EVIDENCE OF CLIMATE CHANGE IMPACTS IN SRI LANKA - A REVIEW OF LITERATURE

Sri Lanka Journal of Economic Research
Volume 11(2) March 2024
SLJER 11.02.04: pp. 69-94
Sri Lanka Forum of University Economists
DOI: https://doi.org/10.4038/sljer.v11i2.205

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Abstract

Sri Lanka is vulnerable to the impacts of climate change due to its geographic location, size, and socio-economic conditions. The country is exposed to a range of climate hazards including floods, landslides, droughts, cyclones, and sea-level rise. Therefore, numerous studies have been conducted to assess the island's vulnerability to climate change and its unprecedented consequences. These consequences are in a slow or rapid-onset nature. Sri Lanka also has a substantial policy context to build resilience and enhance the adaptability of vulnerable communities. Therefore, the literature plays an important role in formulating climate change policies as it provides a wealth of knowledge and insights into the impacts of climate change on human society and the environment. However, the literature is currently scattered, and no single source aggregates such scattered literature. Hence, this article reviews the climate change related literature in Sri Lanka, summarizes, and organises to assist future studies concerning the climate change context in Sri Lanka.

JEL: *Q54, Q56, Q58*

Keywords: *Climate Change, Climate Change Impacts, Climate-Induced Vulnerabilities, Sri Lanka*

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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, 2012, p. 557). Changes in climate can be caused by natural internal processes, external forcings, or persistent anthropogenic changes in atmospheric composition or land use. Changes in temperature and weather patterns throughout time are referred to as climate change (United Nations, 2021). Human activities are the primary cause of climate change, owing to the combustion of fossil fuels such as coal, oil, and gas (Nema, et al., 2012; Letcher, 2019). Fossil fuel combustion produces greenhouse gases which serve as a wrap over the earth, trapping the sun's heat and rising temperatures. As a result of increasing emissions, the earth is currently 1.1°C warmer than it was in the late 1800s and the previous ten years (2011-2020) were the hottest in recorded history (United Nations, 2021).

Intense droughts, water scarcity, devastating fires, rising sea levels, flooding, melting polar ice, catastrophic storms, and dwindling biodiversity are now among the impacts of climate change (Hitz & Smith, 2004; Tol, 2018). Human health, food production, housing, safety, and livelihoods are some of the effects of climate change (Tol, 2018). Sea-level rise and saltwater intrusion have forced entire communities for migragtion and become the cause for prolonged drought which subsiquently led people at risk of hunger (IPCC, 2020). The number of "climate refugees" is anticipated to grow significantly (World Bank, 2018). People living in small island nations and other underdeveloped countries, like Sri Lanka, are already more sensitive to climate change (IPCC, 2021). According to the 2021 INFORM Risk Index, Sri Lanka experiences a high catastrophe risk of climate-induced hazards, ranking 89th out of 191 nations (European Union, 2021).

The Climate in Sri Lanka

Sri Lanka, a tropical island, experiences minimal annual temperature variation due to its latitude, with average annual temperatures in lowland areas ranging between 26.5-28.5°C (Department of Meteorology Sri Lanka, 2019). However, regional temperatures vary significantly with altitude. Despite the lack of high seasonal temperature variation, local climates are primarily influenced by precipitation differences. The country has been warmed by approximately 0.8°C over the twentieth century, positioning it among the world's hottest countries (Carbon Brief, 2018). Rainfall varies widely, from 900 mm in the driest regions to 5000 mm in the wettest, largely due to monsoonal patterns influenced by El Niño and La Niña events, which affect monsoon cycle of the Indian Ocean and subsequently, precipitation and temperature of Sri Lanka (Department of Meteorology Sri Lanka, 2019; Alahacoon & Edirisinghe, 2021).

The climate zones of Sri Lanka are categorized into wet, intermediate, and dry zones, with rainfall distribution significantly influenced by monsoonal seasons. Climate change impacts in Sri Lanka include temperature increases across the island, altered precipitation patterns, rising sea levels, and more frequent extreme weather events. Temperature records indicate a faster warming trend, with rising of nighttime temperatures more significantly than daytime. Precipitation changes are less clear, with some studies indicating a decline in average rainfall but increased variability and more prolonged dry periods, leading to intensified droughts and extreme weather events.

Projected climate changes for Sri Lanka suggest increasing temperatures throughout the twenty-first century, with variations in the magnitude of temperature increase depending on the study. General Circulation Models (GCMs), Regional Climate Models (RCMs), and statistically downscaled GCM projections indicate a warmer future for Sri Lanka, with differences in temperature increases across scenarios (Cruz, et al., 2007; De Silva, 2006; Kumar, et al., 2006; Basnayake, et al., 2004; Thevakaran, et al., 2017). Rainfall projections are mixed, with some models predicting higher mean annual precipitation but differing on seasonal distribution changes. Overall, climate change poses a significant challenge for Sri Lanka, necessitating updated national policies and strategies to address its impacts effectively.

METHODOLOGY

The underlying review followed a non-systematic literature review on climate change and climate change-induced events in Sri Lanka. A non-systematic literature review, also known as a traditional or narrative literature review, is a qualitative method of reviewing literature that does not follow a structured process (Ferrari, 2015). Instead, it involves a comprehensive and critical review of relevant literature on a specific topic or research question based on the researcher's expertise and judgment.

The first step in conducting the non-systematic literature review was to define the research question or topic. In addition, next step was to conduct a comprehensive literature search to identify relevant sources of information. This was done using academic databases, online search engines, reference lists, and other sources. Then, the most relevant sources were screened and selected based on their relevance to the research question or topic. This involved reading abstracts, titles, and keywords to determine relevancy of the source. After selecting the relevant sources, the most relevant information to the research question or topic was extracted and summarized. This involved reading the sources in detail and taking notes on key points, arguments, and evidence. Once, the information is extracted and summarized, the researcher analyses and synthesises the information to identify patterns, themes, and gaps in the literature. This involved comparing and contrasting the findings of different sources and drawing conclusions based on the evidence. Hence, a series of journal articles, international research reports, and source materials were reviewed to generate the knowledge outcomes of this paper.

Impacts of Climate Change / Loss and Damages

Sri Lanka is extremely susceptible to climate change due to its high temperatures, unique and complicated hydrological regime, and susceptibility to catastrophic climate events

(World Bank Group, 2020). The Ministry of Environment (MOE) submitted its Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) in 2012, highlighting critical vulnerabilities in the agriculture and water resources sectors and substantial risk to human health and coastal regions (MOE, 2011). The identified risks and vulnerabilities are discussed under section 1.2.3, emphasising livelihoods and human settlements. Sri Lanka has an increased risk of tsunamis, cyclones and floods including riverine and flash flooding, while drought is a moderate threat. Nevertheless, heatwaves, droughts, floods, cyclones, and coastal erosion are significant natural hazards induced by direct and indirect consequences of climate change that profoundly impact agriculture, livestock, fishery, and other sectors of the country. The overall impacts of climate change fall under three broader categories; rapid impacts, slow onset impacts, and extreme weather events.

Rapid-Onset Events

Rapid-onset climate change events refer to sudden and extreme climate events that severely impact on society and the environment (IPCC, 2012, p. 556). These events can occur over a relatively short period, ranging from hours to weeks, and are often associated with extreme weather phenomena, such as cyclones, landslides, floods, and extreme temperatures.

Floods

Sri Lanka comprises 103 river basins with five major rivers (Mahaweli, Kelani, Kalu, Gin, and Nilwala) flowing across the country and is responsible for yearly floods (Surasinghe, et al., 2019). According to Dasandara et al. (2022), multiple types of flooding are prominent in Sri Lanka. River flooding, flash (or pluvial) flooding, and coastal flooding are the three main types of flood events. Floods have known strong links with other vulnerabilities such as landslides and disease transmission, in addition to their direct repercussions, deaths, injuries, and property damages. Major floods occurred in Sri Lanka in 1907, 1913, 1940, 1947, 1957, 1967, 1968, 1978, 1989, 1992, 2003, and 2017 resulting in significant human casualties (Wickramaratne, et al., 2012; MONPEA, 2017). For instance, the floods of May 2017 wreaked havoc on towns, villages, and agricultural areas along the riverbanks of the Kalu, Nilwala, and Gin rivers, as well as their tributaries. Water levels in certain regions rose to 6 meters and stayed there for 4 to 10 days, damaging urban and rural houses, small and medium businesses, micro (mainly informal) businesses, education and health facilities, as well as governmental and private infrastructure (MONPEA, 2017). Floods in 2017 underlined the growing impact of climate-related catastrophes in Sri Lanka which is compounded by unplanned human development. Floods afflicted 64 percent of Sri Lanka's population between 2005 and 2015 (MONPEA, 2017). Since 2011, high-impact disasters have occurred regularly, yearly affecting an average of over 1 million people. According to the United Nations Office for Disaster Risk Reduction (UNDRR), floods are the primary cause of Sri Lanka's annual disaster-related losses, averaging USD 140 million (World Bank Group, 2020). These impacts are projected to rise due to development and climate change (MONPEA, 2017; World Bank Group, 2020). The situation is anticipated to raise the annual number of vulnerable people by 26,000 persons and the yearly GDP by USD 338 million by the 2030s (World Bank Group, 2020). Table 1. exhibits the estimated number of people impacted by extreme river flooding in Sri Lanka from 1971 to 2004 and in the future from 2035 to 2044.

Table 1: Estimated Number of People Impacted by Extreme River Flooding in Sri Lanka from 1971 to 2004 and in The Future from 2035 to 2044

Estimate	Population Exposed to Extreme Flood (1971–2004)	Population Exposed to Extreme Flood (2035–2044)	Increase in Affected Population
16.7 Per centile	385,942	943,081	557,139
Median	930,866	1,111,418	180,552
83.3 Per centile	1,105,180	1,179,366	74,186

Source: World Bank Group (2020)

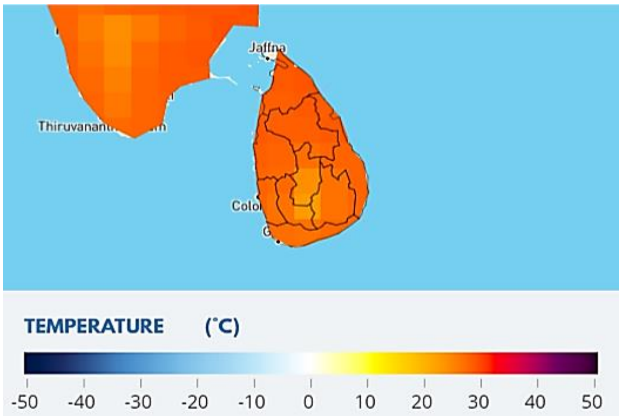
Landslides

In Sri Lanka, intense rainfall frequently triggers flash floods and landslides, causing significant loss of life, livelihoods, and infrastructure damage (Perera, et al., 2018). Approximately 20% of the nation's territory is susceptible to landslides, ranking them as the third most prevalent hazard following floods and droughts (Wickramaratne, et al., 2012). The late twentieth and early twenty-first centuries have seen an increased risk of landslides, attributed to shifts towards more severe extreme precipitation events (Ratnayake & Herath, 2005). Notably, in May 2017, Sri Lanka experienced 35 major landslides, marking the highest disaster-related fatality count for that year, with 176 deaths out of 219 reported (MONPEA, 2017). Early December 2019 witnessed significant rainfall across the island due to strong north-east monsoon conditions, particularly affecting the Northern, Eastern, North-Central, Uva, Central provinces, and Hambantota district. This led to floods and landslides in 13 districts, with Anuradhapura, Badulla, Batticaloa, Polonnaruwa, and Puttalam being the hardest hit (IFRC, 2020). According to the Disaster Management Centre (DMC) situation report as of 23 December 2019, the events impacted 65,316 individuals (19,072 households), resulting in two fatalities, one missing person, 62 completely destroyed dwellings, and 1,463 partially damaged houses. Additionally, 17,776 individuals (5,277 households) were relocated to 133 secure locations (DMC, 2019). The onset of the Southwest Monsoon (SWM) season and a tropical storm, later named "Tauktae," in the southeast Arabian Sea brought substantial rainfall to the western and southwestern regions of Sri Lanka (IFRC, 2021). The Department of Meteorology (DOM) reported 336 mm of rainfall in the Western province (IFRC, 2021). Several districts, including Colombo, Gampaha, Galle, Kegalle, and Nuwara Eliya, faced floods and landslides due to the heavy rains and winds. On 5 June 2021, the DMC updated that 15 individuals had perished, two were missing, and 995 homes were either completely or partially damaged, affecting 271,110 individuals from 67,613 households. Furthermore, 6,177 families (26,806 people) were evacuated to 106 safe centres/shelters (DMC, 2021). These events have severely affected the livelihoods of the most vulnerable communities, further exacerbated by the concurrent COVID-19 lockdown (IFRC, 2021). Hence, while future average rainfall projections remain uncertain, there is an expectation that the frequency of extreme rainfall events, both daily and sub-daily, will increase, potentially elevating the risk of landslides.

Extreme Temperatures

A heatwave (excessive heat) is a prolonged period of unusually warm temperatures (IPCC, 2012, p. 2). Heatwaves are anticipated to become more prevalent, prolonged and more severe in locations where they already appeared as the earth's climate warms as a whole (Meehl & Tebaldi, 2004). Since Sri Lanka is closer to the equator, the country poses a higher risk of heatwaves than those further away (Alahakoon, et al., 2022).

Figure 1: Climatology of Average Mean-Temperature 1991-2020 in Sri Lanka



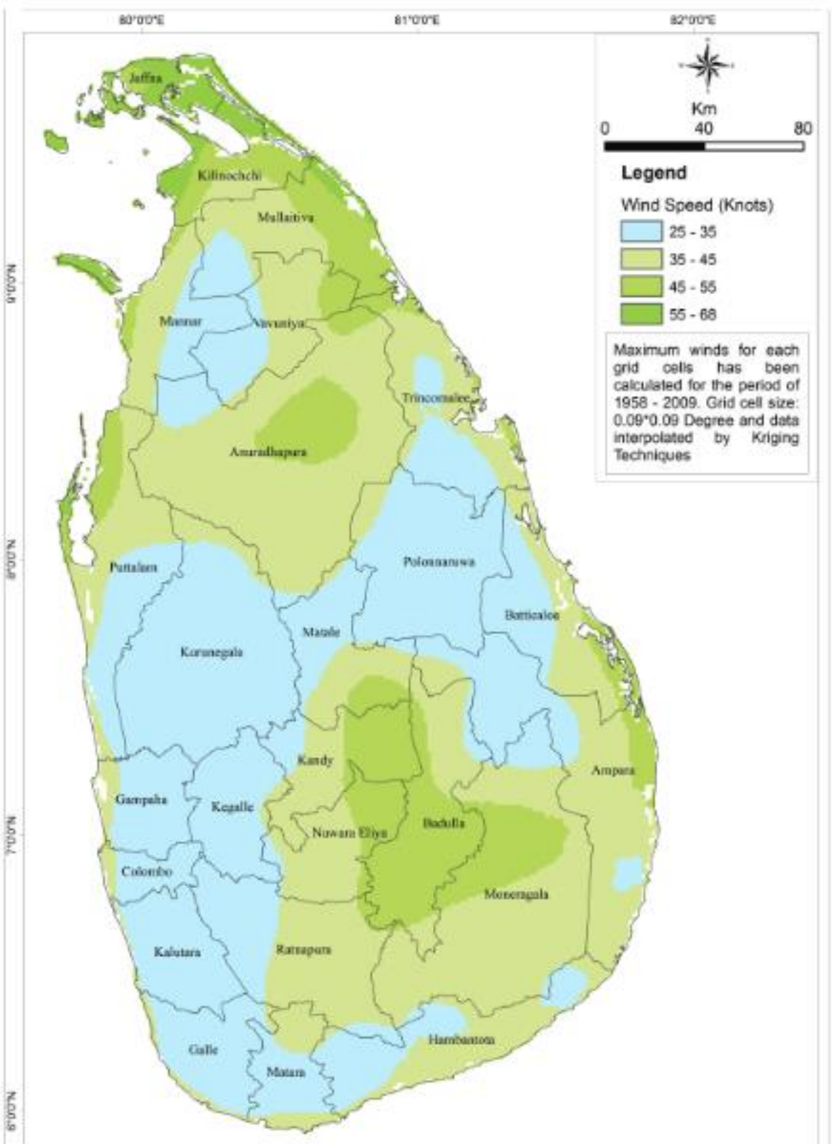
Source: World Bank Group (2021)

Average monthly maximum temperatures hover around 30°C in Sri Lanka with a maximum average temperature of 32°C (See Figure 1). IWMI estimates that between 2001 and 2013, 23 percent of Sri Lanka's population was exposed to dangerous heatwaves (Amarnath, et al., 2017). For instance, northern Sri Lanka has been identified as a hotspot for extreme heat events (Amarnath, et al., 2017).

Cyclones

Sri Lanka also faces significant risks from severe and unpredictable weather phenomena such as cyclones. These events have jeopardized livelihoods, and in some instances, have led to fatalities and extensive property damage (Kafle, 2017). The influence of climate change on cyclone risks presents a complex challenge that remains largely unexplored (Leonard, et al., 2014). Anticipated risks include the amplification of damage from cyclone-induced storm surges due to sea-level rise, alongside an increase in wind speed and rainfall intensity (Srisangeerthanan, 2015). Despite historical data suggesting a decrease in cyclone frequency in Sri Lanka during the twentieth century, research by Balaguru et al. (2014) indicates a significant rise in the intensity of tropical cyclone activity in the Bay of Bengal between 1981 and 2010. This trend underscores the critical need for enhanced disaster risk reduction measures to mitigate the evolving threats posed by climate change.

Figure 2: Maximum Sustained Wind Speed Map When a Tropical Cyclone Crossed Over Vicinity of Sri Lanka



Source: DOM (2017)

Figure 2 exhibits the maximum sustained wind speed map when a tropical cyclone crossed over the vicinity of Sri Lanka.

Current data categorizes cyclone risk in Sri Lanka as significantly high (Global Facility for Disaster Reduction and Recovery (GFDRR), 2021), indicating a probability exceeding 20 percent for the occurrence of potentially destructive wind speeds within the next decade. Cyclone 'Roanu' in 2016 marked a significant unprecedented event, delivering the highest recorded rainfall the country had witnessed in over 18 years which led to extensive flooding across 24 of the 25 districts, affecting an area spanning 1,400 kilometers (Alahacoon & Edirisinghe, 2021). The aftermath saw over half a million people affected, with damages and financial losses surpassing USD 600 million (UNDRR, 2019). The UNDRR (2019) reports highlight that the Kelani River basin and landslides in Aranayake bore the brunt of the devastation, with housing, land, and settlements comprising 53.5 percent of the total impact. Meanwhile, the sectors of industry, commerce, agriculture, and fisheries collectively accounted for 33 percent of the damages (MONPEA & MODM, 2016). The following year, Cyclone 'Mora' inflicted severe flooding and landslides across fifteen southern districts, significantly disrupting the agricultural sector, including tea, rubber, and coconut plantations, and causing extensive damage to paddy fields and infrastructure (MONPEA, 2017). The economic toll of these floods and landslides in 2017 was estimated to exceed USD 415.5 million, after adjusting for inflation (UNDRR, 2019). More recently, Tropical Storm BUREVI hit the northern tip of Sri Lanka on December 2, 2020, with winds reaching up to 74 km/h, leading to widespread flooding and affecting 44,848 people across 13,368 households (Asian Disaster Reduction Centre (ADRC), 2020).

Slow Onset Events

Slow onset events of climate change refer to gradual changes in climate conditions that occur over a longer period, typically decades or even centuries, and significantly impact human societies and the environment (IPCC, 2012, p. 556). These events are often associated with changes in temperature, precipitation patterns, sea-level rise, and ocean acidification (Tosun & Howlett, 2021).

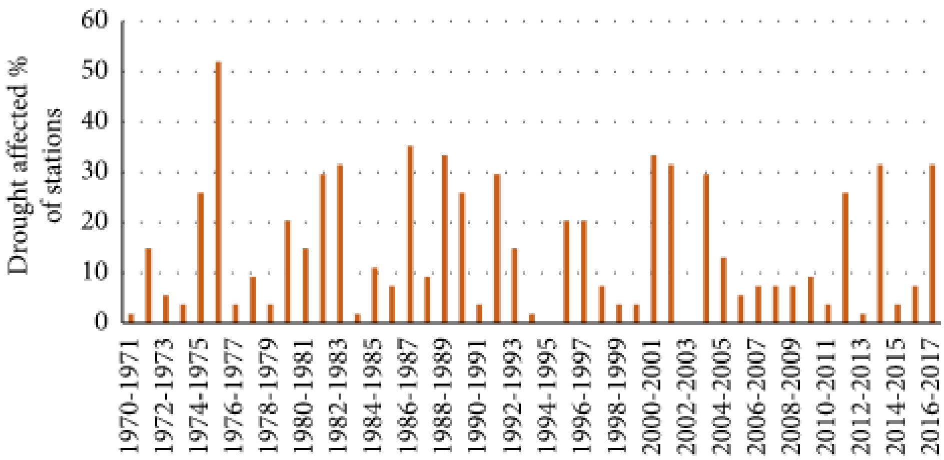
Drought

Climate change significantly impacts precipitation patterns in Sri Lanka, leading to recurrent drought conditions characterized by reduced rainfall (Ampitiyawatta & Guo, 2009; Eriyagama, et al., 2010). Positioned near the equator, Sri Lanka is exposed to abundant sunlight, contributing to high rates of evapotranspiration and exacerbating drought conditions (Niranjan, et al., 2014; Alahakoon, et al., 2022). Droughts in Sri Lanka manifest in two primary forms: meteorological and hydrological. Meteorological droughts stem from prolonged periods of insufficient precipitation, while hydrological droughts result from reduced water flow in surface and subsurface water sources, affecting the region's river basins (Edirisinghe, et al., 2021; Wickramasuriya, et al., 2020).

The country faces an annual risk of experiencing extreme meteorological droughts, with a Standardised Precipitation Evaporation Index (SPEI) of less than –2, indicating a 4 percent likelihood each year (World Bank Group, 2020).

Drought represents a critical vulnerability in Sri Lanka, significantly impacting individuals and necessitating substantial relief efforts (see figure 3). The nation serves as a pivotal case study for understanding drought hazards and risk assessments in tropical regions (Lyon, et al., 2009). Historical records highlight severe droughts in the years 1965, 1982, 1992, 1996, and 2001, with the 1965 and 1982 droughts alone affecting over half a million people (Ariyabandu & Hulangamuwa, 2002). The 2001 drought particularly devastated the dry and intermediate zones, including the Hambantota area, leading to widespread water scarcity and reduced agricultural yields (Manesha, et al., 2015). Between 2001 and 2013, an estimated 10 percent of the population experienced drought conditions, highlighting the significant impact on the nation's livelihoods and economy. The reduced rainfall in Sri Lanka's driest districts, such as Mannar and Hambantota, has led to crop failures and a lack of drinking water, further emphasizing the critical need for effective drought management strategies (Naveendrakumar, et al., 2018). The prolonged drought of 2001-2002 notably reduced the country's GDP growth rate by 1 percent, primarily affecting hydropower generation and the agricultural sector, and underscoring the economic implications of drought (Lyon, et al., 2009). This historical data and ongoing risk assessments call for enhanced resilience and adaptive measures to mitigate the impacts of drought in Sri Lanka.

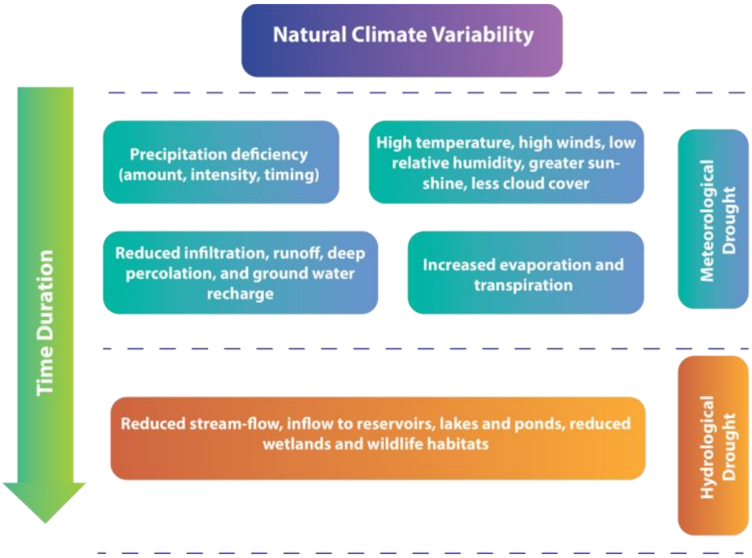
Figure 3: No. of Meteorological Stations (%) Showing Drought Events in Each Hydrological Year (1970 to 2017)



Source: Abeysingha and Rajapaksha (2020)

From October 2016 to October 2017, drought conditions expanded and intensified. North Western, North Central, Northern, and South Eastern provinces which rely largely on agriculture, were the most hit (CFE-DM, 2021). The DMC recorded approximately 266,707 drought-affected individuals across 11 districts as of 16 April 2020 (DMC, 2020). Between March and May 2020, the number of persons impacted by drought allegedly increased from 39,801 in four districts to over 500,000 in 14 districts across eight provinces (Reliefweb, 2020). Figure 4 exhibits the sequence of drought occurrence for commonly accepted drought types.

Figure 4: Sequence of Drought Occurrence for Commonly Accepted Drought



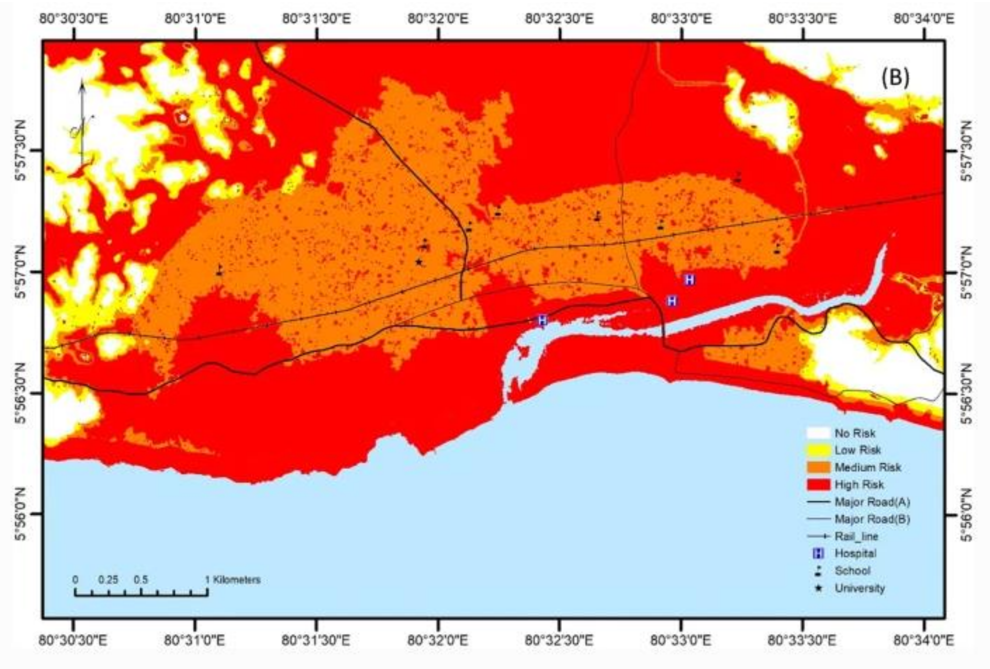
Source: MOE (2020)

Drought is at the forefront of disasters that add to the expense of maintaining national healthcare (CFE-DM, 2021). The yearly healthcare expenses linked with floods and droughts are expected to be USD 52.8 million with droughts accounting for 78 percent of the costs (De Alwis & Noy, 2019).

Sea Level Rise

A significant physical effect of climate change is the rise in sea level (Nianthi & Shaw, 2015). Sri Lanka has been highlighted as having an exceptionally high sensitivity to the combined effects of storm surge and sea-level rise (Dasgupta, et al., 2011). Storm surge-induced coastal flooding exposes a comparatively large number of people in Sri Lanka (Climate Change Secretariat of Sri Lanka, 2016). Around 25 percent population of Sri Lanka's lives within one kilometre (0.6 miles) of the shore in regions vulnerable to future sea level rise (CFE-DM, 2021). However, the number of individuals who will be permanently inundated by 2070–2100 is relatively small, at 66,000 people, if no adaptation measures are taken (World Bank Group, 2020). Approximately 230,000–400,000 people are expected to live on floodplains by the 2030s and 400,000–500,000 by the 2060s (Neumann, et al., 2015). Sea level rise is estimated to be 10 centimetres (cm) for 2030 and 21 centimetres for 2060 (World Bank Group, 2020).

Figure 5: Sea Level Rise Risk of Matara Municipal Area (Projected)



Source: Palamakumbure, et al. (2020)

Sea level rise poses several detrimental impacts on human settlements, accessibility to drinking water, crop cultivation, livestock, fisheries, and tourism sectors (Nianthi & Shaw, 2015; MOE, 2021). Inundation of land, saltwater intrusion, and increasing frequency of storm surges along the coastal strip are the primary risks linked with sea level rise on human communities (Gopalakrishnan & Kumar, 2020). Land, settlements and coastal infrastructures such as housing, roads and tourism infrastructure, may be impacted, resulting in significant asset loss/damage, economic disruption and threats to the physical and social well-being of coastal communities, especially since the coastal zone accounts for about 43 percent of the country's GDP (MOE, 2011; Gopalakrishnan & Kumar, 2020). Saltwater intrusion will limit the supply of freshwater for drinking and agriculture, jeopardising the survival of coastal communities as well as certain downstream human populations (including metropolitan centres) well beyond the coastal zone (Nianthi & Shaw, 2015). Sea level rise and storm surges might harm livestock along the country's coastal belt, causing floods and limiting access to water owing to salt intrusion (Marambe, et al., 2015; Marambe, et al., 2015; Eeswaran, 2018; Wickramasinghe, et al., 2021).

Nearly 20 percent of the island's Class A and B roads, as well as 33.3 percent of its railways, are located in the coastline zone (that is, District Secretariat Divisions with a coastal boundary) (MOE, 2011). The infrastructure in this area is particularly vulnerable to rising sea levels zone (Nianthi & Shaw, 2015). Coastal erosion has already made some damage to railway lines running from Colombo to the south (Rabbani, et al., 2010). Rising sea levels and more frequent and powerful storm surges may have an impact on harbours and ports and also, the services they provide (MOE, 2021). The transport sector is most vulnerable to the effects of climate change on sea-level rise in the island's northern and southern coastal regions (Gopalakrishnan & Kumar, 2020; MOE, 2021).

The tourism sector in the coastal region would be particularly vulnerable to the hazards of rising sea levels, storm surges, and coastal floods (Nianthi & Shaw, 2015). Tourist hotels are clustered near the shore in certain regions, where setbacks may not be sufficient to meet sea level rise or are not strictly enforced to assure storm and hurricane safety (Buultjens, et al., 2018). The tourist industry’s vulnerability is centred along Colombo's western and south western coasts, reflecting the concentration of tourism activity in these locations (MOE, 2011). According to the MOE's climate vulnerability assessment conducted in 2011, drinking water in the north west and south west appears to be the most vulnerable to rising sea levels. In addition, the loss or alteration of coastal ecosystems and species distribution are among the possible hazards of sea-level rise on fisheries. For example, landward migration of coastal wetlands would result in losing freshwater and brackish water habitats vital for coastal and marine fisheries (such as mangroves and coral reefs). Due to beach accessibility difficulties, the loss of beach lands will impact coastal populations such as those who rely on marine fishing. The inland and brackish water fisheries sector's vulnerability to sea level rise is highest in the Puttalam District with a pocket of low vulnerability in the Hambantota District (MOE, 2011).

Physical Effects and Impacts of Climate Change

This section presents the physical effects and impacts of climate change on agriculture, food security, human settlements, and infrastructure.

Impacts on Agriculture and Food Security

Sri Lanka is presently rated 66th out of 113 countries on the Global Food Security Index (2019) with the FAO estimating that 4.1 million people (more than a quarter of the population) lack access to adequate food to live healthy lives (MOE, 2021). Agriculture accounts for around 8 percent of GDP and approximately 21 percent of export revenues (in 2020) (CBSL, 2020). Food security, livelihoods, and export income are already being threatened by climate change. Climate change-induced alterations in prevailing precipitation patterns, rising ambient temperatures, and extreme weather events have unprecedented impacts on the domestic agricultural sector and food security (Esham, et al., 2018). Rainfall periodicity is the most crucial factor determining when the food crops have been grown in Sri Lanka. Since most plantation crops (tea, rubber, coconut, and oil palm) are perennials grown in wetland areas, the seasonality of rainfall is not a concern (Esham & Garforth, 2013). Nevertheless, the food crops subsector primarily comprises seasonal crops that necessitate planning all farming operations around seasonal rainfall availability (Marambe, et al., 2015).

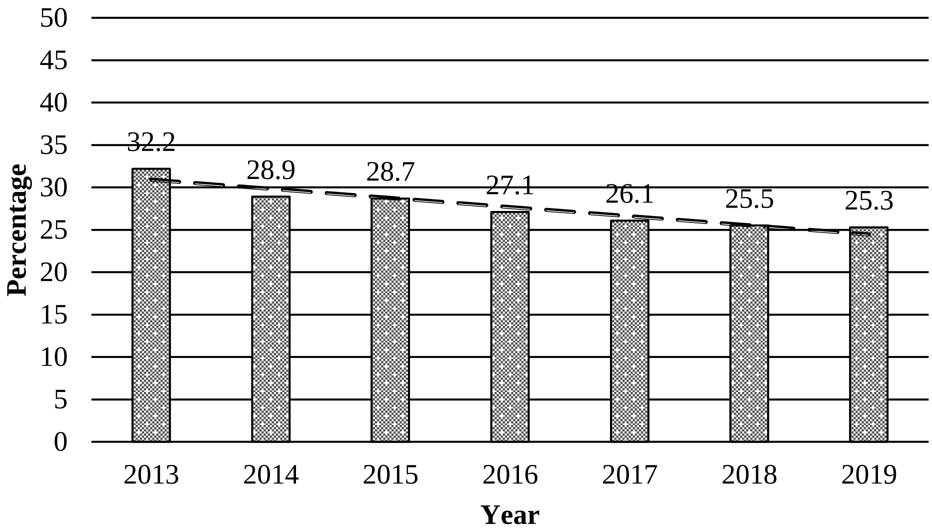
Erratic changes in established rainfall patterns affect the flowering of crops while minimising the pasture availability for livestock (Giridhar & Samireddypalle, 2015). Frequent incidents of intense rainfall with high cloud cover and increased frequency and severity of floods lead to drainage and waterlogging problems, increased soil erosion, and increased susceptibility of crops and livestock to flood hazards. Floods impacted more than one million farmers in 2016 and 2017 (MOE, 2021). Such effects are expected to reduce crop, livestock and fishery productivity. In 2019, the contribution of the livestock industry to GDP was about 1 percent (CBSL, 2020). In addition, the frequency of extreme weather events like cyclones and heavy winds is likely to rise with climate change (Mirza, 2011). Therefore, it would reduce maritime fish yields while damaging inland crop cultivations and livestock holdings (Thadshayini, et al., 2020). The marine and coastal fisheries account for 80 percent of the fish harvest, 2.4 million direct and indirect jobs, and 70 percent of the population's animal protein intake (MOE, 2021). On the other hand, the livelihoods based on coastal habitats are adversely affected by the climate change-induced losses (Gopalakrishnan & Kumar, 2020). For instance, climate change stimulated ocean acidification and physiochemical changes in oceanic environments, damaged coral reefs and accelerated structural changes within marine habitats and species composition (MOE, 2021). High sea surface temperatures (3-5° C above normal) during the 1998 El Niño destroyed coral reefs in the Bar Reef marine reserve (95 %), Hikkaduwa marine sanctuary (90 %), Weligama (60 %), and Rumassala marine sanctuary (80 %) (MOE, 2021). As a result, the reef fish stock and the stock of economically important species change inflicting detrimental consequences on fishers' livelihoods. In a recent evaluation in Sri Lanka, shrimp aquaculture on the north-west coast was determined to be particularly susceptible to the impacts of climate change (MOE, 2021). Changes in temperature, droughts, precipitation, run-off and floods on freshwater ecosystems pose a hazard to inland fisheries (Pushpalatha, 2022). Reduced rainfall during the NEM would exacerbate the threat to inland fisheries (Patrick, 2016).

Sri Lanka is experiencing an increasing trend in the day and night ambient temperatures (Mattssona, et al., 2015; World Bank Group, 2020). Increased day and night temperatures combined with wind speed escalate the evapotranspiration of grown crops. Further with the regular and extended dry spells and increased frequency and severity of droughts, the crops and livestock exhibit a significant susceptibility to heat stress (Marambe, et al., 2015). The phenomenon escalates the water stress on crops and animals by reducing water in reservoirs and groundwater sources (Eriyagama, et al., 2010). With high evapotranspiration levels, the soil moisture is significantly reduced while the salinity increases, minimising the soil quality. The impact of rising night-time mean temperature on rice output is substantial (Esham & Garforth, 2013). In a study conducted at the International Rice Research Institute, paddy output decreased by 10 percent in the dry season for every 18°C increase in growing season low temperature (Peng, et al., 2004). Rainfall unpredictability and decrease will have an impact on crop productivity and the cropping calendar. In Sri Lanka, shorter agricultural seasons are frequent due to the delayed onset of monsoon (Senalankadhikara & Manawadu, 2009). These impacts ultimately lead to regular crop losses and a decline in expected outputs of crops, livestock, and fishery stock in reservoirs (Marambe, et al., 2015). Notably, most of the dry zone farmers rely on water reservoirs, rainfall or agro wells for irrigation (Senaratne & Scarborough, 2011). According to government estimates, extended drought and floods in 2016 and 2017 interrupted two rice production cycles, affecting over 2 million people, limiting economic growth, and increasing food inflation (ADB, 2019). Further, the alterations of thermal ranges for biological organisms (pests, pathogens, parasites, vectors) increase the risks of pest and disease attacks on crops and livestock (Shahzad & Ullah, 2021). Hence, the costs of health management of livestock and plant protection rise for farmers and livestock holders (Gunaratne, et al., 2021). Dairy is the most significant and vulnerable to climate change (MOE, 2021). Increased sensitivity to temperature and humidity changes might result from the intensification of dairy systems in arid regions employing temperate breeds. In most sections of the Dry Zone, the Temperature Humidity Index is expected to be more than 72 units in 2030, and heat stress will be harmful to the sector if temperate breeds are utilised (MOE, 2021).

Paddy, tea, and coconut, the primary crops grown in Sri Lanka, are extremely susceptible to changes in temperature and precipitation (Peiris, et al., 2004). Tea yields in 2020 fell to a 30-year low due to persistent drought in tea-growing regions (MOE, 2021). Plantation and non-plantation agriculture will both be affected by climate change. Climate change will have a greater impact on non-plantation agriculture since the vast majority of farmers are small holders who mostly produce rice (Esham & Garforth, 2013). In the growing regions, coconut output is also sensitive to rainfall and dry spells (Peiris, et al., 2008). Changes in monsoon rainfall patterns and increases in maximum air temperature are two significant variables impacting the variability of coconut output in the major coconut-growing regions (Peiris, et al., 2004). When other external variables are not restricted, projected coconut output after 2040 will not be sufficient to meet local demand (Peiris, et al., 2004). The country's agricultural production and export earnings are supported by these paddy yields and coconut plantations that extend outside the coastal area (Savundranayagam, et al., 1994). The climate change-induced sea level rise leads to the inundation of low-lying coastal regions wherein the enhanced saltwater intrusion increases soil and water salinity while damaging coastal habitats and food systems (Gopalakrishnan & Kumar, 2020). Hence, the salinity development of coastal agricultural lands declines the agricultural productivity in coastal areas (Gopalakrishnan & Kumar, 2020). The farmlands with high salinity levels are no longer productive; hence, the extent of the arable land area is reduced in coastal regions (Marambe, et al., 2015).

Consequently, the impacts of climate change raise severe socio-economic consequences among affected communities (Menike & Arachchi, 2016). With declining agricultural outputs, productivity, arable land extent, and increased cost of production, the expected income and profitability of local farmers, livestock holders and fishers drastically reduce and, on many occasions, lead to loss of livelihood opportunities (Esham & Garforth, 2013). Loss of livelihood drives community members to seek alternative livelihood opportunities outside their communities (Esham, et al., 2018). The employed population in agriculture declined annually by an average of 1.15 percent during 2013-2019 (See Figure 6). In other words, 91,284 people yearly depart from agriculture in Sri Lanka (Samaraweera, et al., 2022).

Figure 6: Percentage of Employed Population in Agriculture (2013-2019)



Source: Department of Census and Statistics (2019)

The cumulative impacts of climate change and the subsequent decline in paddy yields are expected to fall by 12 percent to 19 percent in the Maha season and 27 percent to 41 percent in the Yala season by the 2060s (World Bank Group, 2020). In the setting of a strong local reliance on rice, this is expected to raise poverty rates by 12–26 percent. Other main crops, such as coconut, tea, and rubber are also very sensitive to temperature and precipitation fluctuation, according to Esham and Garforth (2013) with higher temperatures and times of low rainfall posing significant risks. As far as the livelihoods of fishers are concerned, coastal shelf fisheries on which many households rely, are likely to be restructured as a result of rising temperatures and ocean acidification. According to Barange et al. (2014), Sri Lanka is one of the most vulnerable countries on the planet with a projected 20 percent reduction in fish harvest owing to climate change by the 2050s (Barange, et al., 2014). In the lack of external support, farmers are adapting locally to climate impacts on their own initiative. These activities are linked to income diversification and migration in search of off-farm employment (Esham & Garforth, 2013).

Impacts on Human Settlements and Infrastructure

Outmigration in agriculture-dependent communities is anticipated to overpopulate cities throughout the world as climate risks intensify (Koubi, 2019). This might lead to the growth of unplanned, low-income communities in metropolitan areas that confront a number of risks (Satterthwaite, 2007). Human settlements and infrastructure are highly vulnerable to climate change impacts (Ye & Niyogi, 2022). A World Bank assessment of South Asia's Hotspots revealed that 87 percent of Sri Lankans live in moderate or severe hotspots (World Bank, 2018). According to an Asian Development Bank analysis, Sri Lanka's housing, roads, and relief sectors alone are estimated to lose USD 0.38 billion per year due to catastrophes over the long run (ADB, 2019). According to the same research, floods had the largest annual anticipated loss of USD 0.24 billion, followed by cyclones and strong winds (both having an AEL of USD 0.08 billion). Climate change poses two different and evident dangers to human settlements. Higher temperatures will make conditions in both urban and suburban regions around the country uninhabitable.

The increased day and night ambient temperatures, increased evaporation and evapotranspiration, increased frequency and severity of droughts and heat island effect increase the thermal stress on residents and domestic animals while accelerating deterioration of infrastructure facilities, i.e. thermal cracks (Malalgoda, et al., 2013). Droughts and dry winds accelerate the composition of dust and soil particles in the atmosphere, ultimately leading to enhanced exposure to air pollutants (De Anil, 2003). Housing and human settlements are vulnerable to drought across the island; however, they are particularly concentrated in the north-central and southern areas (MOE, 2011). A total of 871,830 people, or 33.8 percent are below the poverty line and reside in 19 District Secretariat Divisions (DSDs) in those areas with communities that are extremely vulnerable to drought (MOE, 2011). Wells are used by 67.59 percent of the population (or 148,174 households), and tube wells are used by 8.27 percent of the population (18,138 households). According to the MOE (2011), Embilipitiya (Ratnapura District), Siyambalanduwa (Moneragala District), and Kalpitiya (Puttalam District) are the three most vulnerable DSDs. Another 32 DSDs are moderately susceptible with a population of 1,494,810 people, 388,416 of whom are deprived (MOE, 2011).

The increased frequency of weather-related disasters such as floods, droughts, and landslides, is the second climate-related danger to human settlements (Edirisinghe, et al., 2021; Wickramasuriya, et al., 2020; Dasandara, et al., 2022). The erratic precipitation patterns and regular, intense rainfall incidents adversely affect drainage and sewage systems, leading to urban flash floods (Lo & Koralegedara, 2015). Furthermore, it accelerates the deterioration of infrastructure facilities (Coningham & Lucero, 2021).

Housing and human settlements appear to be most vulnerable to the predicted rise in floods in the country's western area, while modest pockets of high susceptibility can be observed elsewhere (MOE, 2021). The most susceptible DSDs are Colombo (Colombo District) and Katana (Gampaha District) (MOE, 2011). There were 113,848 dwelling units in these DSDs. The most susceptible DSD, Colombo, has the country's largest population density. Floods in the Northern, North Central, and Eastern provinces in January 2011 cost about USD 600 million in direct losses and displaced over a million people (ADB, 2019). According to the World Bank, natural disaster losses (except from tsunamis) in Sri Lanka's housing, roads, and relief sectors alone equate to 0.5 percent of GDP and 3.0 percent of total government expenditure over the long term (World Bank, 2016). Floods and landslides caused approximately USD 473 million in losses and damage in May 2016 and USD 368 million in damages and losses in May 2017 (MOE, 2021). The rebuilding requirements were predicted to be USD 960 million and USD 790 million, respectively. In 2017, the government's contingent liabilities were LKR 23.8 billion (USD 149 million), or about 1 percent of overall government spending (World Bank, 2018).

Such impacts decrease living comfort and increase the dependence on indoor living environments by reducing walkability and cyclability, especially in urban settlements (Lo & Koralegedara, 2015). Furthermore, increased ambient temperatures enhance the demand for energy and water by raising the cooling demand of residents (Ranagalage, et al., 2017). Additionally, increased frequency and severity of floods, landslides, and extreme weather events (such as cyclones, high winds, heat waves) damage housing, infrastructure, settlements, and critical social facilities (such as health, security, education, communication) (MOE, 2021). The DSDs of Walapane and Hanguranketha (both in the Nuwara Eliya District) appear to have extremely vulnerable human settlements to landslide exposure (MOE, 2011). Moreover, such impacts decline in water quality, leading to problems of supply of drinking water, increased risk to human health and sanitation and incidents of diseases, injuries, and deaths. In addition, in many locations of the country, transportation infrastructure is vulnerable to the projected rise in the frequency and intensity of floods as a result of climate change.

Positioned in the Indian Ocean, Sri Lanka has a low-lying coastal belt surrounding it. Over a third of Sri Lanka's population lives along the coast (Climate Change Secretariat of Sri Lanka, 2016). Many settlements are located along the coast and the infrastructure in such regions is relatively well-developed. Coastal settlements and infrastructure are profoundly affected by the detrimental impacts of climate change (Rabbani, Rahman, & Islam, 2010). Inundation of low-lying areas damages housing, human settlements, and nearshore infrastructure and affect sea outfalls (Palamakumbure, et al., 2020).

Further, saltwater intrusion increases salinity in water resources and increases the deterioration of structures such as concrete and steel material (Nianthi & Shaw, 2015).

Coastline economies contribute significantly to the country's economy and a large portion of the population relies on them (Savundranayagam, et al., 1994). The coastal tourism sector, structures and fisheries settlements are severely affected by rising sea levels as a slow-onset impact of climate change (Buultjens, et al., 2018). Sri Lanka's tourist industry was the country's third-largest foreign exchange earner in 2019 (CBSL, 2020). From USD 2.4 billion in 2014 to USD 4.3 billion in 2018, the sector's share in foreign exchange income has nearly quadrupled in four years (MOE, 2021). During this time, the arrival of tourists increased from 1.5 million to 2.3 million. According to the Tourism Development Authority, Sri Lanka, the sector directly employs 250,000 people and indirectly employs up to 2 million people (SLTDA, 2019) Hence, it is critical to perform in-depth research studies to monitor the effects of climate change.

CONCLUSIONS

Sri Lanka is considered highly vulnerable to the impacts of climate change due to its geographic location and its dependence on natural resources. The country is expected to experience a range of impacts from climate change including sea level rise, changes in precipitation patterns, increased frequency and intensity of extreme weather events such as floods, droughts, shifts in temperature, and weather patterns that can affect agriculture and food security.

Numerous studies have been conducted on the potential impacts of climate change in Sri Lanka. These studies have examined the impacts on various sectors including agriculture, water resources, coastal areas, health, and tourism. Changes in precipitation patterns are likely to lead to increased flooding and landslides in Sri Lanka, which can cause significant damage to infrastructure, property, and human life. Sea level rise is expected to have significant impacts on coastal areas in Sri Lanka including erosion, saltwater intrusion, and flooding. Changes in temperature and precipitation patterns can affect crop yields, food security, and the overall agricultural sector in Sri Lanka. Water availability changes can affect agricultural production and human water consumption, particularly in areas already facing water scarcity. Climate change is expected to exacerbate existing health problems in Sri Lanka including vector-borne diseases such as dengue fever and malaria. Therefore, these studies highlight the urgent need for Sri Lanka to develop and implement effective adaptation strategies to address the impacts of climate change. This may include measures such as improved water management, coastal protection, and diversification of agricultural practices.

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