it is pointed out the importance of the people-centred MHEW mechanisms, multi-stakeholder and multi-agency cooperation and coordination for the exchanging the data and updating the multi-hazard map in order to enhance the community resilience(G. P. Jayasiri, Siriwardena, et al., 2018a; Rathnayake et al., 2020).

4.3 Exposure

Exposure as defined by the IPCC is the presence of people, eco-systems, and man-made elements in places that could be adversely affected (IPCC, 2018). As mentioned earlier, the coastal area of Sri Lanka which is prone to SLR and coastal hazards is highly populated and urbanised (Nilanthi & Shaw, 2015; Baba, 2010). The distribution frequency of hazards, number of people affected, and loss of life throughout the islands show that coastal communities are the most affected (Disaster Information Management System, 2012, as cited in Hettiarachchi et al., 2018).
According to 2019, INFORM Risk Index Sri Lanka faces moderate disaster risk levels, including moderate exposure to flooding, some exposure to tropical cyclones and lesser drought exposure (World Bank Group & the Asian Development Bank, 2020). Landslide hazard, though present in many parts of Sri Lanka, is not explicitly captured (World Bank Group & the Asian Development Bank, 2020). It is also estimated that approximately 230,000–400,000 people could reside in exposed flood plains by the 2030s and that this number will continue to grow (World Bank Group & the Asian Development Bank, 2020). As of 2010, the population annually affected by river flooding was estimated at 59,000 people and the expected annual impact on GDP was estimated at $267 million World Bank Group & the Asian Development Bank, 2020). This figure is expected to increase due to climate change and development (World Bank Group & the Asian Development Bank, 2020). An IWMI study has suggested that around twenty-three percent of the country’s population were exposed to hazardous heatwaves during the period 2001–2013 (World Bank Group & the Asian Development Bank, 2020).

5 Climate change Impact in coastal regions

This section discusses the climate change impacts. The impacts are categorized into the physical, social, economic, environmental and governance. Each impact is broadly discussed within the latter part of the section.

5.1 Physical impacts

Climate change's potential effects, especially global warming's impact on sea temperatures and SLR, as well as increased frequency and severity of tropical storms and other extreme events, would have negative consequences for coastal processes, habitats, and human well-being. This section discusses the physical impacts associated with climate change. Due to the lack of measured impacts for the Sri Lankan context here, the predicted impacts were considered. While global mean SLR is significant, relative SLR is the most important factor in deciding coastal impacts. According to the IPCC's central estimate, global sea levels may rise 0.2 cm and 0.5 cm by 2010 and 2050, respectively. Shoreline retreat, inundation of low-lying and vulnerable areas, saltwater intrusion into inland water bodies, geomorphological changes in sediment transport, and disruption to coastal habitats such as coral reefs are all expected as a result of the potential rise in temperature and relative sea level. The main physical impacts associated with climate change include inundation, storm surge flooding, Erosion and saltwater intrusion.

The major problem associated with climate change is SLR and due to that most of the small island and deltas within the coastal belt will be inundated. Based on the future projection on SLR, the inundated areas due to predicted SLR at the end of 25,50, 75 and 100 years including the areas covered presently as water bodies are given in Table 5.1.

Table 5.1 Projected area of inundation in each district including/Excluding water bodies(Minister of Mahaweli Development and Environment., 2018)

District	The total inundated area including water bodies (ha)				Total inundated area excluding water bodies (ha)			
	25 years	50 years	75 years	100 years	25 years	50 years	75 years	100 years
Colombo	959	1133	1327	1534	201	375	569	776
Gampaha	3638	4154	4631	5073	459	976	1452	1894
Puttalam	11334	12583	13716	14809	1113	2362	3494	4587
Mannar	8024	8262	8518	8758	248	486	741	981
Jaffna	10321	11164	12014	12891	864	1706	2557	3434
Mulaitivu	912	1004	1092	1180	88	180	268	355
Trincomalee	2315	2529	2791	3033	252	467	729	971
Batticaloa	2325	2443	2568	2702	130	247	372	507
Ampara	1880	2175	2479	2762	293	588	892	1175
Hambanthota	4265	5553	6516	7322	885	2173	3136	3942
Matara	1277	1624	1994	2401	38	741	1101	1508
Galle	5622	6462	7249	8014	776	1617	2403	3169
Kalutara	1956	2370	2790	3203	417	830	1251	1664

According to the data given in Table 5.1, north and northeastern coastal belt areas have a higher risk of inundating compare to other coastal regions in Sri Lanka. Figure 5.1 shows the sea level exposure map which was developed by the Ministry of Mahaweli Development and Environment in 2011. According to map, small islands in Jaffna has greater exposure level while other coastal regions having moderate exposure level since it has generally flat topography with a median elevation of 2.72m (Gopalakrishnan et al., 2020)

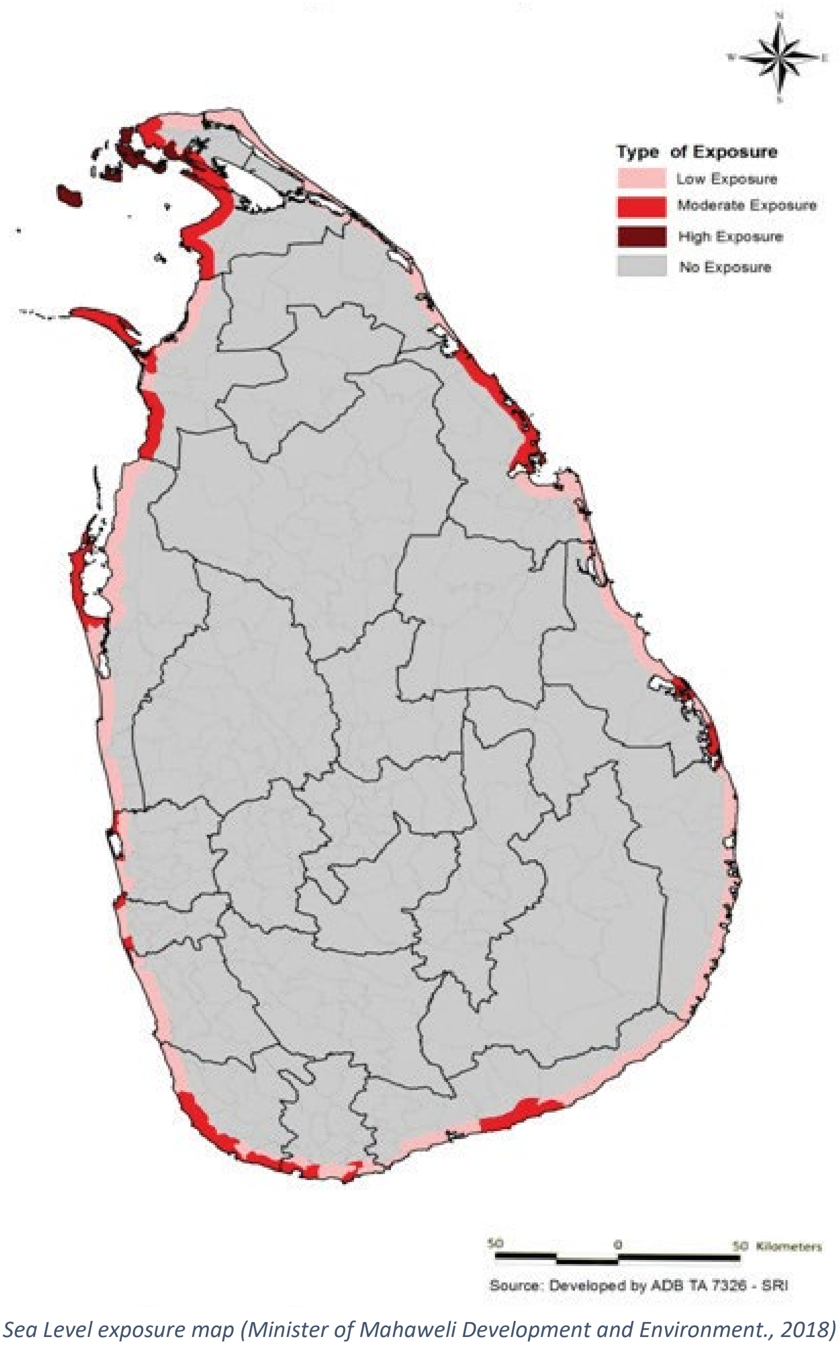

Figure 5.1 Sea Level exposure map (Minister of Mahaweli Development and Environment., 2018)

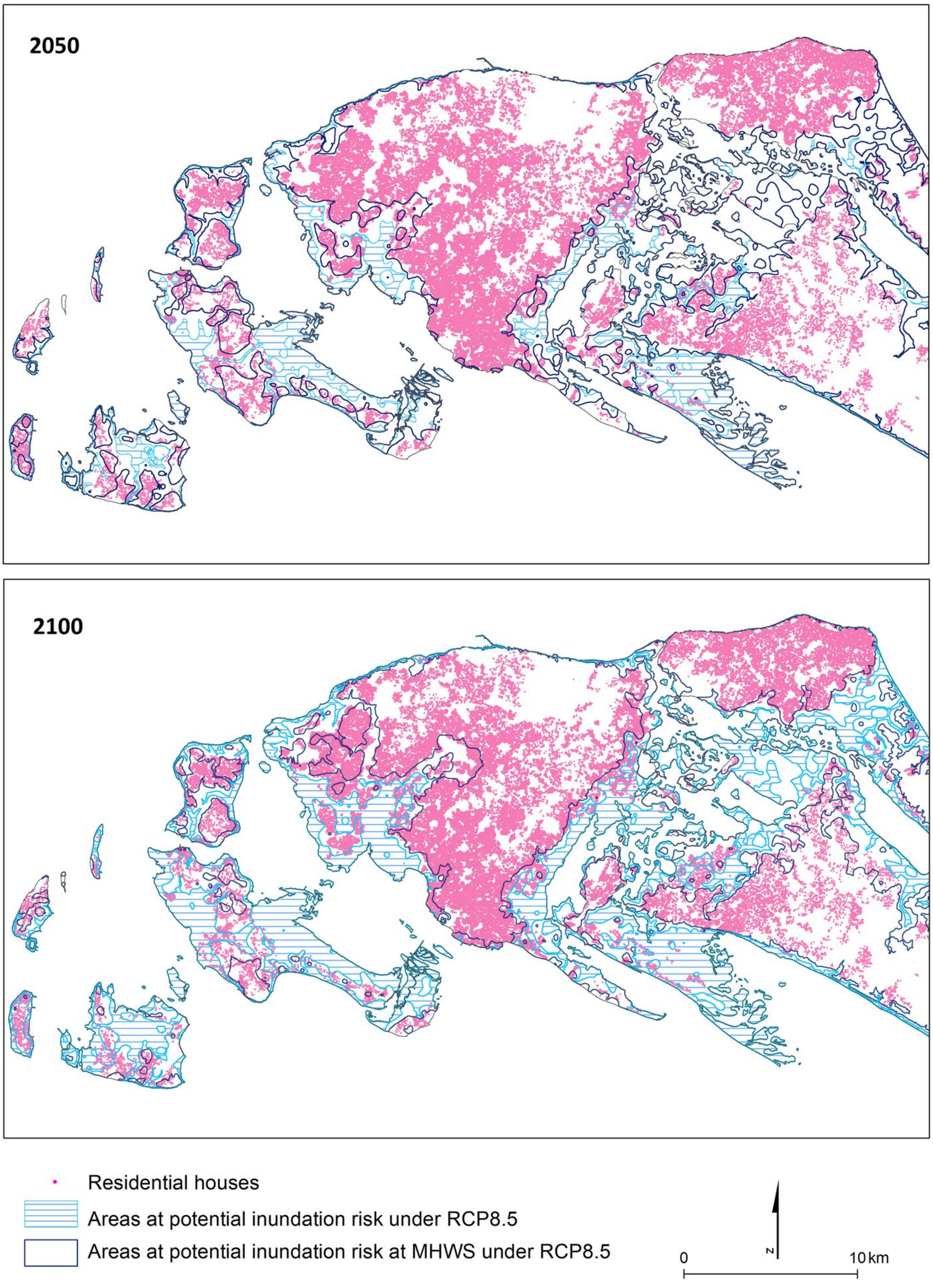

Figure 5.2 Potential areas of inundated land under representative concentration pathway (RCP) 8.5 by 2050 and 2100 considering the mean high water of spring tides(Gopalakrishnan et al., 2020)

Figure 5.2 shows the potential areas inundate land of the Jaffna Peninsula. According to estimation on basis of the intergovernmental panel on climate change RCP scenarios, By 2050, 6.8–13 % of the Jaffna Peninsula's land area will be directly flooded, and by 2100, this figure will increase to 10–35% (Gopalakrishnan & Kumar, 2020).

Following SLR, will have a severe adverse impact on saltwater intrusion processes in coastal aquifers as well. Several studies have shown that impacts on water quality due to the SLR(Chang et al., 2011; Loáiciga et al., 2012). Saltwater intrusion to connecting water bodies such as estuaries and lagoons poses negative impacts on the lifestyle and distribution of aquatic species (Wickramasinghe, 2010). The study carried out by Perera et al., 2018 shows how the seawater intrusion affected the community of the Bentota river basin. The total annual economic loss in the coastal community was 7,529,698.50 USD per year and it was directly happened due to the seawater intrusion(M. D. N. D. Perera et al., 2018). However, there can be found few studies have been carried out in this regard(Bentotage & Dahanayaka, 2012; Jayasiri & Dahanayaka, 2012; M. Perera et al., n.d.). Also, these studies ignore the effect of Climate change and associated extreme event on saltwater intrusion. Hence there is a greater need for further research on this area, especially how the SLR affects the groundwater quality in coastal areas in Sri Lanka.

Storm surges associated with extreme tropical cyclones threaten most of the countries surrounding the North Indian Ocean. The damage caused by storm surge flooding is a serious concern along with India's, Bangladesh's, Myanmar's, Pakistan's, Sri Lanka's, and Oman's coasts. Furthermore, Sri Lanka has experienced severe cyclonic events over the past few decades. A Study conducted by Srisangeerthanan et al., 2015 summarized the major cyclonic event that occurs in Sri Lanka.

Table 5.2 Cyclonic storms and Severe cyclonic storms of Past centuries (Srisangeerthanan et al., 2015)

Cyclonic storms	Severe cyclonic storms	Occurrences of storms
13	9	1907,1912,1922,1931,1955,1964,1978,1992,2000
10	7	1907,1922,1931,1964,1978,1992,2000
10	3	1907,1964,1978,1884
11	5	1907,1922,1931,1964,1978

Table 5.3 Some features of the severe cyclone storms that crossed or were in the vicinity of Sri Lanka(Srisangeerthanan et al., 2015)

Cyclone	Movement		Crossed	Coast	Maximum wind speed (Km/h)	Pressure (mb)	3-day highest rainfall (mm)
	From	To					
Dec,1964	E	W/WNW/NW	Crossed	EC	161	<970	200-250
Nov, 1978	E	NW/WNW/NW	Crossed	EC	>145	953	400-500
Nov, 1992	E	W/WNW/NW	Crossed	EC	>120	998.2	125-150
Dec,2000	E	W/WSW/WNW	Crossed	EC	165	970	300-350
May,2003	E	NW/Northerly	Not crossed	-	140	980	360
May,2010	E	NW/Northerly	Not crossed	-	120	972	-
Dec,2011	E	N/W/NW	Not crossed	-	>140	969	-

** EC- East coast

Table 5.2 and Table 5.3 show the major cyclonic events and features adopted from Srisangeerthanan et al., 2015. From Table 5.3, it can be noted that the east coast of Sri Lanka is highly vulnerable to storm surges. Furthermore, other coastal areas also have a significant impact due to the storm surges. Figure 5.3 shows the storm surge height due to the cyclone scenario of the maximum sustained wind speed of 220 km/h. Severe storm surge height can be highlighted in the north, east and west coastal region according to Figure 5.3.

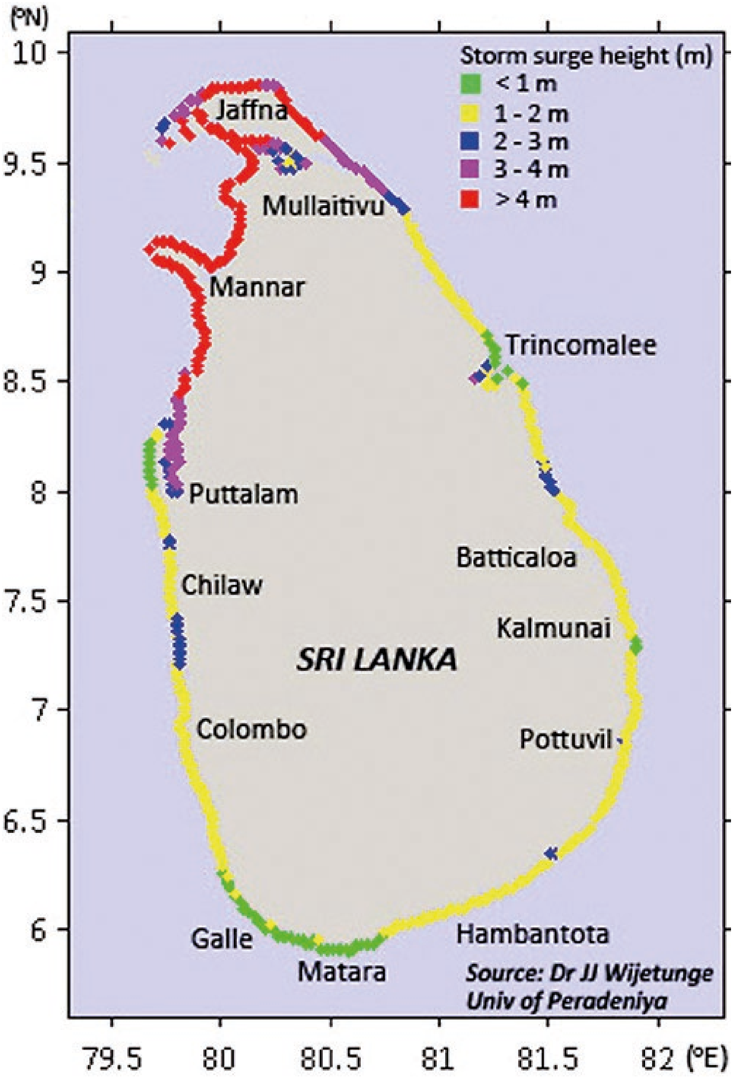

Figure 5.3 Storm surge hazard assessment corresponding to a cyclone scenario of maximum sustained wind speed 220 km/h (Cyclones, n.d.)

Storm surges result in a large number of deaths and property damage to coastal infrastructure, as well as agricultural losses(S. K. Dube et al., 2009). Rain, high winds, and storm surges, are the main causes of destruction from landfalling cyclones(S. K. Dube et al., 1997). Storm surges caused by extreme tropical cyclones are the most dangerous. The strong winds that are typical of tropical cyclones blowing over a vast surface of water cause death and devastation. These winds cause seawater to build upon the coast if they are bounded by a shallow basin, resulting in sudden inundation and flooding of coastal areas. The inundation of land by seawater is responsible for about 90% of the damage (S. K. Dube et al., 2009). Furthermore, river delta flooding happens as a result of the combined effects of tides and sea waves that reach into the rivers, because excess water in the rivers due to heavy rainfall from the cyclone is attempting to flow into the rivers into the sea. Most of the scholars have attempted to estimate the impacts of the storm surges using numerical models (Chittibabu et al., 2002; S. K. Dube et al., 2009, 2013; Shishir K. Dube, 2012; Laknath et al., 2020; Shaji et al., 2014; Xu et al., 2014). Wijetunge, 2014 has used a numerical model to assess the potential risk from the storm surge in the Chilaw area (Wijetunge, 2014). The findings from that study show greater impact due to inundation associated with the storm surges. From Figure 5.3, it can be noted that the northern and southern localities of the study area likely to be inundated most with flood depths exceeding 2.5m(Wijetunge, 2014).

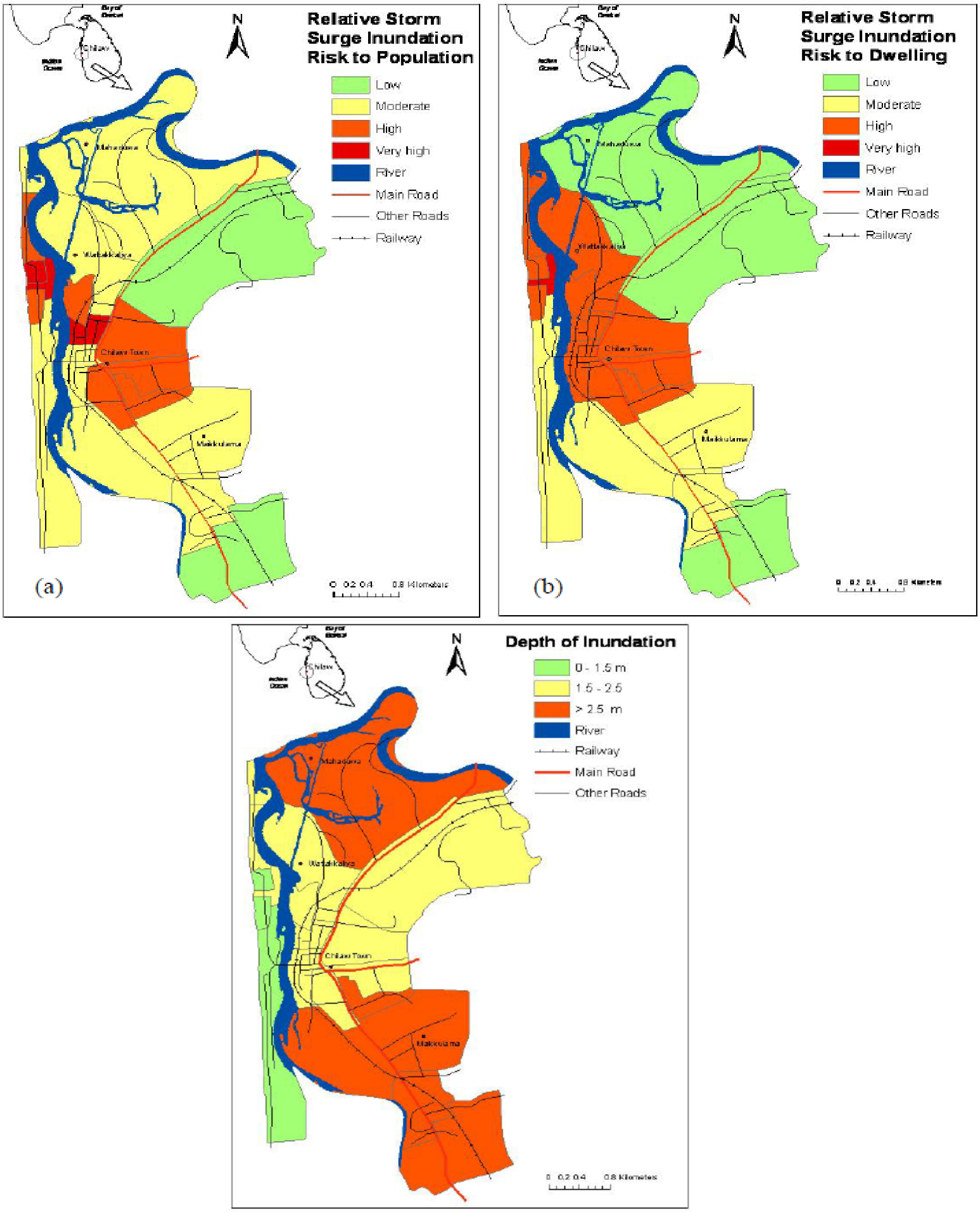

Figure 5.4 Spatial distribution of inundation and relative risk in Chilaw, Sri Lanka due to the storm surge caused by a tropical cyclone of wind speed 270 km/h(Wijetunge, 2014)

Coastal erosion is another major and ongoing issue in Sri Lanka, with socioeconomic and environmental consequences. Erosion is caused by both natural and anthropogenic factors, and it has both public and private costs. Beaches are being lost, leisure and tourism activities are being disrupted, and public and private property and infrastructure are being damaged. The government has been investing in coastal erosion management activities during past years. Coastal erosion, on the other hand, has been negligible in the country's northern and eastern coastal regions over the last three decades. Similarly, in both the northern and eastern coastal segments, investments in coast defence were kept to a bare minimum. There are many natural processes are contributing to coastal erosion as follows,

- Natural variations in the sand supply to the coast from rivers
- Loss of sand inland due to breaching and wash-over of a sand berm
- Offshore sand loss during extreme wave and storm surge conditions
- Loss of sand due to the presence of canyons
- Deposition of sand spits and dunes
- Loss of coastal vegetation
- Tsunami, cyclones and other episodic events
- Loss of material from nodal areas
- Sea level rise

According to IPCC mid-estimates based on linear melting of the ice sheets of Greenland and Antarctica due to increased greenhouse gas emissions, the global sea level is predicted to rise by 30- 40 cm in the twenty-first century (Church, et al., 2013). According to the Bruunn rule (1:100 ratios), the estimated coastal erosion extent due to the SLR as 50 m,65 m, 80 m and 95 m after 25 years, 50 years, 75 years and 100 years respectively (Minister of Mahaweli Development and Environment., 2018). As a result, it's difficult to dismiss the possibility of increased coastal erosion as a result of rising sea levels. When it comes to coastlines near inlets, such as river mouths, lagoons, and estuaries, however, quantifying the extent of erosion is more difficult. With SLR, such impacts around the water bodies would be dramatically accelerated. When it comes to coastlines near inlets, such as river mouths, lagoons, and estuaries, however, quantifying the extent of erosion is more difficult. Other factors, such as inundation due to heavy rainfall, basin filling impacts, and impacts due to saltwater intrusion, have an impact on these areas. With SLR, such impacts around the water bodies would be dramatically accelerated(Minister of Mahaweli Development and Environment., 2018).

According to current Coastal Conservation and Coastal Resources Management Department data, a high rate of coastal erosion has been recorded from the Lansigama over 2007-2012, similar to the higher erosion rates reported in the Mahaoya-Lansigama coastal segment within the period of 2000-2005. In 2010, a substantial (localized) rate of coastal erosion was recorded from the coastal stretch north of Oluvil Harbour. Shows the emergency coastal erosion incidence reported over the 2010-2013(Minister of Mahaweli Development and Environment., 2018; Rajarathna & Nianthi, 2019).

Table 5.4 Locations of emergency coastal erosion reported between 2010-2013(Source: (Minister of Mahaweli Development and Environment., 2018)

District	Location Description/Remarks
Puttalam	• Kudawa-Kandakuliya • Muthupanthiya-NagulEliya • Arachchikattuwa • Illanthidiya-Norochchola Beach • Thalwilla-Ambakandawila Beach • Marawila Beach • Modara-Barudalpola Beach • Kappaladiya
Gampaha	• Maha Oya • Uswetakeiyawa • Wattala Hendala • Paranaambalama • Dungalpitiya
Colombo	• Wedikanda-Ratmalana • Dehiwala-Mt.Lavania
Kalutara	• Magalkanda Beach • Beruwala-Maggona • Pothupitiya • Beruwala-Maradana • Beruwala-Kechchimale
Galle	• Ahangama • Unawatuna • Palutagaha • Goyambokka Beach • Gintota • Induruwa • Boossa • Dodanduwa
Matara	• Kotuwegoda
Hambanthota	• Welipatanwila • Palikudawa • Yarawatta • Tangalle • Unakuruwa
Ampara	• Oluvil • Kalmunai
Trincomalee	• Verugal • Murugan Kovil-Kuchchaveli • Near salli-MuthuAmman Kovil • Kinniya

	• Muthur
Mannar	• Arippu

Furthermore, many scholars have used end point rate (EPR) which is derived by dividing the distance of the shoreline movement by the time elapsed between the oldest and the youngest shoreline position(Oyedotun, 2014) to study coastal erosion. According to Abeykoon et.al, 2021 western and north-western coastal regions show a significant amount of coastal erosion over the past few years (Abeykoon et al., 2021).

Table 5.5 Regions with the Largest and Smallest EPR Changes in Each District of the Study Area(Abeykoon et al., 2021)

District	Rate	Region
Kalutara	High	Kaluwamodara
	Low	Katukurunda
Colombo	High	Wedikanda
	Low	Mount Lavinia
Gampaha	High	Daluwakotuwa
	Low	Dikowita
Puttalam	High	Kudawa
	Low	Kandakuliya

Table 5.5 shows the region with the largest and smallest coastal erosion using EPR in the western and north-western coastal region. However, the reasons for the reported erosion can't be distinguished as erosion is caused by several activities as mentioned before. Hence further research needs to be done to investigate the coastal erosion that is caused by climate change.

5.2 Environmental Impacts

Hettiarachchi has mentioned that certain impacts of climate change such as global warming are measurable and predictable, whereas some impacts such as the impact of climate change on storms and waves cannot be measured or predicted easily because of the complexities of understanding the processes and uncertainty (Hettiarachchi, 2013). The scientific community have tried to find the impact and predict the conditions of the future of eco systems and populations residing within those ecosystems, in order to come up with necessary adaptation measures. "*Rising water levels, shifting temperatures, eroding beaches, dying forests, increased weather anomalies, and natural disasters are just a few dreadful outcomes the island will soon come to face; some of which, it has already had its fair share of"*(Baba, 2010, 5). And according to Baba (2010), Sri Lanka has been experiencing coastal erosion at the rate of 0.30-0.35 meter a year, with the North and East region highlighted as more vulnerable.

- Natural habitat destruction

"The major consequence of coastline recession is the disappearance of the beach, and in severe cases, dunes and back-beach areas, resulting in loss of/damage to the coastal environments and properties" (Mehvaret al., 2019). Coastal environments can include beaches and sand dunes as well as mangroves,

coral reeves and coastal wetlands, which are rich in bio-diversity and natural resources. Seawater intrusion can inundation low-lying areas of the coastal region and damage such coastal habitats, including estuaries, lagoons, mangroves, salt marshes, beaches, sand dunes, coral reefs, sea grass beds, deltas, islands, barrier beaches and spits (Ministry of Mahaweli Development and Environment, 2016). The flora and fauna living in these ecosystems might face existential risks. In addition, the salt water intrusion into estuaries and river mouths could cause changes in those eco-systems (Ministry of Mahaweli Development and Environment, 2016) and make them inhabitable to existing flora and fauna.

Coastal disasters can uproot natural vegetation (Satyanarayana et al., 2017) and can destroy coastal forests. However, different coastal plant species were affected differently by the tsunami in 2004 (Satyanarayana et al., 2017). It was assessed that coconut palms, casuarina trees, and mangroves were more able to stand the pressure of tsunami waves and subsequent salinization (Satyanarayana et al., 2017).In fact, there were local tsunami witnesses who specified that the mangrove forests protected several lives and properties located behind the vegetation (Satyanarayana et al., 2017). However, in Sri Lanka, it is revealed that more than ninety percent of the coastline is vulnerable to water-related impacts and that existing bio shields like mangroves could only protect less than one-third of it (Feagin et al., 2010, as cited in Satyanarayana et al., 2017)

- Ecosystem collapse

It is said that due to their small size and fragile ecosystems, many developing island nations in tropical regions are highly vulnerable to climate change (Kariyawasam, Kumar, & Ratnayake, 2020).In most cases, the inundation and salinization of coastal ecosystems would make them inhabitable to the existing flora and fauna. Eco-systems such as mangroves and coastal wetlands could collapse. This would also mean the loss of eco-system services to the people who were depending on those ecosystems for their needs and livelihoods (Ministry of Mahaweli Development and Environment, 2016). Especially fishermen would be heavily affected due to lack of fish resources. Barange et al. (2014) project a potential decline in fish catch due to climate change to be around twenty percent by the 2050s (World Bank Group & the Asian Development Bank, 2020). The impacts on the livelihoods of local communities would be severe (Ministry of Mahaweli Development and Environment, 2016).

- Bio-diversity loss

Loss of natural habitat and collapsing of eco-systems would naturally result in the perishing of flora and fauna that inhabit these environments. Sri Lanka is known to be a biodiversity hotspot (De Silva & Yamao, 2007). De Silva & Yamao (2007) have noted that changing temperatures from climate change and rapid urbanisation may negatively impact terrestrial forest cover near urban settlements and the flora and fauna within them. Besides climate change is expected to influence the introduction and spread of invasive alien species in future (Kariyawasam, Kumar, & Ratnayake, 2020). The existing flora and fauna would be affected by such invasions, and possibly some species would face extinction. The rich and diverse biodiversity of Sri Lanka would suffer irreparable losses.

- Coral bleaching

Physiochemical changes in the oceanic environment, such as acidification of the oceans can damage coral reefs. Increasing atmospheric carbon dioxide levels can lead to changes in ocean acidification (Hoegh-Guldberg et al., 2007; IPCC, 2018). Acidification in turn leads to coral bleaching (IPCC, 2018). Tropical coral reefs are said to be particularly vulnerable to impact at 1.2°C, with most available evidence suggesting that coral-dominated ecosystems will cease to exist at this temperature or higher (IPCC, 2018). Coastal storms can exuberate the damage and even ‘flattening’ the structure of reefs without recovery (Alvarez-Filip et al., 2009, as cited in IPCC, 2018). Coral reeves support a vibrant and diverse collection of fish and fauna within them. The impacts of warming, coupled with acidification of oceans, are expected to make tropical coral reefs inhabitable for many species and desist the supply of a range of ecosystem services such as food, livelihoods, coastal protection, and cultural services to people (Burke et al., 2011, as cited in IPCC, 2018). The acidification of the oceans and destruction of coral reeves in Sri Lanka is predicted to result in stock changes in economically important species, which would, in turn, impact the livelihoods of fishermen (Ministry of Mahaweli Development and Environment, 2016). Destruction of corals can also lead to reduced tourism (IPCC, 2018) in future.

- Agricultural productivity

Rising SLR is already impacting the lives and livelihoods of Sri Lankans along the coast through the salinization of soils and groundwater in the coastal zones (World Bank Group & the Asian Development Bank, 2020). An increase in the mean sea level results in an increased tidal prism, which is the volume of water carried into bays of lagoons during a tidal cycle (Nianthi & Shaw, 2015). It is predicted that where there are narrow rivers entrances with flanking sand bars such as in Gin Ganga, Bentara Ganga, Kalu Ganga, and Maha Oya in Sri Lanka, the rising sea level could destroy the sands bars, resulting in a widening of the inlet. This would in turn in increase the volume of sea water entering an estuary or lagoons and cause the peripheral agricultural crops and lands to become salinized as well (Nianthi, 2005, as cited in Nianthi & Shaw, 2015)

Effects such as alterations to carbon dioxide availability, precipitation, temperatures, water resource availability, seasonality, soil organic matter transformation and soil erosion(World Bank Group & the Asian Development Bank, 2020), can negatively impact certain crops or the entire cultivability of land. Abandonment of coastal agriculture and degradation of water sources used for human consumption has already occurred in certain areas according to studies (World Bank Group & the Asian Development Bank, 2020). Coastal hazards can cause coastal water bodies to fill up with debris, beach erosion, uprooted vegetation, and salinization of drinking water and agricultural fields (IUCN, 2005; UNEP & MENR, 2005, as cited in Satyanarayana et al., 2017). Cleaning up land and water bodies after coastal hazards can also incur additional costs which the farmers may not be able to bear. In these instances, the government may need to step in to compensate and support the local farmers.

Rice is a staple food item in Sri Lanka, and the increases in temperature during the rice-growing season have been shown to have negative consequences for yields (World Bank Group & the Asian Development Bank, 2020). Salinization and soil erosion has led to the abandonment of paddy land close to the Walawa River estuary and saltwater intrusion has reduced yields (Ensor &Weragoda, R., 2009). Salinization of the paddy lands is caused by saline contamination of irrigation systems, temperature increases and SLR (Ensor & Weragoda, R., 2009). Ensor and Weragoda (2009) have critiqued the Rice Research Institute in Sri Lanka normally reserves its focus for large-scale irrigated paddy cultivate rather than the marginal or small-scale producers such as those Hambantota. They further mention that the Institute developed a few varieties of rice which are suitable for saline conditions, but without the involvement of local farmers, and that these varieties of rice are limited in terms of the levels of salinity that they can tolerate (Ensor, J. and Weragoda, R., 2009). This points to the need for more proactive adaptation needs. Other key crops, such as coconut, tea, and rubber, are also found to be highly vulnerable to temperature and precipitation variability (World Bank Group & the Asian Development Bank, 2020).

5.3 Economic Impacts

Oliver-Smith (1996) has pointed out that disasters cause destruction to a physical environment and to the material resources of a society, including the people, occupying that environment. The destruction of the physical and natural environment will have obvious detrimental effects on humans. In addition, to increase in temperatures, SLR and related disasters, issues like poverty and, the detrimental impacts on human health are expected to increase because of climate change (IPCC, 2018). According to UNDP, about 1.5 billion people live in multidimensional poverty globally and an additional billion are at risk of falling into poverty (UNDP, Cited in IPCC, 2018). Hence, climate change and the increase of disasters could cause more people to fall behind the poverty line.

- Damages to infrastructure

Sea level rise and hazard situations caused by climate change can cause damage and destruction of infrastructure. Infrastructure is explained to be a significant asset to the economies and modern economies rely on the ability to move goods, people, and information safely and reliably (Little, 2002). Hence, the flow of services provided by a nation’s infrastructure is needed to continue unimpeded in the face of hazards (Little, 2002). Infrastructure failure occurs when the infrastructure is unable to withstand hazard (Little, 2002). Infrastructure failure can be catastrophic when there are interconnected impacts, such as power outages, water mains or fires that occur simultaneously (Little, 2002). This could result in additional loss of lives and destruction. In developing countries like Sri Lanka which are already lacking infrastructure facilities, the destruction of existing infrastructure can be devastating.

- Damages to businesses

There are several industries located in the coastal area of Sri Lanka including coconut and fisheries-based industries, quarrying and mining (both sand and coral) and tourism (Nianthi &Shaw, 2015). The concentration of industries in the coastal zone is much higher than in other regions of the country, with over eighty per cent of the industrial units located in and around Colombo alone (Nianthi &Shaw, 2015). The large majority of Sri Lanka’s tourism economy is also located along the coastal zone (World Bank Group & the Asian Development Bank, 2020). Tourism infrastructure, major commercial ports, fisheries, harbours and anchorage are some of the infrastructures situated in the coastal areas (Nianthi & Shaw, 2015).

According to Baba (2010) coastal belt is one of the major lifelines in Sri Lanka's economy, which is facing danger from the rise in sea levels and disasters. Sri Lanka has been experiencing coastal erosion and coastline recession at a speedy rate in the past years (Baba, 2010; Nianthi & Shaw, 2015; Dastgheib et al., 2018). In addition, coastal hazards threaten the coastal environment and wetland ecosystems, such as in the case of the touristic beaches of the Trincomalee district (Dastgheib et al., 2018). Tourist infrastructure and natural coastal tourism assets, such as beaches and coral reefs, will be the most vulnerable to climate-induced shoreline change (Philips & Jones, 2006; Scott et al., 2012, as cited in Tam, 2019) Exploring the risks and trade-offs that will be faced as communities and infrastructure are forced to retreat from the present-day coast due to sea level rises and storm surge, has revealed a retreat distance of between 37 and 262 m along Sri Lanka's East coast is ideal, which is associated have significant economic costs (Dastgheib et al., 2018, as cited in, World Bank Group & the Asian Development Bank, 2020).

- Relocation and reconstruction cost

Rajendra Pachauri, chairman of IPCC, predicted that up to sixty million coastal people in the low-lying areas of South Asia could be displaced by global warming by the end of the 21st century (Baba, 2010). High-intensity rainfalls can not only damage houses but culminate in floods which breed different diseases (Baba, 2010), and in extreme cases lead to permanent inundation. Human settlements could become dislodged due to flooding, as seen during the tsunami of 2004, and during the flooding of the Ratnapura District in May 2003, where the whole town was submerged and the issue became a national emergency (Baba, 2010). As mentioned earlier the coastal zone of Sri Lanka is highly populated and urbanised (Nianthi &Shaw, 2015). Increasing coastal hazards and sea water intrusion inland will mean that much of the coastal population will have to be relocated. Housing and other infrastructure will have to reconstruct, incurring more costs. The tsunami of 26 December 2004 displaced many coastal residents in addition to the direct destruction of life, livelihood and property.

In addition to the cost of relocation and reconstruction, there would be psychological, and socio-economic stresses on people who will be forced to relocate from their homes and communities. A study revealed that tsunami relocation and resettlement brought persistent uncertainty to fishermen in Hikkaduwa and Weligama, as well as threatened to disrupt their community bonds and social networks (De Silva and Yamao, 2007) Post-disaster aid has been noted to cause delays, and dehumanizing effects in certain situations, create dependency and exacerbated the disruption suffered by local people (Oliver-Smith, 1996). Mulligan and Nadarajah (2012) have highlighted that the presence of planned evacuation shelters, can provide safe refuge during the disaster, and reduce the urgency of rehabilitation and reconstruction, thereby allowing those activities to be carried out in a well-planned and durable manner (Rathnayake et al., 2019). The lack of well-planned shelters can cause harm or difficulties to shelters' residents, especially women and children live (Rathnayake et al., 2019). Existing differences can be multiplied during such occasions, leading to patterns of discrimination in housing provision (Oliver-Smith, 1996), especially when political hands are involved. Some scholars have predicted that relocation could lead to conflict or exacerbate existing disasters. In the Sri Lankan situation, Baba (2010) has mentioned that the necessary migration of people from the submerged areas is likely to make the civil conflict resurface (Baba, 2010).

- The increased cost of resources

Climate change is predicted to challenge global food security (IPCC, 2013, as cited in, Demel et al., 2019). This is mainly because climate change is predicted to yield low harvests both in the agricultural, and fisheries sectors. However, with the collapse of eco-systems and destruction of bio-diversity, it can be assumed that certain resources will become scarce. Erratic rainfall and salt water intrusion can cause shortages of fresh water sources. With the scarcity of resources, the cost of resources would increase. In Sri Lanka which depends largely on hydroelectricity, water shortages and erratic rainfall could lead to shortages of energy production too. And it is shown that lack of resources could be simultaneously met with an increase in demand for resources such as in the case of cooling (World Bank Group & the Asian Development Bank, 2020). The projected increase in cooling requirement in Sri Lanka is significant, rising to at least ten percent by the 2040s under all emissions pathways (World Bank Group & the Asian Development Bank, 2020). This would place a strain on energy generation systems which are compounded by the heat stress on the energy generation system itself (World Bank Group & the Asian Development Bank, 2020). Hence the shortages of resources could lead to increasing costs of resources as well as more cracks in the systems of resource and energy generation.

- Loss of employment

According to the IPCC report, populations at higher risks from drastic changes in climate include marginalised communities, indigenous people, and local communities dependent on agriculture and fisheries (IPCC, 2018, 9). Agricultural and fisheries sectors could face severe fall backs because of climate variations. Hence, the livelihoods of people depending on agriculture, and the fisheries industry is directly under threat. The damage loss of property, the inward flow of seawater into agricultural land and the destruction of fish resources in the ocean during the tsunami are found to have caused difficulties in livelihoods, especially for people involved in trade, agriculture and the fishing industry (Rathnayake et al., 2020). Restoration of the various sector has taken different amounts of time with some businesses, industrial and agricultural activity not been restored (Suppasri et al., 2015, as cited in Rathnayake et al., 2020).

Various levels of socioeconomic vulnerability among people (Demel et al., 2019) cause the levels of coping to differ. According to López et al. (2011), social vulnerability is a measure of the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards (Demel et al., 2019). The socio-economic vulnerability of a community is said to be influenced by economic resources, power relationships, institutions or cultural aspects of the social system they occupy (Demel et al., 2019). And one of the largest contributors to social vulnerability is said to be the social class, which includes employment (type and stability), income, savings, the quality of human settlements, and education levels, among others (Cutter & Emrich, 2006, as cited in Demel et al., 2019). The loss of livelihood and employment, especially in the agricultural and fisheries sectors, due to climate change, would increase the socio-economic vulnerability of people to a great extent.

5.4 Social Impacts

There are various pieces of literature that have recognized the impact of climate change in the general community rather than the coastal community in general. Therefore, this section will discuss related studies which have presented various sub thematic areas under this broad impact called social impacts.

- Human health

Sri Lanka's first-ever communication to the United Nations Framework Conversation on Climate Change was done in 2000. In the said report, the following main health hazards were highlighted resulting due to climate change:

· Temperature increase – People with poor working conditions will be affected by illnesses such as dehydration and fatigue.

· Droughts and dirty water – diseases such as cholera, hepatitis, and typhoid will be spread.

· High-intensity rainfalls – will result in flooding which breeds diseases such as dengue (Baba, 2010).

USAID (2018) has recognized increased temperature, increased drought frequency and duration and increased storm frequency and intensity as climate stressors that affect health in Sri Lanka. They further alarm the following risks of climate change-related to health in Sri Lanka:

· Shifts in vector and water-borne diseases such as dengue
· Decreased nutrition and food security
· Reduced availability and increased disruption of health services
· Reduced water quality and availability
· Difficulty maintaining sanitation and practices

Health-related mortality is such an impact that has been frequently quoted. The World Bank Group and the Asian Development Bank (2020) predicts that there will be approximately 73 climate-related deaths per million populations due to malnutrition in Sri Lanka by 2050. They further project deaths related to the emerging heatwaves in South Asia.

An increase in disasters can also result in an increase in mental distress and mental illnesses. Studies revealed there were high amounts of cases of posttraumatic stress disorder (PTSD) among children in the aftermath of the tsunami (Neuner et al., 2020) A study among two hundred and sixty-four children who lived in severely affected coastal communities in Manadkadu in the Northern Province, Kosgoda in the Western Province, and Galle in the Southern Province revealed a prevalence rate of tsunami-related PTSD ranging between fourteen percent and thirty-nine percent, with an additional five to eight percent having PTSD unrelated to the tsunami (Neuner et al., 2020) The PTSD symptoms were explained by the trauma exposure and family loss, as well as previous traumatic events such as the war that ranged in the Northern and Eastern Provinces (Neuner et al., 2020).

- Poverty and Inequality

As per the World Bank Group and the Asian Development Bank (2020), many of the climate changes predictions are likely to affect the poorest groups in Sri Lanka in various manners. For example, as per Kjellstrom et al (2016), heavy manual labour jobs are common among the lowest paid whilst also being most at risk of productivity losses due to heat stress. Poorer businesses are least able to afford air conditioning as a remedy for heat stress. Poorer farmers and communities are unable to afford local water storage, infrastructure for irrigation, and technologies for adaptation (World Bank Group and the Asian Development Bank, 2020). Sri Lanka has been identified as a country with a high vulnerability to food price rises, and a country is expecting a particularly large increase in extreme poverty in the event of any climate-driven price rise (Hallegatte, Vogt-Schilb, Bangalore, & Rozenberg, 2016). These processes are likely to amplify existing societal inequalities and vulnerabilities, for example, between rural and urban areas. As of 2015, access to improved drinking water sources was around 3.5% higher in urban areas compared to rural (WHO/UNICEF, 2018).

Slow onset disasters such as droughts threaten the agricultural livelihoods of farming communities. This may force them to explore alternative income sources despite the fact that rural settings do not have attractive alternative income-generating opportunities. As per a study conducted by IOM in 2016 on Sri Lanka’s dry zone, it states many families already live on the verge of multidimensional poverty or have to pay off loans for seeds and equipment. Climate change can render small-scale agriculture, home gardening, tank fisheries, and other rural income sources unprofitable, forcing them to either find alternative employment, fall into poverty, or move away (SLYCAN Trust, 2020). Social class is the main factor that decides social vulnerability (Cutter & Emrich, 2006, as cited in Demel et al., 2019). Factors that decide social class include employment type and stability, income, savings, the quality of human settlements, and education levels (Cutter & Emrich, 2006, as cited in Demel et al., 2019). For example, hired labour will fare worse than land holding farmers or fishermen who own boats. Categories that revealed vulnerabilities of populations to tsunami included; age, gender, income, employment, land ownership, social networks and membership of organisations, loans and savings (Birkmann et al., 2007). Data has shown that those engaged in daily paid labour as mobile fish sellers and fishermen, and types of small-scale self-employment, were among the most affected (Birkmann et al., 2007). Many small-scale businessmen, fishermen and self-employed people faced a decline in income or lost their job (Birkmann et al., 2007).

Studies also showed that age and gender played a role in vulnerability (Birkmann et al., 2007). Children and the elderly population were very vulnerable to the tsunami. Gender also played a role, with studies showing that nearly twice as many females (sixty-five percent) as males (thirty-five percent) were dead or missing due to the tsunami (Birkmann et al., 2007). A study that specially focused on people with special needs denoted a lack of preparedness and mechanisms for the evacuation of people with special needs in the coastal community (Jayasooriya et al., 2019, as cited in Rathnayake et al., 2020). There is a need for these layers of social vulnerability need to be unravelled and incorporated into adaptation frameworks.

- Conflict

Baba (2010) introduces conflict as one of the direct social impacts of climate change. He points out that the impact of sea level rises in the Northern and Eastern areas of Sri Lanka will initiate climate migration. The reason for such impact is being that the lands in the Northern and Eastern parts of Sri Lanka are flatter than the rest of the lands on the island. This climate migration will lead to a civil conflict with the host communities in relation to land management.

- Human Mobility

‘Human mobility in Sri Lanka comes in many forms: temporary or permanent, internal or cross-border, for economic, social, or demographic reasons. It includes disaster displacement, migration between districts or provinces, labour migration abroad, student migration, inbound migration of foreign citizens, and more. One in seven Sri Lankans is an inter-provincial migrant, one in five an inter-district one. Remittances from migrants contributed ten percent of Sri Lanka's overall GDP and are a major source of income for one in eight households. (Department of Census and Statistics 2016)’ (SLYCAN Trust, 2020, p:1).

SLYCAN Trust (2020) further recognizes climate change as one of the main reasons which lead into human mobility in Sri Lanka. They discuss the impact of both sudden onset and slow-onset disasters on human mobility. Sudden onset disasters such as floods and landslides make people lose their land, homes, and properties, and make them move out of affected areas into temporary shelters. While some may return back to their original settings, many will have to relocate themselves permanently SLYCAN Trust, 2020).

5.5 Governance and Institutional Impacts

Climate change indeed has a vital impact on the governance and the institutional infrastructure of Sri Lanka. It is a common celebrated notion that Climate Change policy formation is a responsibility lies in the hand of the national government (Pallawala, 2018). It is also recognized that Climate Change must be formulated and implemented as a collaborative and mainstream strategy (USAID, 2018). Besides that Sri Lankan Disaster Management (DM) and Disaster Risk Reduction (DRR) policy framework yet to be aligned with the comprehensive global guidelines such as Sendai Framework for Disaster Risk Reduction (SFDRR) and Sustainable Development Goal(SDGs). Siriwardana et al.,2018 studied the efficiencies and effectiveness of the existing DM and DRR policy framework in Sri Lanka. In their study, the efficiency and effectiveness of the Sri Lanka National Disaster Management Policy (SLNDMP) were checked and evaluated under several criteria, utilizing several case studies in Sri Lanka. Findings from the study show that there are plenty of alignments that need to be done in the SLNDMP to cope with the disasters and extreme events associated with climate change (Siriwardana et al., 2018). Besides, that current national policies and frameworks related to coastal hazards are yet to be aligned to the post-2015 global standards(G. P. Jayasiri, Siriwardena, et al., 2018a). As per these lines arguments, the international community has taken efforts in encouraging national governments to make several Climate Change efforts in their national initiatives. Sri Lanka is no stranger to such international collaborative efforts. The following 2 international tools are the key turning points that have had a major impact on the governing and institutional structures in Sri Lanka:

1. United Nations Framework Conversation on Climate Change (UNFCCC) – Sri Lanka ratified this in November 1993
2. Paris Agreement on Climate Change - Sri Lanka ratified this on the 22nd of April, 2016

It was an obligation of UNFCCC (1993) that Sri Lanka should prepare and launch national communications on climate change periodically (Nonis, 2017). The initial national communication was presented to the UNFCCC in 2000. In the said communication, it has been acknowledged that the subject of climate change has not been directly addressed in almost all the existing policies. However, it further mentions that there are a number of environmental policies, legal enactments and plans that contain provisions that could contribute to reducing or mitigating the effects of climate change. It also adds that there are also many acts that deal with the subject areas dealing with climate change. These however have not been effectively implemented due to enforcement weaknesses (Sri Lanka, 2000). The report predicts the impact of SLR, temperature rise, droughts, high-intensity rainfalls and increased thunder activities. The report interprets policy measures as general measures that would increase resilience to climate change. It names several major policies that have been formulated up to date. These are the Agricultural Policy, National Land Use Policy (Draft), Transport Policy, Forestry Policy, and Energy Policy. There is a need for revising these policies taking into account the climate change impacts. When strengthening the policies and preparing new policies the reports claim that it is important to bear in mind - the need for:

- building up a database,
- to provide incentives/disincentives,
- to consider the cost-effectiveness of policies,
- need to adopt an integrated approach,
- to promote stakeholder collaboration, and
- to increase the awareness of climate change (Sri Lanka, 2000).

Sri Lanka's second National Communication on Climate Change was tabled at UNFCC in 2011 by the Ministry of Environment. The core feature of this communication is the attention given towards the Climate Change capacity building of government officials and researchers to undertake activities in compliance with the UNFCCC. It speaks on the following programmes and centres dedicated to capacity building and networking Climate Change:

1. In 2002, the Ministry of Environment has received funding from GEF to implementing a climate change capacity building programme for young scientists.
2. In 2008, the establishment of the Climate Change Secretariat at the Ministry of Environment has dedicated to the capacity building of the government officials in his regard.
3. The National Meteorological Centre set us at the Department of Meteorology maintains a global telecommunication system on Meteorological data.

Further, the report emphasises the importance of having a solid foundation for physical planning in Sri Lanka in order to tackle the ongoing and anticipated challenges of Climate Change. It refers to the National Physical Planning Policy and the National Physical Plan which have been formulated to achieve this objective. The specific objectives of the said plan have been:

1. Protecting the environment
2. Protecting people from disaster risks
3. Creating a strong network among cities, towns and villages
4. Protecting water resources
5. Balancing production and protection (Ministry of Environment, 2011)

In 2010, the Ministry of Environment implemented the first-ever National Climate Change Strategy 2011-2016. The strategy followed the following five principles:

1. Pursue pragmatic solutions, in line with the national development agenda
2. Initiate process to mobilize significant investments
3. Mobilize people/institutions to work towards integrated solutions
4. Harness the wealth of expertise and knowledge already available in Sri Lanka
6. Contribute towards developing the nation (Ministry of Environment, 2010)

The Strategy identifies strategic priorities required to be addressed when facing the threat of global climate change. The scope of the Strategy is restricted only to adaptation. Hence its scope covers five strategic thrusts, 25 thematic areas of action and 91 priority adaptation measures. Hence, it goes beyond the identification of strategic priorities and suggests a broad selection of interventions to address these strategic priorities without a specific plan of actions to implement them or to monitor the progress (Ministry of Mahaweli Development & Environment, 2016).

In 2012, Sri Lanka introduced their first-ever National Policy on Climate Change. This policy has a broad policy statement that covers the following core cross-cutting thematic fields:

1. Vulnerability
2. Adaptation
3. Mitigation
4. Sustainable consumption and production
5. Knowledge management, and
6. General statements

The main guiding principles of this policy could be listed out as:

· Climate change possesses an immediate and potentially irreversible threat to life on earth and timely action is necessary to reduce vulnerabilities and build resilience in the country.

· Steps taken to address climate change shall be environmentally sound, nationally appropriate, socially acceptable, and economically viable.

· Sustainable consumption and production can significantly address the current and future challenges of climate change.

· Ecosystems stability is ensured aiming at poverty eradication and Sustainable Human Development.

· A shared vision coupled with a shared responsibility of all the citizens is a necessity to effectively address the climate change problems/issues.

· Precautionary principles shall be followed in the absence of scientific-based evidence in decision making (Ministry of Mahaweli Development & Environment, 2012, p: 02).

Under the general statement, the policy acknowledges the need of having a mechanism for institutional coordination in tackling climate change. It emphasizes the following mechanisms to achieve the said objective:

1. Develop and strengthen an inter-institutional coordinating, collaborating and monitoring mechanism for effective implementation of the activities related to climate change at

national, provincial, district and divisional levels under the National Focal Point to the United Nations Climate Change Multilateral Agreements.

2. Foster good governance practices at all levels to improve mutual understanding and trust among stakeholders to ensure accountability of implementing the policy.

3. Performance of the national climate change policy should be evaluated through a sound monitoring and reporting system at national, provincial, district and local levels (Ministry of Mahaweli Development & Environment, 2012).

It further emphasises the need of having a sound legal and regulatory system to take effective measures to meet and address climate change challenges. Using the above initiatives in 2010 and 2012 of the Sri Lankan government Ministry of Mahaweli Development & Environment (2016) introduced the National Adaptation Plan for Climate Change 2016-2025. The plan is based on the following planning concepts and approaches:

- Mainstreaming adaptation to national development
- Integration of sectoral and cross-cutting national dimensions
- Adaptive policy and management
- Anticipatory adaptation

The major goals of the plan are to:

- Raise the adaptive capacity of individuals, communities and the society to cope with impacts of climate change effectively;
- Reduce the vulnerability to climate risks by enhancing the resilience of communities and ecosystems, and;
- Capture any opportunities that arise due to changes for maximum gain for the society and people (Ministry of Mahaweli Development & Environment, 2016).

One of the other key features of this plan is their acknowledgement on connecting their efforts with other national policies such as National Action Plan for Haritha Lanka Programme, Sri Lanka Comprehensive Disaster Management Programme 2014-2018 (SLCDMP), National Action Programme for Combating the Land Degradation of Sri Lanka (NAPCLD), Coastal Zone Management Plan (CZMP), National Physical Plan 2011-2030 (NPP), Sri Lanka Water Development Report 2010 (SLWDP), and Draft National Agriculture Policy. Speaking of the institutional changes that were made in the state sector of Sri Lanka in the Climate Change, 4 institutional set ups stand out.

1. Climate Change Secretariat: Climate Change Secretariat (CCS) is the main institution in Sri Lanka that coordinates the climate change-related matters in the country. It is one of the divisions established under the Ministry of Environment and currently under the Ministry of Mahaweli Development and Environment. CCS has been established in 2008 and now it is a fully-fledged division under the ministry and headed by a Director. CCS is the national focal point on climate change-related matters and leading the process of mainstreaming climate change into other development areas. It also takes the lead to liaise with other stakeholders from public, private and civil society (Pallawala, 2018).

2. National Expert Committees: CCS has established two expert advisory committees comprised of sector experts to provide advisory guidance on adaptation and mitigation related issues to CCS and

the ministry. The National Expert Committee on Climate Change Adaptation (NECCCA) and National Expert Committee on Climate Change Mitigation (NECCCM) are the two committees comprised of experts from government, academic, private and non-government sectors. These committees meet at least once a quarter and discuss relevant matters on a priority basis. These committees generally actively engaged in the preparation and reviewing of major plans, policies, communications, proposals, etc. as those are routed through the committees and subjected to their approval (Pallawala, 2018).

3. Inter-Ministerial Coordination Committee: CCS took significant steps to mainstream climate change into the development processes of the country. As the main step to coordinate among other line ministries, MoMDE through CCS facilitated the establishment of the Inter-Ministerial Coordination Committee on climate change. This committee is represented by Ministers and/or high-level officials of all the ministries, CCS and Chairpersons of the National Expert Committees. This committee provides a perfect platform to coordinate national-level climate change-related matters at the government level. Recently this committee has been renamed as Inter-Agency Coordination Committee (Pallawala, 2018).

4. Nationally Appropriate Mitigation Actions (NAMA) Coordinating Body: Recently the MoMDE and CCS in partnership with UNDP worked collaboratively to establish a mechanism to develop and approve Nationally Appropriate Mitigation Actions (NAMA) projects in Sri Lanka. This process has clearly identified an institutional mechanism and relevant institutions. Renewable Energy, Transport, Waste, Forestry, Industry and Agriculture sector focal institutions have been identified under this mechanism making it clear for mitigation actions under NAMAs (Pallawala, 2018).

Speaking specifically on the governing and institutional impacts of climate change for the coastal zone, coastal governance is vital to be discussed. The “Department of Coast Conservation and Coastal Resource Management (CC&CRM)” is the key institution in combating Coastal Erosion in Sri Lanka. Further, a Coast Protection Unit was established in the Colombo Port Commission in 1963. The realization of the government that a comprehensive approach to coastal erosion control is required, led to the establishment of a Coast Protection Engineering Unit (CPEU) in the Colombo Port Commission in 1971. In 1978, the CPEU was transferred to the Ministry of Fisheries and Aquatic Resources (MFAR) and was functioning as Coast Conservation Division. It was upgraded to a Department, the Coast Conservation Department, in 1984. During the last 38 years, the coast protection and management works were continued under different ministries and their supporters, and the Department was converted into as a Department of CC&CRM and "Director of Coast Conservation" of former CCD became as "Director-General" under the Coast Conservation (Amendment) Act, No. 49 of 2011 (Katupotha, 2016).

In 1981, Parliament enacted the Coast Conservation Act No 57 of 1981 and amendment Act, No. 64 of 1988. This Act introduced a position called ‘Director of Coast Conservation’ with the following responsibilities:

- Administrating and implementation of the relevant provisions of the Act;
- Formulating and executing schemes of the work for coast conservation within the Coastal Zone; and

· Conducting research, in collaboration with other Departments, Agencies and Institutions for the purpose of coast conservation (Katupotha, 2016).

The said Act requires a survey of the Coastal Zone and prepare a Coastal Zone Management Plan (CZMP). The CZMP, prepared by the Coast Conservation Department, was adopted by the Government and implemented as the Coastal Zone Management Plan 1990. A Resource Management strategy for Sri Lanka's coastal region, "Coastal 2000", which provided the direction for Coastal Resources Management of Sri Lanka, was prepared in 1992. The first revised CZMP was implemented since 1997. The last revision of the CZMP was done in 2004 and is currently being implemented. The objectives of the plan are to:

1. Identify coastal problems that need to be addressed;
2. Indicate why these problems are important;
3. Present the results to the Coast Conservation Department's Management Programme in order to address these problems;
4. Identify what should be done by Governmental and Non-Governmental organizations and the public to reduce the scope and magnitude of the coastal problems; and
5. Identify research on issues that need urgent action to the management of coastal resources (Katupotha, 2016).

Speaking of coastal management, the impact of the Tsunami in 2004 cannot be ignored. The government created the Task Force to Rebuild the Nation (TAFREN) as the primary institutional mechanism for recovery and reconstruction, to coordinate, facilitate and assist implementing organizations, to coordinate donor assistance and fund-raising activities, to expedite the procurement process and to enable implementing agencies through capacity building. TAFREN focused on four thematic areas.

- Getting people back to their homes;
- Restoring livelihoods;
- Health, education and protection for everyone; and
- Upgrading national infrastructure (Samaranayake, 2015).

The tsunami was also such a juncture that lead to redefining the coastal land use of Sri Lanka in the context of governance. 'Twenty-four percent of Sri Lanka is under the Coastal Divisional Secretariat, but along the coast, beaches and coastal reservations are state lands. Before the tsunami, most of the Crown lands in urban areas were encroached on by the coastal communities. In these populated areas, it was very difficult to maintain the set-back zones stipulated under coastal zone management plans owing to unauthorized construction and demolition orders to eject them. A set-back (buffer) zone is defined as an area left free of any physical modification. It is good planning practice to leave a minimum set-back from the mean sea level line. A setback is desirable to allow for the dynamics of seasonal and long-term fluctuations of the coastline and to ensure public access to the waterfront and visual access to it. Therefore, a set-back area belongs to the owner of the land and it benefits the owner to protect the property from hazards. However, the enforcement of these regulations was not successful in some areas owing to socio-economic conditions and political interferences. The encroachers of the set-back areas were devastated by the tsunami and had to be provided with emergency accommodation' (Samaranayake, 2015).

Vulnerability factors such as exposure to extreme natural events, geo-morphological characteristics, current development densities and availability of free space, the cabinet decided to implement set-back zones of 100 and 200 metres in the west and south coasts and north and east coasts respectively. Then a senior committee was appointed to prepare interim guidelines for all the development activities within the coastal zone; these are effective until formal guidelines are formulated based on the findings of studies on vulnerability assessments, coastal bathymetry and coastal mapping (Samaranayake, 2015).

6 Climate change impact on the built environment in coastal regions

Built environment is generally defined as the part of the physical environment that is constructed by and through human activity (Forrest &Kearns, 2001). The built environment can include houses, schools, hospitals, public spaces, urban forest and infrastructural facilities such as roads, power and water lines. The peaceful, prosperous and cohesive built environment are interconnected with social capital and social cohesion (Baldwin & King, 2017). With the advancement of technology in recent years, society has undergone a significant transformation. Because of urbanization and the rapid rise in human basic needs, the built environment has become increasingly relevant in human day-to-day activities. The catastrophe and severe weather conditions have had a significant impact on the buildings and Critical Infrastructure Systems (CIs) in recent years. The environment has changed dramatically, resulting in extreme disasters around the world. The interest in identifying the impacts of climate change on CIs and extreme weather events has increased in the last decades at the global and national level. This section aims to discuss the climate change impacts on the built environment in coastal regions.

6.1 Impact on district-level / city level

The coastal areas of Sri Lanka which are vulnerable to are densely populated, with much of the urban cities including the capital city of Colombo locate there (Nianthi & Shaw, 2015). Urbanization in conjunction with climatic has made urban residents increasingly vulnerable to extreme weather and other natural disasters (De Silva & Yamao, 2007). The urban poor who are located in urban slums in Sri Lanka is the most vulnerable as they lack the strength to withstand extreme conditions and are least able to afford preventive measures (De Silva & Yamao, 2007).

The rising trend of temperatures in urban areas is becoming more apparent with the expansion of urban land intermixing with climate change impacts (De Silva & Yamao, 2007). The interaction between urban human activities and local climate change is contributing to human-induced heat emission (De Silva & Yamao, 2007). Rainfall extremes with high intensity and frequent rainfall causing flash floods have become a frequent phenomenon in urban areas has been frequent during recent years particularly in wet-zone cities like Ratnapura, Ratmalana, and Colombo (Naveendrakumar et al., 2018, as cited in De Silva & Yamao, 2007). The need to make cities resilient to disasters has been recognised in development strategies for Sri Lankan cities such as the UNHabitat program to strengthen the community resilience of the cities and townships in disaster-prone regions of Sri Lanka (Jayasiri et al., 2018). Mannar and Batticaloa are two coastal towns, recognised under this strategy (Jayasiri et al., 2018). Sustainable urban drainage systems, built environment adaptation and integrating social and economic development by enhancing community networks are seen as important areas (Jayasiri et al., 2018).

Climate change would impact different cities and districts differently depending on factors such as geographical factors, socio-economic and cultural factors and the availability of resources. Baba (2010) has pointed out the unequal impact of sea level rises on the Northern and Eastern areas of Sri Lanka which could lead to a re-emergence of civil conflict with the host communities in relation to relocation and land management. Negambo and Batticaloa municipal areas are also predicted to be vulnerable to the rise of sea level, with SLR affecting fifteen to twenty percent of the total population by 2040 (Ministry of Environment, 2012, as cited in De Silva & Yamao, 2007). Coastal erosion is said to have reduced the availability of land and forests undermined the livelihoods of the Hambantota communities who are now having to access land resources illegally (Ensor, J. and Weragoda, R., 2009). With the impact of climate change being felt differently across different cities and districts in Sri Lanka the approaches to prevention and adaptation also need to be differently formulated with attention to specificities of context.

6.2 Impact on infrastructure

Society has undergone a dramatic change with the evolution of technology during recent years. The built environment has to become an important role in day-to-day activities of the human being because of urbanization and rapid increase of the basic needs of the human. In the past recent years, the climate has undergone a dramatic change. The built environment in different nations has significantly affected by climate change-related disasters all over the country. Critical Infrastructure Systems (CIs) which are openly defined as primary resources and structures which are essential to the social and economic wellbeing and effective functioning of the communities play a major role in the built environment by providing day-to-day essential services to human beings. They are profoundly ingrained in their surroundings and designed to function in a specific range of environmental conditions. Climate change presents a potential challenge to these networks by altering the “normal” spectrum of environmental factors, as well as the frequency and intensity of extremes, from undermining their integrity and functionality to inciting network-level failure. Over the last decade, the research community has shifted its emphasis away from infrastructure's sole position in climate change mitigation and toward the identification of possible vulnerabilities and the need for adaptation. Numerous studies focusing on various infrastructures, such as water, electricity, and transportation, reflect this change.

Infrastructure within the coastal belt in Sri Lanka significantly affects due to climate change and its associated hazards. Many infrastructures within the coastal belt zone are highly vulnerable to the SLR. For example, the study that has been carried out by the ministry of environment (Ministry of Environment, Sri Lanka, 2011) map out the vulnerabilities of the transport infrastructures (i.e. Figure 6.1 and Figure 6.2) to the SLR and floods. The major highlights of Figure 6.2 as follows,

- The main transportation infrastructures in Sri Lanka includes roads, railways, airport and seaports are highly vulnerable for SLR. These vulnerabilities are highest in the Northern and South-western coastal region of the island as infrastructures are not designed to accommodate climate change and its impacts. Apart from that vulnerabilities would be magnified as a substantial segment of transportation networks runs parallel to the coastline.
- Based on the study, 8 Divisional Secretariats Division (DSD) appear to be extremely vulnerable. Within 500m of the coast, these DSDs have 117 km of main roads, 183 km of secondary roads and 38 km of railroads.
- The 10 moderately vulnerable DSDs have a total of 75 km of main roads, 143 km of secondary roads, and 24 km of railroads, all of which are within 500 m of the coast.
- Jaffna District has 14 DSDs, 4 of which are extremely vulnerable and 4 of which are moderately vulnerable, making it one of the most vulnerable districts in the country. Over the next few years, significant investments are planned in Jaffna.

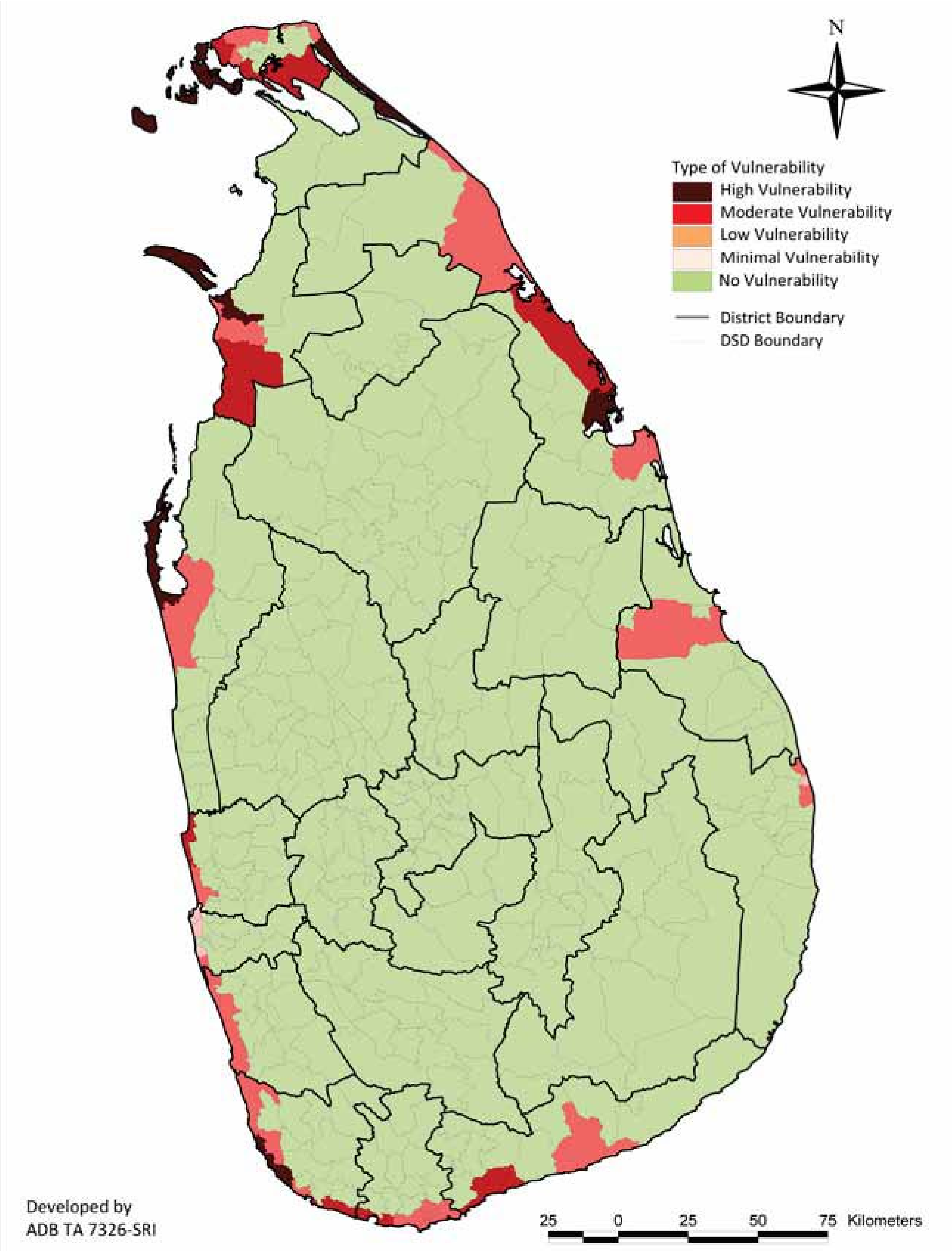

Figure 6.1 Transport sector vulnerability to the SLR (Ministry of Environment, Sri Lanka, 2011)

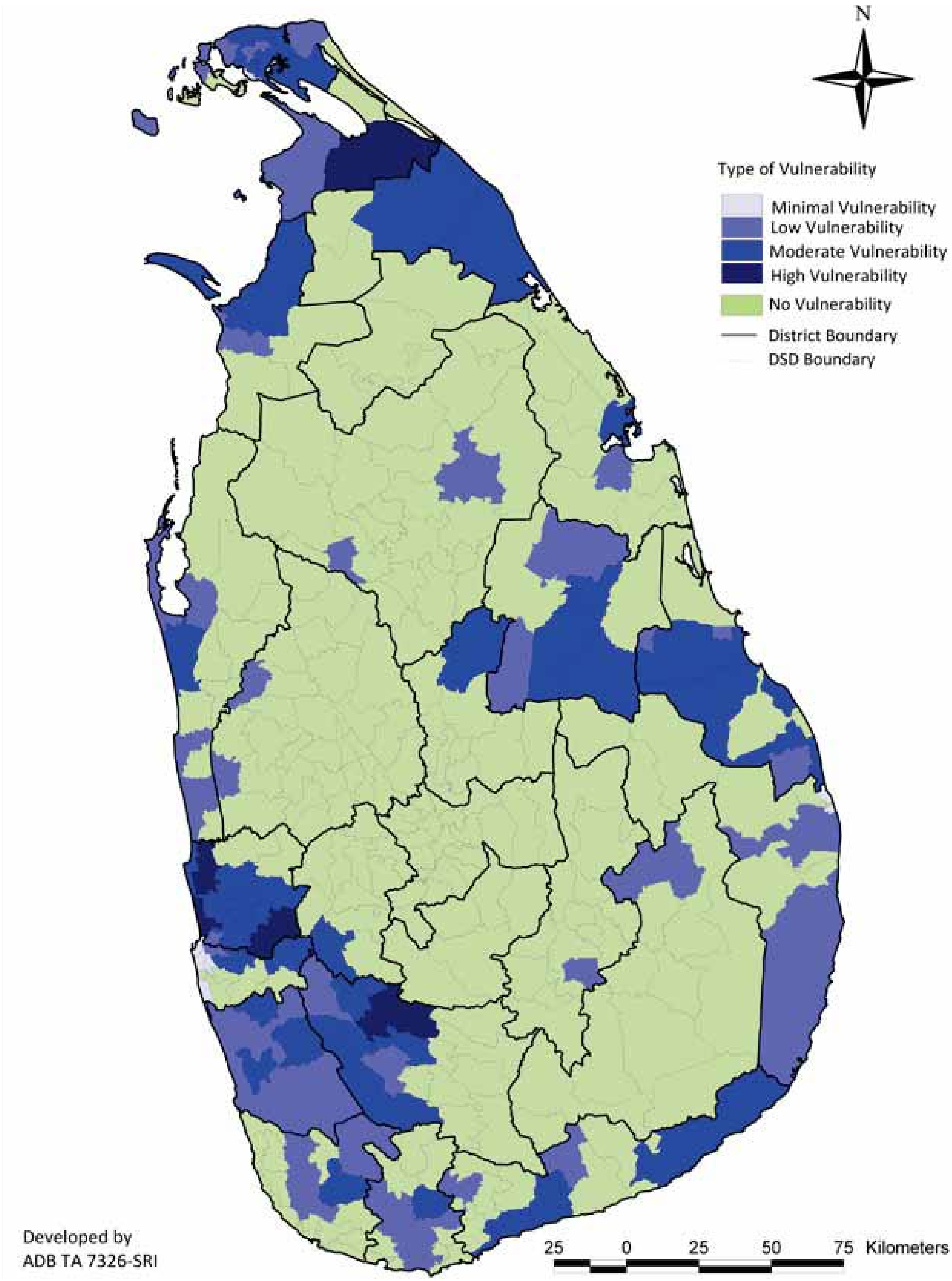

Figure 6.2 Vulnerabilities of the transport sector to flood(Ministry of Environment, Sri Lanka, 2011)

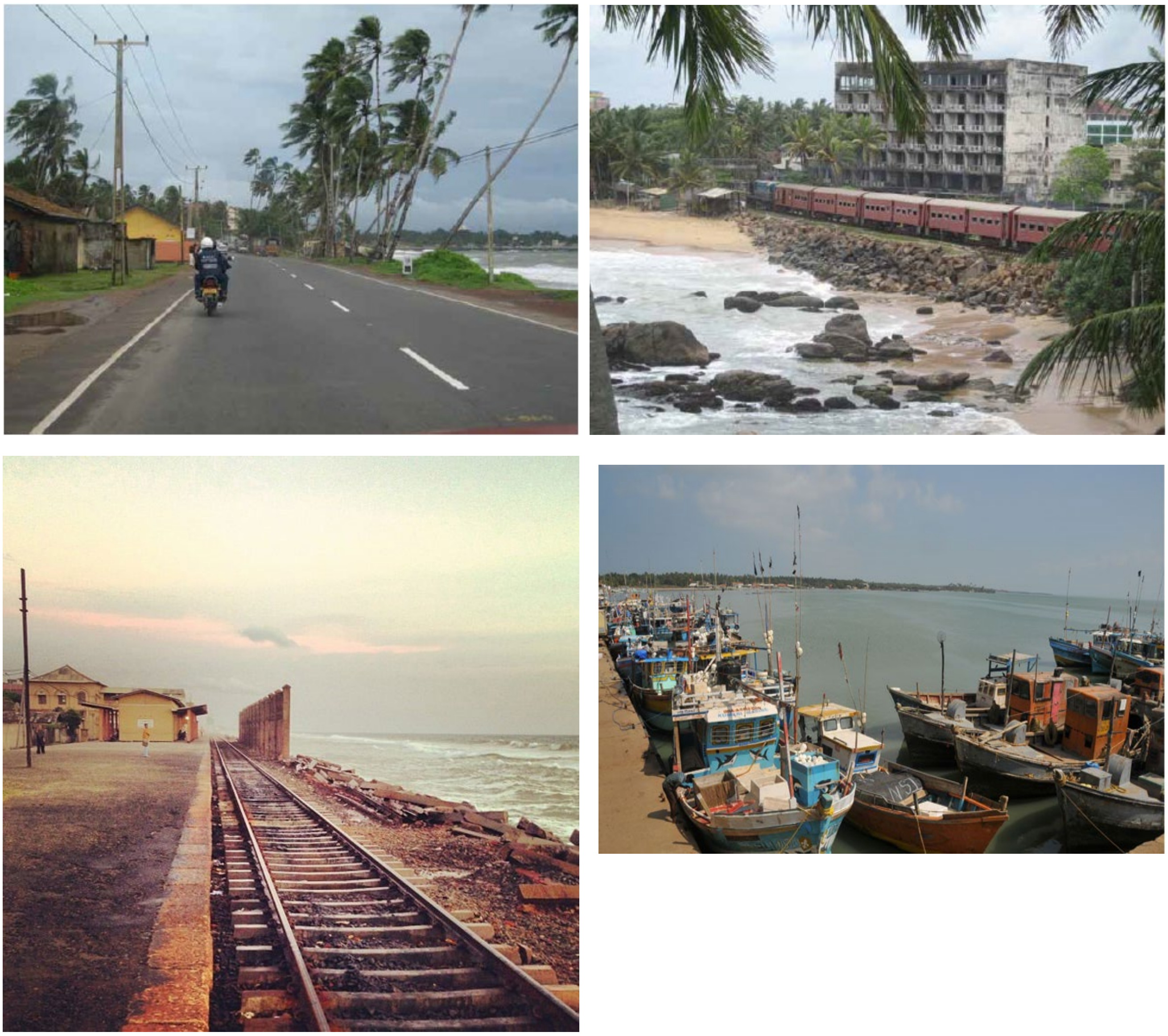

Figure 6.3 Transportation infrastructure within the coastal belt in Sri Lanka

Figure 6.3 shows the transportation infrastructures that are highly vulnerable for the SLR within the coastal belt zone in Sri Lanka. Apart from the SLR, these infrastructures are highly vulnerable to floods that induced by storms and extreme rainfalls. Figure 6.2 shows the flood vulnerability map that has been developed by the ministry environment, Sri Lanka (Ministry of Environment, Sri Lanka, 2011). According to the map, transport infrastructure vulnerabilities to the increased frequency and intensity of floods associated with climate change is widespread and prevalent in many parts of the country. Based on the study, 5 DSDs appear to be highly vulnerable to floods, while 43 DSDs are moderately vulnerable. The most vulnerable DSD is Gampaha in this regard. Furthermore, this study stressed that other infrastructure sectors have a significant impact due to the change of climate. Specially, water infrastructure vulnerability maps highlighted how climate change affected the water for domestic needs and irrigation as Changes in the pattern and quantity of rainfall, evapotranspiration, surface run-off, and soil moisture storage are expected because of climate change, and changes in water supply for irrigated agriculture and public use are likely.

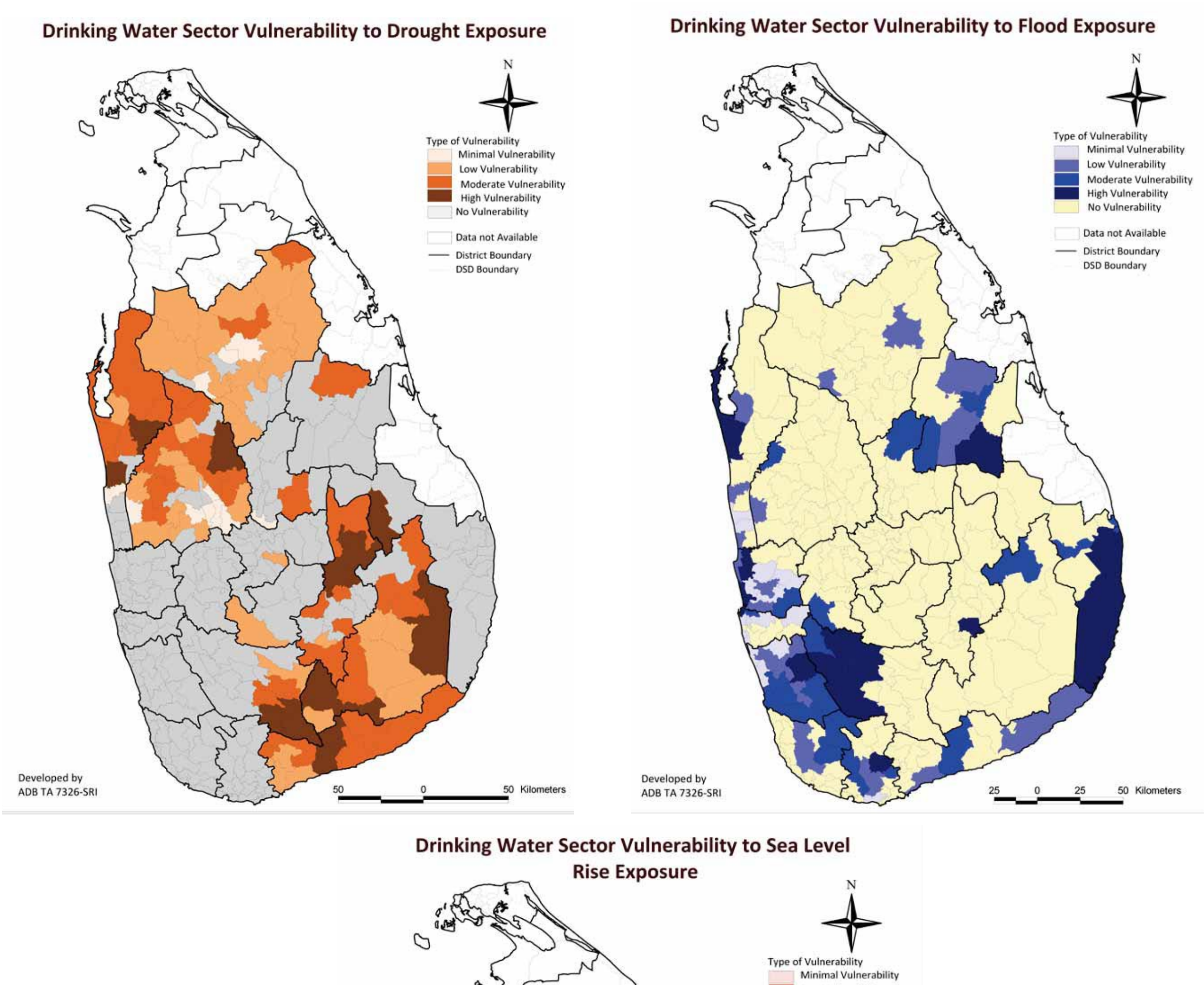

Figure 6.4 Vulnerabilities of the drinking water sector to the climate change(Ministry of Environment, Sri Lanka, 2011)

As it can be noted from Figure 6.4, water resources within the north-western, south and south-eastern coastal region are highly vulnerable to climate change and associated hazards. Specially drinking water sector in Sri Lanka highly vulnerable to droughts. As it can be seen most of the areas in Sri Lanka specially, north, north-western, south and south-eastern areas highly or moderately vulnerable to a decrease in precipitation and increase of temperature. On the other hand, due to high levels of exposure to the SLR, it is suspected that vulnerability would be high in the northern and eastern provinces. However, due to the lack of data in other areas, this study did not cover other areas in vulnerability analysis.

The other problem associated with the CIs is that they are highly interconnected and interdependent systems. They tend to behave as a system leading the complex behaviour and interactions among them. Due to the systemic nature among the CIs, disruption of the one CI would be highly affected to the other CI sectors. Figure 6.5 illustrates cascading impacts of electricity failure which have been experienced by Sri Lanka recently. As it can be noted from Figure 6.5, there is a high impact on other infrastructure sectors if one sector gets affected raising the complexity of the problem associated with climate change.

This section discusses the impacts on infrastructures associated with climate change. Table 6.1 the climate change impacts on the infrastructures. Due to the lack of studies for the Sri Lankan context, table 6.1 is developed based on the studies that have been carried out globally.

Figure 6.5 Cascading impacts due to electricity failure (Source: developed by the author)

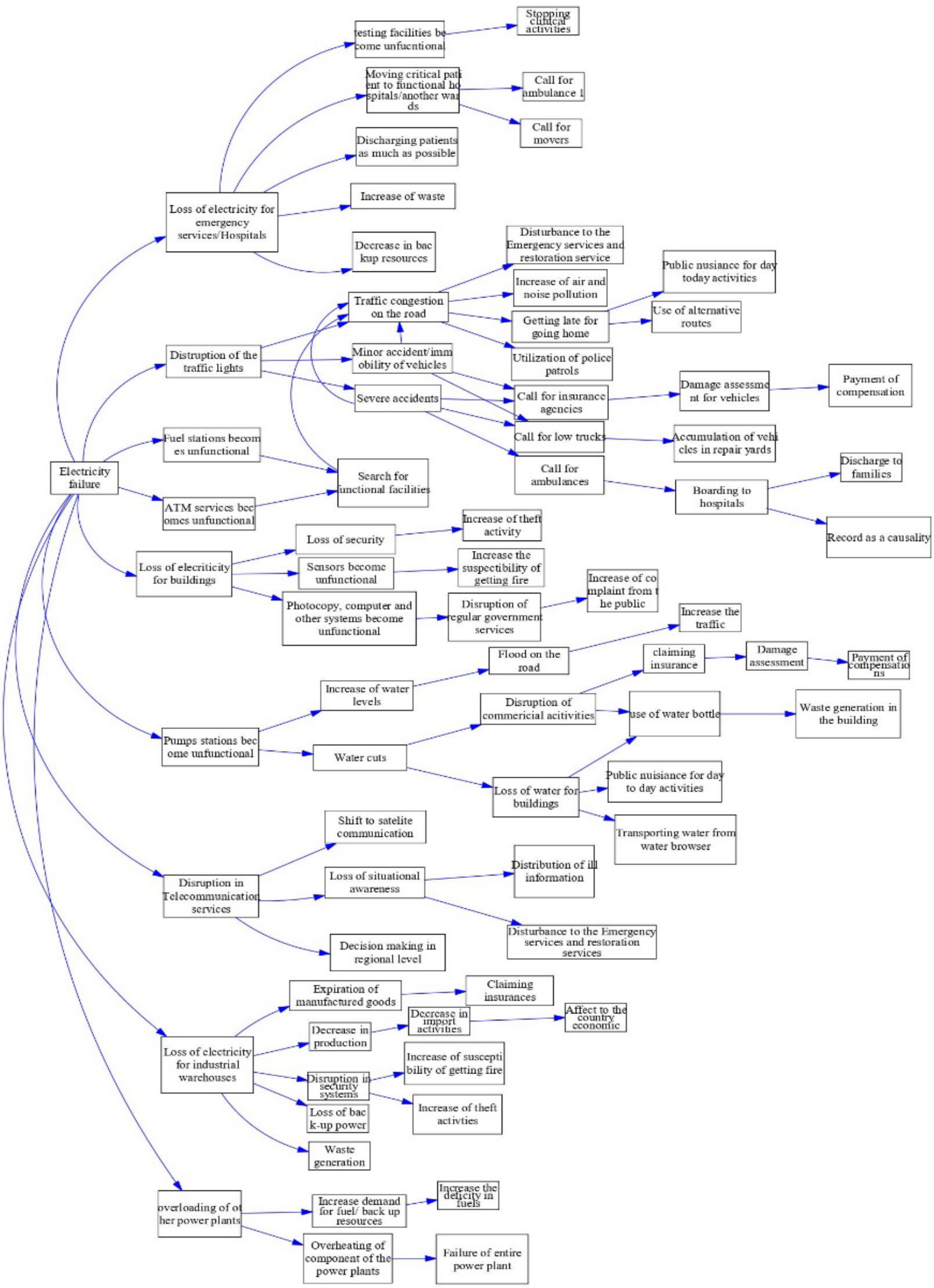

Table 6.1 Climate change impacts on infrastructures

Climate Change	Potential impacts	Infrastructure sector	Reference
Extreme precipitation	• Changing annual or seasonal patterns of precipitation can affect the river flows and water level behind dams, impacting hydropower output and generation costs • Heavy rains and flooding can lead to erosion weakening transmission tower structures. • An increase in the moisture content of coal reduces its heating value and combustion efficiency.	Energy and electricity sector	(Johnston, 2012a; Sieber, 2013; Spalding-Fecher et al., 2016; Vicuna et al., 2008)
Drought or decrease in precipitation	• Droughts reduce the water level in reservoirs affecting the hydropower generation • Decreasing precipitation can reduce the amount of hydropower generation due to decreased water storage in dams and reservoir • Increasing demand for other alternative energy sources • Drought can increase damage to transmission and distribution lines from increased dust. • Water shortages and elevated water temperatures may reduce electricity generation • Decreased soil moisture levels may affect the load ability of underground distribution cables.		(Abi-Samra et al., 2010; Cortekar & Groth, 2015; Davis & Clemmer, 2014; GAO, 2014; Johnston, 2012b; Mukheibir, 2013; Schaeffer et al., 2012)
SLR	• Damages to offshore wind farms • Increased sea levels and storm surges could damage coastal energy infrastructure.		(Davis & Clemmer, 2014; Johnston, 2012)
Extreme events	• Extreme events can damage the infrastructure of offshore wind farms and make access to them difficult for maintenance or repair works.		(Davis & Clemmer, 2014;

including flooding, storms, hurricanes	• Increased risk of physical damage or destruction to hydropower generation infrastructure from debris such as logs damaging the components of the systems. • Extreme events such as storms and lightning strikes can damage solar PV systems and solar power infrastructure. • Electricity infrastructures such as transmission lines, electricity poles, towers can be severely damaged due to extreme flood and storm events. • Flooding and storms can result in inundation of power plant sites • Hurricanes and high wind speeds can damage the overhead transmission and distribution lines and can damage or break down cooling towers in power plants • Lightning during a storm can strike tanks in the power plant igniting the fuel • Flooding can result in rupture of underground tanks due to collision with flood debris • Flooding can result in short-circuiting and malfunctioning of cooling systems, safety systems and pumps in power plants • Reduced coal production • Flooding can affect the quality of coal • Flooding may affect railway lines disrupting coal transportation • Transport of coal by barge can be affected when water levels in rivers and ports are too high, such as during a storm surge drop.		Dowling, 2013; GAO, 2014; Johnston, 2012b; Mukheibir, 2013; Schaeffer et al., 2012; Sieber, 2013)
Temperature increase (including increased frequency and intensity of extreme heat)	• Reduces generation efficiency • Reduces the electricity capacity of transmission lines and grids • Increases losses within substations and transformers • Increasing water temperatures can reduce the plant generation efficiency and may result in exceedance of thermal discharge limits • Heatwaves can result in the failure of transformers as higher temperature increase their deterioration. • In high temperatures or heatwaves, coal stocks may spontaneously combust or self-ignite.		(Abi-Samra et al., 2010; Cortekar & Groth, 2015; Davis & Clemmer, 2014; Dowling, 2013; Golombek et al., 2012; Johnston,

			2012b; Kirshen et al., 2008; Mideksa & Kallbekken, 2010; Schaeffer et al., 2012; Sieber, 2013)
Extreme precipitation	• Increased overflows and increased blockage and breakages in wastewater conveyance and pump stations • Increased inflows to wastewater treatment plant leading to more frequent bypassing • Soakage performance affected when soils are waterlogged in treatment plants • Floatation of below-ground chambers • Soil structure damage reducing soakage performance • Ecological changes to the soakage field.	Waste water treatment plants	(Hughes et al., 2021)
Drought or decrease in precipitation	• Corrosion due to low flows resulting in increased concentration in water conveyance and pump stations • Blockages or siltation when combined with increased temperature and reduce water use in water conveyance and pump stations • Increase the strength of influent risking breach of toxicity levels • Ecological changes to the soakage field		(Hughes et al., 2021; Langeveld et al., 2013)
SLR	• Pipe float due to increased groundwater level causing cracking • Corrosion • Groundwater ingress leading to loss of functionality and capacity • Erosion/inundation causing damage to infrastructure • Raised groundwater table preventing sludge management • Dewatering • Outfalls may be impacted (increased pumping heads for outfalls.		(Hughes et al., 2021; Kirchhoff & Watson, 2019)

Extreme events including flooding, storms, hurricanes	• Increased blockages and breakages associated with extreme events due to debris • Flooding causing a reduction in the service zone of the pump station • Damage to infrastructure facilities and accessibility to the site make difficult • Strom related power outages and road closures • Affects the performance of the soakage		(Hughes et al., 2021)
Temperature increase (including increased frequency and intensity of extreme heat)	• Increase odours • Blockages due to user behaviour changes in hot weather • Performance of biological systems such as oxidation ponds and sludge management varies with temperature		(Hughes et al., 2021)
Extreme precipitation	• Swelling of soils leading to increase pipe loading • Reduced water quality leading higher capital for purification of water	Water infrastructures	(Bollinger et al., 2014; Hunt & Watkiss, 2011; Kundzewicz et al., 2018; McNutt, 2013; Miara et al., 2017)
Drought or decrease in precipitation	• Consolidation, oxidation of soil, differential settlement • The decrease water level in water resources affecting water supply services		
SLR	• Salinization of ground water •		
Extreme events including flooding, storms, hurricanes	• Movement of trees and roots due to extreme wind leading to increase pipe loading • Damages to infrastructures due to debris • Impact on water quality from the increased turbidity • Increased concentration of pollutants • Making access to infrastructure facilities for repairing and maintenance work difficult		

Temperature increase (including increased frequency and intensity of extreme heat)	• Thermal expansion of pipes • Increased water demand • Weakening of thermoplastic material leading to reduce pipe strength • Corrosion • Increased evaporation in surface water supplies contributes to deteriorating water quality due to the concentration of contaminants		
Extreme precipitation	• Flooded road/Tunnels • Reduced visibility leads to accidents and may cause reduced road speed/capacity • Water accumulation on the road • Increased of landslide	Transportation infrastructure	(Bollinger et al., 2014; Camp et al., 2013; Lambert et al., 2013; Meyer et al., 2010; L. Wang et al., 2018)
Drought or decrease in precipitation	• Instability of road substructure that will lead to closed or blocked roads and higher maintenance cost		
SLR	• Increased in sea level caused in inundation of road infrastructure and consequences associated with flood		
Extreme events including flooding, storms, hurricanes	• Debris such as trees and branched on the road • Overturned trucks, caravans • Increased noise • Long-term changes to travel patterns and hence increase the demand for new infrastructure to cater for the demand • Flooded road and tunnels • Evacuation of people from infrastructures at the extreme event • Increased traffic congestion		
Temperature increase (including	• Melting asphalt and rutting • Roadside fire • Opening/closing problems of steel bridges leading to structural instability		

increased frequency and intensity of extreme heat)			
Extreme precipitation	• Heavy rains may result in the weakening of telecommunication infrastructures • The changes in the precipitation levels could cause subsidence, damaging the above-ground and underground communication infrastructure	Telecommunication infrastructures	(Salimi & Al-Ghamdi, 2020; Wilbanks & Fernandez, 2014; Zimmerman & Faris, 2010)
SLR	• The flood can cause to erosion and deterioration of ICT infrastructures		
Extreme events including flooding, storms, hurricanes	• Debris could damage ICT infrastructures • Lightning strikes can damage transmitters • Internet traffic increases and accessibility declines • Calling carrying capacity reduced, lost or blocked • Power disruption/outage frequency and severity affect communication equipment. • Equipment flooded and stored materials damaged		
Temperature increase (including increased frequency and intensity of extreme heat)	• Reduce the range of wireless communication • Destruction of equipment and increased maintenance		

6.3 Impact on Building Level

The impacts of climate change events appear to be having a growing influence on society, according to recent climate observations. These effects would almost certainly have an influence on the building construction industry. Several studies have been carried out to estimate potential building energy consumption rates(Yau & Hasbi, 2013). These studies, on the other hand, often ignore climate variability and consumer reactions to climate change, especially temperature changes (Ding et al., 2021; Yau & Hasbi, 2013). The effect of climate change on buildings is discussed in this section.

Potential impacts on buildings that may be experienced throughout their life span can be categorized into four main groups; impacts on building structures (mainly caused by natural hazards due to extreme events), building construction (deterioration of fastening system and water supply system), properties of building material, indoor climate/energy use (Hrabovszky-Horváth et al., 2013) as shown in Figure 6.6.

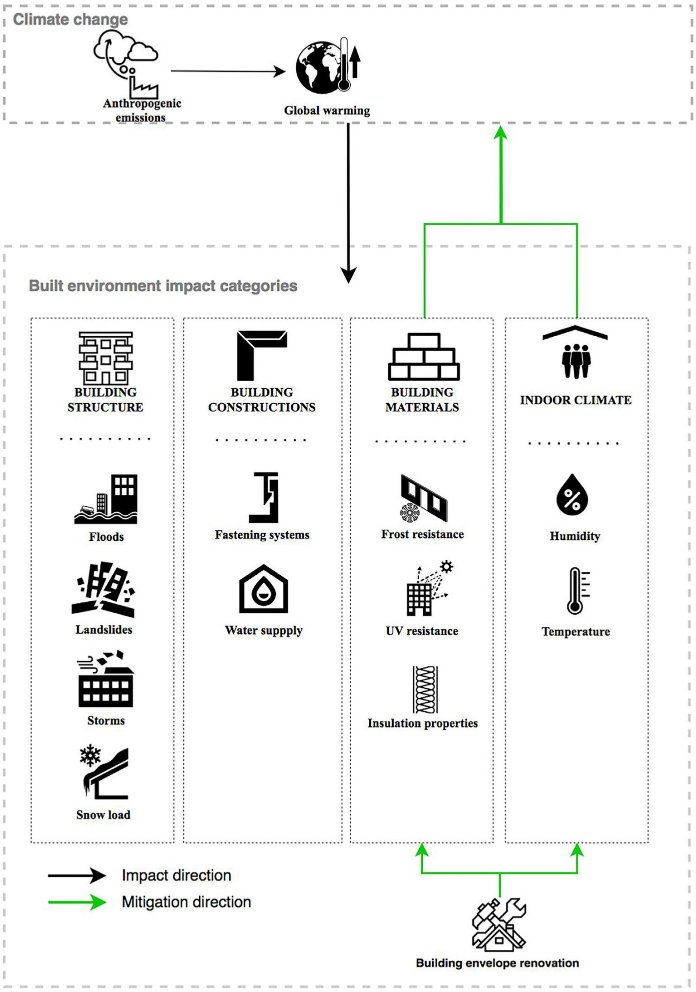

Figure 6.6 Connection between climate change and buildings sector(Andrić et al., 2019)

Sri Lanka has been experiencing impacts due to extreme events over the past years. These events turned into disasters damaging lots of building. This increasing trend of disaster losses caused to the built environment is mainly due in part to the unprecedented rate of urban growth, increasing dependence on complex infrastructure, unplanned urbanization, outdated and poor-quality buildings and infrastructure(Amaratunga et al., 2017). Table 6.2 shows the damages that occurred due to extreme events in Sri Lanka.

Table 6.2 Summary of associated losses due to extreme events(Abeysinghe et al., 2021)

Extreme events/ Hazards	Number of deaths	Houses of destroyed	Houses damaged	Number of affected victims	Local losses ($)
Coastline & coastal erosion	0	153	437	4137	0
Cyclone	846	18208	111,565	1375005	0
Cyclone and Flood	9	13178	37371	319128	0
Drought	0	0	0	20725949	0
Flash flood	6	72	684	8812	0
Heavy rains	37	689	7583	780213	0

From Table 6.2, it can be seen that most of the residential buildings are getting damaged due to coastal erosion, cyclone, flash flood and heavy rains events that are associated with climate change. Furthermore, a study that is conducted by Gopalakrishnan et al., (2020) shows how residential buildings are getting affected due to inundation due to SLR in Jaffna Peninsula (Gopalakrishnan et al., 2020). Hence there is a huge impact on buildings especially residential buildings from the extreme events associated with climate change.

On the other hand, building material and building design and construction process would have significant impacts on climate change. Buildings are typically built to provide occupants with weather protection as well as to achieve a certain internal atmosphere independent of the external weather. The exterior elements of a building, collectively known as the external building fabric or envelope, are built to shield the interior environment from unnecessary external climate interaction. There is a lot of variance in what these forms of loading can be around the world, but they generally include (Phillipson et al., 2016):

1. Protection from external temperature conditions (both heat and cold)
2. Protection from precipitation
3. Protection from winds (Maintaining both structural integrity and shelter while enabling appropriate ventilation)
4. Protection from external humidity conditions (through appropriate ventilation to control psychrometry)

But buildings materials are subjected to severe deterioration due to climate change and associated extremes events. Table 6.3 shows the climate sensitivity of the durability of the general material types and it shows how the durability of the building materials is affected by climate change(Phillipson et al., 2016; Stewart et al., 2011). Also, it can be noted that almost all building materials have a significant impact due to precipitation and temperature changes.

Table 6.3 Durability of the building materials and climate change

Material type	Durability issues	Climate dependence	Reference
Concrete	• Corrosion of reinforcement	CO_2, Temperature, Drying	(Stewart et al., 2011)
	• Chemical and salt attack	Precipitation, temperature and drying	(Neville, 2004)
Brick and ceramics	• Frost damage	Freeze-thaw cycles	(Lourenço et al., 2014)
	• Shrinkage of unfired materials	Precipitation and drying	(Brimblecombe et al., 2011)
	• Salt staining	Precipitation and drying	(Bakar et al., 2009)
Wood	• Biological deterioration	Temperature and precipitation	(Nofal & Kumaran, 2011)
	• Wrapping and structural movement	Uneven drying	(Haque, 2010)
Glazing	• Failure of double-glazing seals	Precipitation and humidity	(Garvin & Wilson, 1998)
Plastics/Polymers	• UV deterioration	UV exposure, temperature	(Chaochanchaikul et al., 2013)
	• Thermal ageing	Temperature	(Leuteritz et al., 2016)
Steel/metals	• Various corrosion mechanisms	Temperature, precipitation	(Revie, 2011)
Stone	• Weathering and erosion	Temperature	(Smith & Přikryl, 2007)
	• Acid deposition	Precipitation	(Moncmanová, 2007)
	• Salt attack	Precipitation and drying	(Flatt et al., 2014)

Hence it is important to address these issues at the design and construction stages. Building codes and standards provide major guidance in the building design and construction process. There can be found few standards and building codes in the local context, but there is a greater need for local building codes and standards to integrate climate change and disaster into their standards. Hence more research and development work needs to be done in this area.

The other major impact on the buildings due to climate change is the energy usage of the building. Currently, there is growing concern about energy use and its implications for the environment. The IPCC reports increased public awareness of energy use and its consequences for climate change and sparked a lot of interest in learning more about energy use and its relationships with current weather conditions (*AR4 Climate Change 2007*, n.d.-a; *AR4 Climate Change 2007*, n.d.-b). Previous studies have shown that building energy demand and climate change correlates with each other(Andrić et al., 2019;

Ding et al., 2021; Hussain et al., 2020; Yau & Hasbi, 2013). It has been experienced that climate change in terms of global warming would mean less energy use for winter heating and more for cooling during summer months. The extent of reduction in heating and increase in cooling varies from one region/climate to another and depends very much on the prevailing local weather conditions and energy efficiency measures. Sri Lanka, being a tropical country lead to an increase in energy demand due to an increase in temperature specially in the coastal region(Kumareswaran et al., 2021). However, there is a lack of studies that have been carried out in this regard in the Sri Lankan context. Table 6.4 illustrates the impact on energy use in buildings in the Asia region.

Table 6.4 Overview of climate change impacts on building energy demand in Asia

Reference	Country	City	Reference period	Observed period	Heat demand decrease (%)	Cooling demand increase (%)	Total building demand (%)
(Y. Wang et al., 2017)	China	Jinan	2020	2050	-	+30.7	-
(Xiang & Tian, 2013)		Tianjin	1971-2010	2011-2050	-18.1	-	-
(Wan et al., 2011)		Harbin	1971-2000	2001-2100	-	-	-6.1
		Beijing	-	-	-	-	+1.9
		Shanghai	-	-	-	-	-3.4
		Kunming	-	-	-	-	+7.9
		Hong Kong	-	-	-	-	+7.6
(Huang & Hwang, 2016)	Taiwan	Taipei	2000-2010	2050	-	+59	-
(Yau & Hasbi, 2013)	Malaysia	Kuala Lumpur	2000	2050	-	+8	-
(Shibuya & Croxford, 2016)	Japan	Sapporo	1990-1999	2040-2050	-27	+23	+3
		Tokyo			-263.6	+17	+13
(Radhi, 2009)	United Arab Emirates	Al-Ain	2009	2050	-9.5 to -39.2	+7.3 to 24.1	+4.1 to 12.5
(Roshan et al., 2012)	Iran	-	2005	2050	-14	+30	-

It is obvious that there is an impact on the cooling and heating demand of building due to temperature increase. Also, it can be noted there is an increase in the cooling demand in most of the study areas in Table 6.4. From the above table, it can be concluded that the cooling and heating demand of the buildings have a greater impact due to temperature rise and climate change thereby affecting the energy use of the buildings.

7 Conclusion

Recent research on local, regional, and global climate patterns shows the climate is changing with time. There are two main information sources: observed changes in climate and projected changes on climate. Academics and researchers have conducted several studies on patterns that can be seen by analysing historical meteorological data, and the results show that Sri Lanka's climate is gradually changing. Trends in temperature, shifts in precipitation patterns, SLR and data on extreme events drew the most interest from researchers and provide good evidence for climate change. The temperature of the atmosphere appears to be steadily increasing almost everywhere in the world, according to proof. Also, most of the studies show that intensities of the rainfall have increased together with the increased duration of dry spells. The strong year-to-year variability of Sri Lanka's rainfall is a notable feature. However, there has been no discernible trend of transition. Rainfall varies even less in the lowlands than in the highlands. However, these all studies about climate pattern cover whole countries topography. There can be found few studies on trends of climate change that are specific to the coastal region which is an indication of a new research area to explore.

Evaluating three aspects of hazard, vulnerability and exposure (IPCC, 2018) one can find enough evidence to assume that Sri Lanka faces a considerable risk from climate change-related impacts and disasters. The major climate change driven physical impacts includes inundation, storm surge flooding, coastal erosion, saltwater intrusion, rising water tables, and changes in coastal ecosystems. Few scholars have stressed out that north, south and south-west coastal areas in Sri Lanka could be inundated due to SLR. The effects of inundation would include the destruction of homes, agricultural lands, and ecosystem services available to people and communities residing in these areas. Coastal habitats, including estuaries, lagoons, mangroves, salt marshes, beaches, sand dunes, coral reefs, sea grass beds, deltas, islands, barrier beaches and spits will be adversely affected. The flora and fauna living in these environments will face existential risks. Sri Lanka is a hot spot of biodiversity and the loss of eco-systems and species will be a loss both to both the national and international community. The saltwater intrusion into estuaries and river mouths could cause changes in those ecosystems. In addition, this could render agricultural land further inland uncultivable. The loss and abandonment of agricultural lands in the coastal areas of Sri Lanka are already happening. Fisheries resources will also dwindle due to the destruction of habitat and acidification of oceans. This can cause livelihood and employment loss and thereby increase the poverty levels of people. Human health is also predicted to deteriorate, with the increased spread of vector and water-borne diseases such as dengue, decreased nutrition and food security, reduced availability and increased disruption of health services, reduced water quality and availability and difficulty maintaining sanitation and practices.

Hazards could cause direct loss of lives, property and infrastructure failure, leaving cities towns and villages unable to cope. They can also cause massive losses to businesses. Climate change is one of the main reasons which leads into human mobility in Sri Lanka. It is predicted that many will have to relocate houses and businesses completely in the face of rising sea and increasing hazards. There can be resource scarcities such as scarcities in arable land, water and even food. Societal and communal relations will be stressed due to the stresses of disasters, losses and relocation. Some scholars have even predicted the resurgence of civil conflict in Sri Lanka due to climate change. Sri Lanka is a developing country that has emerged from a thirty-year civil war, with much loss of life and many people still living in dire socio-economic conditions. It is questionable whether the country and people would be able to bear the strain of more conflicts. However, it can be mentioned that the signing of key international tools has had a major impact on the governing and institutional structures in Sri Lanka, namely; the United Nations Framework Conversation on Climate Change (UNFCCC) and the Paris Agreement on Climate Change. Under the UNFCCC agreement, Sri Lanka formulated its first National Adaptation Plan for Climate Change 2016-2025. The plan is based on the concepts of mainstreaming adaptation to national development, integration of sectoral and cross-cutting national dimensions, adaptive policy and management and anticipatory adaptation. Sri Lanka has also set up several national governing bodies to makes sure these adaptation goals are formulated, implemented and achieved. Much attention has been directed to coastal conservation as well, especially through the Department of Coast Conservation and Coastal Resource Management.

The built environment has been said to be directly interrelated to social capital and social cohesion by scholars. Hence the wellbeing of a society depends upon the existence and efficiency of proper infrastructure. Climate change and related hazards can destroy, damage and inundate coastal built environment. In fact, infrastructure has been damaged by climate change associated extreme event over past recent years. The impact on Sri Lanka will be much worsened because much of the urban cities including the capital city of Colombo located along the coast which is at risk from SLR and hazard situations. The rising trend of temperatures and rainfall extremes with high intensity and frequent rainfall causing flash floods has already become a frequent phenomenon in urban areas. Unsustainable urbanization in conjunction with climatic has made urban residents vulnerable to hazards, especially the urban poor. Climate change is predicted to impact different cities and districts differently depending on factors such as geographical factors, socio-economic and cultural factors and the availability of resources. Hence context-specific, sustainable solutions have become an urgent necessity. Much research has undergone to investigate the climate change impacts, assessing risk, vulnerability and exposure of the infrastructure globally. However, these studies ignore the underline systemic behaviour of the infrastructures. Recent catastrophic events emphasise how these interdependencies and interconnected nature of the infrastructure turned into catastrophes through cascading impacts. Many scholars have attempted to capture the systemic nature within the infrastructure applying system thinking and many modelling and simulation techniques such as agent-based modelling, system dynamics, Complex network theory, etc. However, such studies cannot be found locally. Many infrastructures lie within the coastal belt in Sri Lanka. Therefore, it is obvious that climate change and associated extremes have a significant impact on those infrastructures and disruption of one of those infrastructure sectors could have a significant impact on other infrastructure through cascading links. Furthermore, these complexities within the infrastructure sectors exacerbate the impacts to society and the economy country as they are primary resources and structures which are essential to the social and economic wellbeing and effective functioning of the communities. Identification of impacts would be the first step to build resilience within those systems. This report explains how climate change affected the infrastructure systems by reviewing studies that are carried out at the global level. Also, few studies have shown vulnerabilities of the local infrastructures to climate change-related scenarios and those studies indicates most of the infrastructure sectors within the coastal belt zone are vulnerable to SLR, floods associated with storm surges and drought. In addition to that, Climate change-driven changes of the ecosystem could have multiple impacts on the building: the impact on building structures, building construction, materials and indoor climate. Also, the building sector is contributing to climate change through the emission of GHG. Hence at present scholars, professionals have been moved to investigate the more sustainable material and thereby reduced the carbon footprint of the buildings. But with the other major emitters, the climate is going to change dramatically. Sri Lanka has been experiencing climate change-related hazards during the past few decades. With the increase of frequencies and severity of extreme events, the building sector specially, residential houses damaged severely from the disasters that are associated with climate change since they are lack resilience to climate change. Specially, with the SLR most of the buildings within the coastal belt will be inundated. Furthermore, building materials which can be considered as a vital component of the buildings, are subjected to progressive depletion over time causing higher maintenance and repairing cost. On the other hand, building an indoor climate highly depend on the outdoor environment. With the increase of the temperature in a tropical country, building's cooling loading will increase progressively. Hence climate change is affecting building's energy demand. Overall, this could have a severe impact on the life cycle of the buildings. Hence, building codes, regulations and guidelines need to be upgraded concerning future climate change thereby building resilience. However, there can be found few studies in the local context in investigating climate change impact on the building. Hence it is required more attention to investigate the climate change impact on the built environment considering complexities within it. Moreover, this will enable practitioners to make risk-informed decision making in the design, construction and operation phases of buildings and infrastructures.

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