ASSESSMENT OF CLIMATE CHANGE WITH SPECIAL REFERENCE TO THE MAGNITUDE AND TEMPORAL VARIABILITY OF THE EXTREME CLIMATE EVENTS ACROSS SRI LANKA

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgment any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

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ABSTRACT

Assessment of Climate Change with special reference to the magnitude and temporal variability of the Extreme Climate Events across Sri Lanka

Climate change has emerged as a critical global challenge, characterized by increasingly frequent and severe extreme weather events. This research focuses on the impacts of climate change on extreme rainfall events in Sri Lanka, a country highly dependent on agriculture and particularly vulnerable to climate-induced natural disasters. Recognizing the limitations of traditional methods for identifying extreme precipitation trends, this study adopts an innovative approach by integrating multiple ETCCDI indices. By combining these indices, the research provides a holistic and nuanced understanding of extreme rainfall patterns, offering valuable insights that are beneficial across sectors such as agriculture, disaster management, and climate policy.

The study addresses the evolving challenges of agricultural planning by re-demarcating Sri Lanka's Agro-Ecological Zones (AEZs). This re-demarcation incorporates a range of critical factors, including yearly catchment runoff, irrigation infrastructure, land use dynamics, and administrative boundaries. By integrating these diverse elements, the research establishes a comprehensive and adaptive zoning framework that better reflects contemporary climatic, hydrological, and socio-economic conditions. The refined AEZs aim to optimize land use, enhance agricultural productivity, and improve disaster risk management.

The findings of this study hold significant implications for climate adaptation and sustainable development. They provide actionable recommendations for targeted interventions and evidence-based policy-making, helping to build resilience among vulnerable communities and sectors. Ultimately, this research contributes to a deeper understanding of climate change impacts and offers pathways for addressing its challenges effectively.

Keywords: Climate change, Extreme precipitation, Agroecological Zones

Table of Content

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AEZ - Agro-Ecological Zones

AHP - Analytical Hierarchy Process

CDD - Consecutive Dry Days

CWD - Consecutive Wet Days

DEM - Digital Elevation Model

ETCCDI - Expert Team on Climate Change Detection and Indices

FAO - Food and Agriculture Organization

GIS - Geographic Information System

IPCC - Intergovernmental Panel on Climate Change

LULC - Land Use Land Cover

NBRO - National Building Research Organization

NDVI - Normalized Difference Vegetation Index

NDWI - Normalized Difference Water Index

PM10 - Particulate Matter with a diameter of 10 microns or less

R95p - Precipitation exceeding the 95th percentile

R99p - Precipitation exceeding the 99th percentile

RClimDex - Software for climate indices calculation

Rx1day - Maximum one-day precipitation total

Rx5day - Maximum five-day precipitation total

SDII - Simple Daily Intensity Index

SPI - Standard Precipitation Index

VTCS – Village Tank Cascade System

WMO - World Meteorological Organization

1. INTRODUCTION

1.1 Background

Climate change refers to a complex and dynamic variation in the climate system of the Earth embracing its interactions between the atmosphere, oceans, land surfaces, and living organisms(Romm, 2022). From a rather insignificantly small field of research in climatology a century ago, it has grown to become the mainstream of global environmental research today(M. Ahmed, 2020). First attempted by early twentieth-century climate studies, the concept has evolved through time and has been subsumed under global change research focusing on how transformations in the environment directly affect human life, ecosystems, and socio-economic development(Quansheng et al., 2008).

The increase in greenhouse gas emissions, essentially CO2, CH4, and N2O, lies at the core of the global warming problem. Sometimes referred to as invisible architects of global warming, these gases envelop the earth, trapping heat in the atmosphere and raising temperatures(F. P. Singh, 2017). This rise in temperature manifests a long-term trend that has deep implications. With the temperatures soaring, weather patterns seem to get destabilized, resulting in more and more hazardous extreme climatic events such as hurricanes, droughts, floods, etc. This type of change is a bad omen for world food systems, threatening millions' livelihoods and exacerbating inequalities in the world's poorest regions. This urgency is underlined by the Intergovernmental Panel on Climate Change itself, as it wants global warming to be kept at 1.5°C above preindustrial levels(IPCC, 2023). Exceeding this threshold can unleash a wave of unstoppable environmental change, from the loss of crucial ecosystems to accelerated sea-level rise and more frequent natural disasters(M. Ahmed, 2020).

As mentioned above, climate change is mainly affected by greenhouse gas emissions due to many human activities, primarily the expansion of capitalist economies of the countries and rapid population growth(Rosa et al., 2015). According to the research done by (Karousakis, 2007), approximately one-fifth of all anthropogenic greenhouse gas emissions worldwide in the 1990s were attributed to deforestation, making it a significant contribution to these emissions. The causes of deforestation are complex and vary with the relevant regions (Kissinger et al., 2012). Therefore, specific policy measures and interventions are required to mitigate those issues. Although it has been ation (REDD) is a financially viable mitigation strategy, the complexity of the factors that contribute to deforestation and the requirement for major institutional and technical capacity building in developing nations limit its effectiveness (Porrúra & Corbera, 2007). Mitigating climate change would require a multi-dimensional strategy that includes, besides technological advancement, some basic changes in the production system(Rosa et al., 2015).

Climate change has a significant impact on global weather patterns, seen and projected to cause an increase in the occurrence of extreme weather events in terms of intensity, frequency, and duration (Handmer et al., 2012; sobre Cambio Climático, 2007). It is attributed to anthropogenic greenhouse gas emissions, natural climate variability, and changes in exposure and vulnerability(Bouwer, 2018; Robinson, 2021). This is evident in the rising intensity and occurrence of heat waves, droughts, tropical cyclones, and other local disastrous weather events in the continental United States(Robinson, 2021). Although increasing exposure driven by the rise in population and capital assets accounts for the majority of losses from extreme weather today, a role for anthropogenic climate change will likely emerge as of some importance in the future(Handmer et al., 2012). These more frequent and heavier extreme events very likely stand to have the greatest impact on human and natural systems. While some uncertainties exist within model projections, the increasing trend in extremes is already clear enough to warrant stringent mitigation and adaptation strategies(Robinson, 2021).

One of the biggest challenges of climate change could be that it is truly a global problem which requires unprecedented levels of international cooperation(Xued, 2010). Countries need somehow to manage burden-sharing with burden division mainly between developed and developing nations. Understanding intricate linkages within the climate system makes mitigation strategies such as GCM deployment key(M. Ahmed, 2020). It enables scientists to model future climate scenarios and, likewise, guides policymakers in the design of sustainable strategies, among others, including switching to renewable energy sources and enhancing the efficiency of energy.

Unexpected, the global COVID-19 lockdowns demonstrated what recovery might look like for the climate(M. Ahmed, 2020). Due to reduced industries and transportation activity, Earth got a short breather and hence, visible improvements in air quality were noticed with the lowering of greenhouse gas emissions. This unplanned pause into the present serves as a wake-up call that rapid environmental recovery may well ensue if bold steps toward reducing emissions and living sustainably are firmly pursued.

Understanding the climate change affected in the South Asian region is important because Sri Lanka is located in that region. Climate change is one of the most serious threats facing South Asia which is home to more than 20% of the world’s population (A. Kumar & Saxena, 2021). The region faces numerous environmental problems such as temperature increase, rapid melting of the Himalayan glaciers, sea-level rise, and increased intensities and frequencies of extreme weather events(B. B. Singh et al., 2020). These changes most conspicuously affect vital resources such as water and agriculture and, hence, food security. Shifting monsoon patterns and declining rainfall are worrisome, as they upset traditional farming schedules and reduce crop yields, consequently heightening vulnerability to food shortages in the region(Rabbani et al., 2020).

Although South Asia contributes much to the emissions of greenhouse gases, it is also one of the regions most vulnerable to these phenomena(Cerutti et al., 2021). While there has been some progress on mitigation and adaptation, large challenges persist in terms of developing more consistent strategies and improving tracking of adaptation spending. Even though remote sensing and GIS technologies are overly integrative, offering solutions through real-time data and warnings to enhance adaptive capacity in changing conditions, the achievement of sustainable development within a climate change scenario will still require collective policy frameworks for South Asia, improved knowledge-sharing, and stronger commitments to addressing environmental challenges(A. Kumar & Saxena, 2021).

South Asia is highly vulnerable to climate change, due to its special geographical features and socio-economic conditions(Islam et al., 2009; Rhaman et al., 2022). The region faces rising sea levels, increases in the frequency and intensity of extreme weather-related events, and worsening unpredictability in monsoon patterns(B. B. Singh et al., 2020). In particular, considering its heavy dependence on agriculture and natural resources, the population of South Asia is heavily exposed to climate-related disturbances. Climate change impacts already manifest in visible declines of plant growth and agricultural productivity, thereby threatening food security and livelihoods throughout the region(Rhaman et al., 2022).

The situation is further confounded by the rapid urbanization and demographic pressures in this region, and by limited capacities to adapt to these stresses(Gopichandran & Dawson, 2016). In terms of greenhouse gas emissions, South Asian countries rank among the lowest in the world. Yet they feel climate change impacts far more disproportionately than most other regions of the world, from both an environmental and a socioeconomic perspective(Gopichandran & Dawson, 2016). Indeed, in tackling the challenges that lie ahead, enhanced regional cooperation is put forward, and improved observational networks and modeling capabilities prescribed by experts(Islam et al., 2009; B. B. Singh et al., 2020). These will be very important in understanding the impacts of climate change and in formulating appropriate mitigation and adaptation strategies for this changing environment.

Climate change is not only a regional issue, it is a global one. As a result, discussing the effects of climate change and its mitigating actions is crucial. This study will examine future projections as well as a few particular issues and potential ways to mitigate those issues.

1.2 Research Problem

Of all the global challenges, climate change has emerged at the top of the list, with its manifestation readily observable in various forms of extreme weather events. According to the Intergovernmental Panel on Climate Change(IPCC, 2023), the frequency and intensity of extreme climate events have increased in most of the land regions with adequate observational coverage. Among them, extreme rainfall events are particularly outstanding because of their huge impact on human activities and potential to cause different kinds of natural disasters(Alexander et al., 2013; Allan & Soden, 2008).

In the context of Sri Lanka, the increase in extreme rainfall events has posed a significant challenge to the socio-economic development of the country in the past few decades(Shelton & Pushpawela, 2023). The frequency and intensity have increased, hence leading to the increment of the occurrence of floods and landslide, induced natural disasters that bring devastating impacts both in urban and rural areas, as affirmed by(Alahacoon & Edirisinghe, 2021; Herath & Ratnayake, 2004). In addition to the natural disasters mentioned above, the agricultural sector, one of the drivers of the economy in Sri Lanka, has also been among the hardest hit by extreme climate events. The inconsistencies in rainfall patterns have disrupted productivity in agriculture, leading to food insecurity and economic instability (Amarasingha et al., 2021)

Previous studies conducted on extreme rainfall events in Sri Lanka used various climate indices that characterized trends over time but lacked the depth needed to understand seasonal and regional variability for those events(Jayawardena et al., 2018; Premalal et al., 2020; Thevakaran et al., 2019). Since the climatology of Sri Lanka is dominated by its four monsoonal periods, there is a dire need for further refinement of analysis in extreme precipitation events to include seasonal time frames. Second, understanding the areas disproportionately affected during these seasons will go a long way in designing mitigative efforts that target the impact of such disasters while countering manifestations within the agricultural sector.

When assessing the impact of extreme climate events on various sectors in Sri Lanka, the country's zoning systems play a crucial role. The National Land Use Policy, developed by the Land Use Policy Planning Department (LUPPD), is based on technical considerations and general principles. These principles take into account factors such as topography, climate, soil characteristics, soil erosion, forest cover, environmental concerns, and economic viability (Department of Land Use Policy Planning, 2020; Fukasawa & Munasinghe, 2022). Among the zoning systems, the agroecological zoning system is particularly significant. It demarcates land into different subdivisions based on multiple factors and is not only vital for the agricultural sector but also holds importance for numerous other sectors (C. S. De Silva et al., 2007).

Agroecological zones for Sri Lanka have been identified by the Department of Agriculture as a decision-making tool in the choice of location for agricultural investments, considering soil type, topography, and patterns of rainfall. This is an increasingly debatable point with changes in rainfall patterns over the country due to climate change(C. S. De Silva et al., 2007). Hence in continuation, this study takes the reassessment and re-demarcation of the existing AEZs of Sri Lanka with the help of the newly revised climate data, especially the extreme climate factors and some of the factors that will be relevant based on guidelines of the United Nations concerning agro-colonial zoning for (FAO, 1996b) and (John et al., 2001).

The integration of extreme rainfall analysis with agroecological zoning concepts is expected to yield more practical outcomes, enabling the application of the analyzed data across various sectors in Sri Lanka.

1.3 Significance of the Study

This study is important for several reasons. One such reason is that it fills a huge gap in the available literature regarding extreme rainfall events in Sri Lanka(Jayawardena et al., 2018; Premalal et al., 2020; Thevakaran et al., 2019) by doing an in-depth analysis of their seasonal and regional variations. Knowing how these factors vary is important in different periods with different regions helps to effective mitigation measures that decrease a community's vulnerability to floods, landslides, or other natural disasters(Herath & Ratnayake, 2004).

Another important impact of the study is on the agricultural sector in Sri Lanka. The research, against the backdrop of recent changes in rainfall patterns especially considering the extreme rainfall events, will serve to reassess the existing AEZs. This will also help gain an understanding of the most suitable areas for the various types of agricultural activities involved, thus increasing the resilience of the agricultural sector to climate change and, consequently, ensuring food security and people's livelihoods.

In this context, findings from the study will be significant to feed into policy decisions of disaster risk reduction and climate adaptation in the country of Sri Lanka. It will therefore base guided solid evidence to develop targeted interventions in which to mitigate the harsh effects of climate change on vulnerable communities by identifying regions most affected by extreme rainfall events and re-demarcating AEZs.

Finally, the research improves the global understanding of the impacts of climate change in the tropics and specifically on small island nations like Sri Lanka. Therefore, the findings from this research will be useful for other countries that share similar challenges and will help push the broad frontier of climate science and adaptation.

1.4 Aim and Objectives of the Study

Aim

With the rapid climate change of the world, understanding and answering the changes to localized environments is essential. This study tries to unveil the complex patterns of extreme rainfall events in Sri Lanka, a country whose socioeconomic face is responsible, deeply interconnected with its agricultural landscape, and vulnerable to natural disasters. It will, therefore, be in a position to identify regions most affected by these extreme rainfall events for the development of comprehensive frameworks for mitigation of negative impacts, particularly in agricultural and disaster management sectors. This will build ultimate resilience in these sectors for sustainable development under a changing climate.

Specific Objectives

Following this overall aim, the study is guided by three specific objectives. They are,

- To Assess Climate Change with Special Reference to the Temporal Variability of Extreme Rainfall Events over Sri Lanka
- To Re-demarcate Agro-Ecological Zones in Sri Lanka
- To Evaluate the Impact of Extreme Precipitation Analysis and New Agro-Ecological Zoning on Agriculture and Other Decision-Making Processes

2. LITERATURE REVIEW

2.1 Climate Change Overview

2.1.1 Global Climate Change

Climate change refers to significant and long-term changes in temperature, precipitation, and wind patterns, among other atmospheric phenomena, that occur over decades to millions of years (IPCC, 2021). The general term normally refers to current trends of high temperatures and unpredictable weather, mainly blamed on human activities from the beginning of the Industrial Revolution. According to IPCC, this can be understood comprehensively and over the long term. The Intergovernmental Panel on Climate Change firmly asserted in its recent Sixth Assessment Report that "human influence has warmed the atmosphere, ocean, and land," adding further that many of the changes experienced are without precedent in centuries to millennia (IPCC, 2021). Such a consensus among researchers lays bare the need to seriously treat the issue of climate change as a global crisis largely driven by human-related activities: the burning of fossil fuels, deforestation, and high-intensity agriculture.

The body of evidence supporting climate change is enormous and can be seen through several different observable patterns. From the late 19th century into the present, global temperatures have risen by approximately 1.1°C, with the greatest amount of acceleration in recent decades (Hansen et al., 2010). The temperature rise has been highly correlated with the increased levels of greenhouse gases, particularly carbon dioxide (CO_2), which has seen an approximate 50% increase since pre-industrial times (NOAA, 2022). Methane (CH_4) and nitrous oxide (N_2O) are other important greenhouse substances in which both gases have a much higher potential for warming, although both exist in far lower concentrations than carbon dioxide (CO_2). These gases trap heat inside the Earth's atmosphere, creating a "greenhouse effect" that produces global warming and associated climate changes (IPCC, 2021).

There are manifold impacts and multi-modal consequences due to global climate change in nearly every region of the Earth. Consequently, another critical effect brought about by global warming is the alteration of the weather conditions in the atmosphere that increases the frequency and intensity of severe weather events(Bolan et al., 2024). To illustrate, heat waves have become more intense and prolonged in duration, while various regions such as Europe and North America have experienced unprecedented temperatures, which have disastrous implications for human health, agriculture, and ecosystems (Dunne et al., 2013). Comparably, the occurrence and severity of tropical cyclones, hurricanes, and typhoons have risen, resulting in catastrophic effects on coastal populations, infrastructure, and economic systems. The Intergovernmental Panel on Climate Change (IPCC) indicates that the likelihood of extreme precipitation events has risen markedly, culminating in a higher frequency and intensity of flooding, especially in tropical and subtropical areas (IPCC, 2021).

In addition, global climatic change has also accelerated the melting of polar ice caps and glaciers, further raising the sea level. The affected items in this are the low coastal areas, small island nations, loss of land from the rise of the sea, enhanced coast erosion, and salinization of freshwater resources. NASA reports mentioned that global sea levels have risen by about 20 cm since 1880, while the rate of rise is still growing (NASA, 2020). The Greenland and Antarctic ice sheets' losses of mass contribute significantly to rising sea levels worldwide (Shepherd et al., 2020). This effect is not confined to just the human population, but it is considered major in the marine and coastal ecosystem leading to habitat loss for ice-dependent species.

The further implication is that rising levels of CO_2 are being inhaled and the oceans absorb it, thereby becoming more acidic in pH. The changing chemistry of the ocean constitutes a huge, serious threat to marine biodiversity, especially for those with calcium carbonate shells and skeletons such as corals, mollusks, and some plankton species (Hoegh-Guldberg et al., 2007). Coral reefs are most at risk since this ecosystem is considered one of the earth's most biologically varied ecosystems. It is from these stressors, directly leading to the occurrence of coral reef bleaching on a large scale in the Great Barrier Reef and many other areas, that a reduction in marine biodiversity results, together with the degradation of essential ecosystem services offered by the reefs (Hughes et al., 2017).

The present era of rapidly changing climate is driven by factors directly linked to anthropogenic activities, which have disturbed to the intrinsic balance of Earth's climatic systems. Up to now, combusting fossil fuels, such as coal, oil, and natural gas, is still responsible for about 75% of total global GHG emissions and remains the leading factor in this change (IEA, 2022). Another major parameter comes from deforestation, mainly in tropical regions where forests act as potential carbon sinks. Deforestation results in the release of already stored carbon into the atmosphere as the trees are felled, at the same time reducing land capability for future storage of carbon emissions (Baccini et al., 2019). In addition, industrial activities, agricultural practices, and waste management greatly contribute to greenhouse gases, particularly methane and nitrous oxide. Agriculture contributes to around 14% of anthropogenic GHG emissions worldwide, with livestock and rice agriculture being the two largest anthropogenic sources of methane (Smith et al., 2014).

In addition to these direct causes, there are feedback loops in the climate system that amplify global warming. For example, melting Arctic ice contributes to a lower albedo effect. This means that not as much sunlight gets reflected back to space compared to in previous times, while a larger amount of the Sun's heat gets absorbed on Earth's surface thus causing further planetary warming (Notz & Stroeve, 2016). Similarly, thawing permafrost at polar regions unleashes enormous volumes of methane, an extremely potent greenhouse gas into the atmosphere while generating a self-sustaining cycle of accelerating warming (Schuur et al., 2015). These answers underline how intricate and interlinked the climate system is: changes in one alone can have a very strong and far-reaching effect on the whole.

2.1.2 Climate Change in Sri Lanka

South Asia, home to more than a quarter of the world's population, is one of the most vulnerable regions to the impacts of climate change. (Nazrul Islam et al., 2009). Geographically, it ranges from the high Himalayas down to the middle river basins and then to the vast coastal plains, which very importantly renders it prone to most hazards related to the climate. For example, it has been projected that in South Asia, increases in temperature are magnifying the frequency and intensity of floods, droughts, and heatwaves with changing rainfall patterns (Wang et al., 2017). All these looming problems are great threats to agriculture and the available water systems as well as affect the stability of the socioeconomic systems of this region, where a good number of individuals rely on weather-sensitive sectors to help support their livelihoods.

Sri Lanka is an island in South Asia, and its climate change challenges are unique. Two major monsoon seasons prevail in the country: the Southwest Monsoon, called Yala, from May to September, and the Northeast Monsoon, called Maha, from November to January (Marambe et al., 2015). Both are very important for agriculture, water management, and the general economy. Traditionally, these currents have been fairly predictable in providing reliable rainfall for agricultural cycles in the country(Marambe et al., 2015). But the most recent studies show that such trends are increasingly erratic and synonymous with drastic changes in the onsets, durations, and severities of the monsoons (C. S. De Silva, 2006). In this sense of the term, unpredictability is critical because farmers plant crops and harvest by calculating time-mean normalized distributions of rainfall.

The Southwest monsoon, which is expected to prevail between May and September, indicated a late onset and low rainfall in the recent past. This caused long-lasting droughts that particularly affected south-western Sri Lanka where most agriculture and hydroelectric power depend on monsoon rainfall (C. S. De Silva, 2006). This Northeast Monsoon, occurring from December to February, has become variable. Some areas experience an increased frequency of rainfall, which eventually causes flooding, while other areas receive scanty rainfall. In this regard, the observed changes in the pattern of monsoons reflect broader changes in the regional climate system likely due to global warming coupled with other anthropogenic factors (Zubair et al., 2008).

These changes in monsoon patterns mark a significant impact on Sri Lanka's agriculture. Rice, being the staple food of the country, requires available water throughout the entire growth period by nature. Research has documented that variability in the timing and intensity of monsoon rains can lead to either water stress or waterlogging, both conditions which can reduce crop yield(Eriyagama et al., 2010).

Changes in temperature and precipitation patterns affect not only rice but also tea, coconut, and rubber crops that form Sri Lanka's major export commodities. For instance, the tea industry is sensitive to temperature conditions, with optimal conditions able to prevail within a very narrow range of temperature and humidity levels. Because the weather is gradually getting hotter, tea plantations-mostly those at low elevations-can be expected to realize a decline in yield and quality(Wijeratne, 1996).

Other than the direct impacts of climate change on agriculture, changes in Sri Lanka also relate to more frequency and intensity of extreme weather events, such as flooding and landslides. Such instances have been more frequent during the recent past, particularly with the monsoon seasons, and have resulted in widespread infrastructure damage, displacements of communities, and loss of life(Gunaratne et al., 2021). This trend is boosted by increased rainfall intensity and deforestation in the central highlands, which are generally less event-prone areas. The lives of the people in the immediate vicinity are directly affected by such changes, which increasingly stretch the disaster management and response apparatus of the country.

More importantly, the rise in the level of seawater will pose a great danger to the coastal lines of Sri Lanka, where huge parts of its population live. Due to coastal erosion, saltwater intrusion and more frequent storm surges are currently menacing coastal communities and ecosystems (Ranasinghe et al., 2004). Tourism was embraced as one of the mainstays in the national economy (Dharmaratne & Siriwardena, 2024). At the same time, the sector seems to be so vulnerable in the face of such change because many tourist destinations of Sri Lanka, like beaches and coral reefs, lie along the coast. Its destruction due to the element of climate change might lead to huge economic impacts that threaten job opportunities and lessen its appeal as a country for tourists to visit (Ranasinghe et al., 2004).

These historical and current climatic conditions in Sri Lanka move along a different path towards more variability and unpredictability. Evidence from historical data indicates that the climate of the nation was much more stable earlier, with well-marked monsoon seasons giving good rainfall for agriculture and water supply, according to the study (Zubair et al., 2008). However, in recent decades there has been a shift in the natural variations of the weather toward more abnormality of events and changes in the very monsoon patterns themselves. These changes are part of bigger regional and global trends, highlighting how much the impacts of climate change are interconnected.

Various studies on climate change in Sri Lanka have focused on pursuing adaptive measures, which will provide a reduction in vulnerable impacts due to such changes. The National Climate Change Adaptation Strategy emphasizes enhanced resilience in critical sectors of agriculture, water resources, and disaster management for the country (Mawilmada et al., 2010). These include better water management practices, the use of resilient varieties in agriculture, and the enhancement of early warnings on extreme meteorological events. Natural ecosystems conservations and restorations, for example, forests and wetlands, are at the very foundation of the intrinsic resilience of the country against climate change.

This means that, in contrast to other South Asian countries, Sri Lanka has very serious issues as a result of the ramifications of climate change. Other issues include changes in monsoons, increasing frequencies of extreme weather events, and rising sea levels, which are contributing to impacting the economy of the country, its ecosystems, and humans negatively. These call for holistic approaches wherein mitigation and adaptation measures are integrated, with a clear focus on resilience building among the vulnerable sectors and areas. These measures are indispensable because, with the impacts of climate change in the coming decades predicted to deteriorate further, probabilities are progressively becoming critical to the well-being of the nation with sustainable development as a whole.

2.2 Extreme Climate Events

2.2.1 Definition and Classification of Extreme Climate Events

According to the definition of the WMO, such events are a situation occurring when the value of a climate variable or a function of a combination of climate variables is above (or below) those that might reasonably be expected over a given period and region, considering the distribution of extreme events in this period (WMO, 2023). Such events may have disastrous implications on human lives, property, ecology, and economies. The categorization of such events, according to this organization, is made concerning their magnitude, period of endurance, and period of recurrence, considering the factors as critical for monitoring since their impacts are major (Stephenson, 2008).

Extreme climate events can be classified based on heat waves, cold waves, droughts, and extreme precipitation events (Meyer et al., 2022). Of these, extreme precipitation events are relatively more important because of their association with secondary impacts like floods, landslides, and damage to infrastructure. All of those events have been increasingly frequent and intense with climate change; this indeed has been reported by the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC, 2023), which highlights the increased intensity and frequency of extreme climate events across many regions of the world.

Extreme climate events can be classified into the following categories (Meyer et al., 2022; WMO, 2023).

- Temperature Extremes - The extremes involve heatwaves and cold waves in which the temperature exceeds or falls below threshold values concerning regional norms for a prolonged period.
- Droughts - Extended rainfall shortages that can have a huge impact on water supplies, agriculture, and natural ecosystems.
- Extreme precipitation - Those events where the amount of precipitation is very high in comparison with the usual condition of a particular region within a few hours or days, causing floods and landslides.
- Storms and tropical cyclones - In general, come with severe wind speeds and heavy rainfall that often result in large-scale damage

Extreme precipitation can be defined as an event where the accumulated rainfall or snowfall surpasses a certain threshold that creates significant impacts, such as flooding or landslides. The World Meteorological Organization defines extreme precipitation events based on local climatological data. Events are usually measured over short periods, such as hourly, and over long periods, such as several days, with precipitation well above the local average conditions by a great amount (WMO, 2023)

Two basic contexts are widely used and considered for classifying precipitation as extreme regarding thresholds (WMO, 2023). They are,

- Fixed Thresholds - The exceedance of a fixed value of precipitations corresponds to the situation when severe impacts occur, for example, 50 mm/day in many regions.
- Percentile thresholds - Based on rarity the most frequently used values are the 90th, 95th, or 99th percentiles of historic precipitation data. This kind of threshold provides, in particular, a good capability for extreme events in areas with various topographies or microclimates.

In fact, such percentile thresholds are far more efficient in the identification of extreme events over a topographically diverse country like Sri Lanka because they can account for the local climatological variability (Marambe et al., 2015). Besides, extreme precipitation is described in its duration and intensity by focusing on how much above the normal values it is and during what period. Understanding these extreme precipitation events and categorizing them helps in identifying the trends (Seneviratne et al., 2012). Hence assessing the risk involved, especially in vulnerable regions prone to monsoon impacts like Sri Lanka. Historical precipitation records over Southeast Asia indicate a marked increase in the frequency and magnitude of extreme precipitation events (Premalal et al., 2020). Of particular note, there is an increase in rainfall magnitudes throughout the two monsoon seasons of Sri Lanka over its central highlands, hence exacerbating flood and landslide risks related to these phenomena (Eriyagama et al., 2010; Thevakaran et al., 2019).

2.2.2 Historical Analysis of Extreme Events

Historical analyses of extreme precipitation events show an increase in frequency and intensities on a global scale because of changes in the moisture-carrying capacity of the atmosphere due to global warming. This is a consistent record observed globally, including in South Asia (Loo et al., 2015). The extreme rainfall events, particularly those during the Southwest Monsoon in Sri Lanka, have risen tremendously in the last few decades in terms of intensity as well as duration (Deoras et al., 2023). While trends in extreme rainfall events are not consistently increasing or decreasing across Sri Lanka, there is evidence of increasing dry days and decreasing wet days during the summer half-year (Thevakaran et al., 2019). Across South Asia, most extreme precipitation indices show increases, although changes are spatially variable (Sheikh et al., 2015). In Sri Lanka, specifically, recent research indicates increasing trends in extreme precipitation events and total annual precipitation from 1980-2015 (Jayawardena et al., 2018). These changes in precipitation extremes have important implications for climate-sensitive sectors such as agriculture and water resource management. Concurrently, temperature extremes across South Asia show warming trends, with warm extremes becoming more common and cold extremes less frequent (Sheikh et al., 2015). It is important to devise flood protection-related infrastructures and disaster preparedness systems in countries like Sri Lanka, where the monsoon controls rainfall. Nowadays extreme precipitation events have become more frequent (Ranasinghe et al., 2004).

Standard Precipitation Index (SPI) and Rainfall Anomaly Index (RAI) are other climatological indices of extreme precipitation that quantify deviations of the rainfall from the long-term average and, hence, are useful in assessing the severity of such events. Recent research in Sri Lanka has shown that extremes of precipitation already exceed the 99th percentile of historical rainfall with growing frequency, particularly in the highlands and southwestern parts of the country. Indeed, this is a shift toward more extreme and frequent precipitation, consistent with trends seen around the world (Thevakaran et al., 2019). Characterizing extreme precipitation events is very important for efficient planning and response, especially in countries like Sri Lanka prone to the vagaries of recent climate change. Past trends and future projections of extreme precipitation events are increasing in both frequency and magnitude; thus, the demand for increased monitoring and upgraded disaster management will be required to mitigate such impacts on helpless populations and infrastructure (WMO, 2023).

2.2.3 Impacts on Natural and Human Systems

Among these extreme climate events, extreme precipitation events have a greater prominence on natural and human systems. Due to anthropogenic climate change, which has intensity due to the enhanced hydrological cycle, these events have increased in frequency, leading to increases in frequency and severity of weather extremes (IPCC, 2023). The impacts on extreme precipitation depend on the variabilities of geographical locations, system resiliency, and regional preparedness but, extreme precipitation causes significant disruptions to ecosystem disturbance, infrastructure, agriculture, human health, and economic or financial disruption. The impact of heavy precipitation events is associated with increasing trends in vulnerable regions, especially in the South Area, most probably countries like Sri Lanka. The situation shows incidents of flooding, landslides, the spread of waterborne diseases, agricultural losses, and other casualties (Ranasinghe et al., 2004).

Natural systems are so sensitive to destruction by extreme events of precipitation. Heavy rainfall often leads to flooding, soil erosion, and landslides, which can drastically alter ecosystems and reduce biodiversity (IPCC, 2023). These processes can destroy habitats and disrupt natural ecosystem functions, such as nutrient cycling and water filtration (Vitousek et al., 2017). Wetlands, coastal areas, and river systems are particularly susceptible to flooding, which can degrade water quality by introducing pollutants, sediments, and chemicals into water bodies, threatening both terrestrial and aquatic life (Jongman et al., 2018). Coastal ecosystems, in particular, face heightened risks, as heavy rains combined with rising sea levels can exacerbate the effects of storm surges and saltwater intrusion (IPCC, 2023). Coral reefs and other marine ecosystems can be smothered by increased sedimentation from runoff, reducing light penetration and impacting species that rely on clear waters for feeding and reproduction (Vitousek et al., 2017).

Most significantly, terrestrial ecosystems, especially forest ecosystems, are very susceptible to extreme rainfall. Heavy rainfall leads to saturation in the soil, weakening tree root systems and making it prone to landslides that cause habitat destruction and contribute to deforestation (Vitousek et al., 2017). Landslide occurrences, due to heavy rainfall events, become more frequent in countries like Sri Lanka, especially in the central highland areas of the country where steep slopes and deforestation make the landscape much more vulnerable (Thevakaran et al., 2019). These events not only destroy the vegetation but also disrupt the ecosystem services that control water regulation and carbon sequestration. This most definitely aggravates the climate change impacts again, as noted by (Zubair et al., 2008). According to research, this loss of ecosystems as a result of extreme weather events reduces their buffering potential about future climatic changes positive feedback (Vitousek et al., 2017).

In addition to that, extreme precipitation will also be greatly impactful on freshwater systems. Flooding will alter river and lake hydrology, affecting flow and sediment deposition regimes. While some sediment deposition can be beneficial, replenishing nutrients in floodplains, excessive runoff can lead to riverbank erosion, reducing water quality and destroying aquatic habitats (Jongman et al., 2018). Floods can also lead to the contamination of freshwater supplies, as pollutants from agriculture, industry, and sewage systems are washed into rivers and reservoirs (IPCC, 2023). This has been specifically problematic in the coastal areas, as rising sea levels and extreme rainfall events act together to increase the risk of saltwater intrusion into freshwater aquifers, compromising both drinking water supplies and agriculture (Ketabchi et al., 2016).

Impacts on human systems are equally devastating due to extreme precipitation events. Flooding and landslides more often than not leave a wide swath of infrastructure damage in their path: these include means of transportation, buildings, and public utilities. Economic rebuilding following extreme precipitation events can be very high, especially for developing countries with less resilience within infrastructure or recovery resources (S. Kumar et al., 2022). Sri Lanka has repeatedly suffered from flash floods and landslides associated with the monsoon seasons, which have wrecked homes, displaced several thousand people, and caused massive disruptions in transport and commerce. Events of this nature often have heavy, long-term economic consequences and in that perspective, flooding can reduce productivity, disrupt trade, and stress national economies due to the high costs of rebuilding (Ranasinghe et al., 2004; Thevakaran et al., 2019).

Agriculture is one of the important industries for most countries and is greatly vulnerable to extreme precipitation. Various types of severe precipitations are reported to flood fields, wash away crops, and result in waterlogging that reduces yields in agriculture (Zubair et al., 2008). In Sri Lanka, excessive fall of monsoon rains badly affected the paddy fields and resulted in losses in rice production, which was considered a staple crop for the country. Long-term damage to such areas may lead to food shortages, increased food prices, and economic instability among rural communities reliant on subsistence farming (Thevakaran et al., 2019). Furthermore, extreme rainfall will enhance soil erosion processes, which will decrease agricultural land productivity in the long run, thus impacting food security, as stated by (Jongman et al., 2018)

Other critical health impacts arise from extreme precipitation events, and floods is it create breeding grounds in tropical areas, providing avenues for the spread of disease vectors. Waterborne diseases such as cholera, typhoid, and dysentery, which emanate primarily from grossly contaminated water supplies, are mostly reported after floods (Jung et al., 2023). In addition, other vector-borne diseases, such as malaria and dengue, whose vectors appear in stagnant water, generally have higher numbers of outbreaks after heavy rainfall events (Ranasinghe et al., 2004). Sri Lanka has of late been experiencing an increase in dengue cases, which closely coincides with the heavy rainfall period since the flood waters standing in the environment serve as ideal breeding sites for mosquitoes (Duchet et al., 2017). This situation is further made worse by the destruction of healthcare facilities whenever there is flooding, hence impeding any efficient management of the outbreaks or even treatment.

Economically, extreme precipitation events impose significant direct and indirect costs. In addition to the expenses of rebuilding damaged infrastructure, there are substantial economic losses due to disruptions in trade, agriculture, and industry (Jongman et al., 2018). Insurance costs also rise in the aftermath of extreme events, adding financial burdens to both governments and private citizens. While global economic losses from flooding have been rising with time, the impacts have been much higher in developing countries because of the increasing extreme precipitation events and a lack of adequate infrastructure that has consequential cascading (Ratnayake et al., 2021). In Sri Lanka, for example, the economic impact of repeated monsoon flooding has been a major impediment to long-term development, as resources are continuously diverted towards recovery and rebuilding efforts (Ranasinghe et al., 2004).

In conclusion, the effects of extreme precipitation events upon natural and human systems remain so widespread and extreme. Extreme degradation or loss of ecosystems and biodiversity, and disruption of important services from water filtration through carbon sequestration are major impacts that face in the natural environment. It is affecting human systems with infrastructure destruction, agricultural loss, public health crises, and economic disruption. During such a decade when climate change operates to increase the frequency and intensity of extreme precipitation, every country has to invest in climate resilience through better early warning systems, new infrastructure techniques, and better land-use practices to reduce the growing risk of these events.

2.2.4 ETCDMI Indices for Identifying Extreme Events

The ETCCDI (Expert Team on Climate Change Detection and Indices) indices, were initially developed for monitoring, detecting, and analyzing extreme weather events around the world (Keshari & Pant, 2015; Vinod & Mahesha, 2023). It was developed in response to the need for a consistent methodology that can be used by climate scientists and meteorologists in tracking changes in extreme weather over various regions and times. The ETCCDI indices have become essential tools for climate studies, providing a framework that enables comparisons of extreme weather patterns in different parts of the world and helping researchers assess how these patterns evolve in response to climate change (Alexander et al., 2006; Zhang et al., 2011)

The ETCCDI Indices was developed in the late 1990s, by World Meteorological Organization (WMO) in collaboration with both Climate Variability and Predictability (CLIVAR) project and the Intergovernmental Panel on Climate Change (IPCC) (WMO, 2023). The first workshop was organized in Asheville, North Carolina, USA, in 1999 with the gathering of experts from all over the world in the climate field and as a result of that workshop, they established a standard set of indices for the detection and monitoring of extremes in climate (Karl et al., 1999). Among the experts who involved in that workshop, Dr. Xuebin Zhang from Canada played an important role in the formulation of the ETCCDI framework and the promotion of the application of these indices in global climate studies (Zhang et al., 2011). The team's objective was to create a set of indices that could detect changes in extreme weather patterns in a manner that was both regionally and globally consistent, thus addressing the variability in methodologies that had previously hampered cross-regional climate comparisons (Peterson et al., 2001).

The ETCCDI established 27 main indices to identify extreme climate events and, out of them 16 indices represent temperature extremes and the rest of the 11 indices are precipitation extremes. These indices represent the various features of the climate extremes including frequency, intensity, and duration. The climate indices based on temperature comprise days when the maximum temperature exceeds its 90th percentile (TX90p), the minimum temperature is less than the 10th percentile (TN10p), and the annual highest maximum temperature (TXx). Other relevant indices of temperature extremes are the annual lowest minimum temperature (TNn), frequency of warm days and nights, and the duration of heat waves (Alexander et al., 2006; Donat et al., 2014). The precipitation-related indices are the maximum one-day precipitation total (Rx1day), five-day precipitation total (Rx5day), the total precipitation on days over the 95th percentile (R95p), the count of consecutive dry days (CDD), and that of consecutive wet days (CWD) (Karl et al., 1999; Peterson et al., 2001).

The development of these indices is driven by the need for a unified system capable of detecting, measuring, and analyzing extreme events across diverse geographical and climatic regions (IPCC, 2012). Before the establishment of the ETCCDI, national meteorological services used a range of thresholds and methodologies in classifying extreme weather events, making an assessment and comparison of global climate trends quite hard to conduct (Frich et al., 2002). The ETCCDI indices allowed for a solution whereby the criteria defining extremes were standardized, hence allowing for better global comparisons of the effects of climate change on extreme weather patterns. Importantly, these indices are allowed to be flexible towards the different regional climates and are derived using daily temperature and precipitation data to make them accessible to many meteorological services around the world (Zhang et al., 2011).

The calculation of all these indices involves some percentile thresholds and statistical methodologies to identify extreme events out of daily records of temperature and precipitation. For example, extreme temperatures are defined in terms of comparison of daily maximum and minimum temperatures with appropriate long-term historical percentiles. For instance, days with temperatures above the 90th percentile of the long-term record can be considered as extreme in heat, and those below the 10th percentile minimum temperatures to be cold extremes (Alexander et al., 2006; Donat et al., 2014). The percentile scaling thresholds represent a non-rigid identification of temperature extremes into coherent classes across diverse climates, that is, percentiles capture the relative nature of regional baseline shifts in temperatures.

Similarly, precipitation indices have their definition based on percentile thresholds for the detection of events of extreme rainfall. For example, the R95p index calculates sums of the total precipitation from days when rainfall exceeds the 95th percentile of the long-term distribution and hence provides an unambiguous indicator of extreme precipitation events concerning the local climatology (Zhang et al., 2011). Another important precipitation index is Rx1day, conventionally defined as the highest rainfall on any one day in a year and, it is useful for describing short-duration extreme events which may cause flooding and landslides (Karl et al., 1999). The use of consecutive dry or wet day indices (CDD and CWD) allows researchers to identify long-term drought or excessive wet periods, providing critical insights into changing hydrological patterns (Donat et al., 2014; Frich et al., 2002).

The ETCCDI Indices are useful not only to identify single extreme events but also to analyze time-dependent trends in climate extremes. Many such studies by using the ETCCDI indices identified a clear global picture of the trend in extremes, both in temperature and precipitation. This is manifested in the increased frequency and intensity of heatwaves in most parts of the world, while at the same time a decrease in the number of cold extremes, especially in the Northern Hemisphere, has been observed (Chervenkov & Slavov, 2019). On the other side, extreme precipitation has increased in frequency over most of the world, therefore increasing the risks for flooding and other water-related disasters (IPCC, 2023). These findings are based on ETCCDI data and have been crucial for the assessment reports of the IPCC that inform global climate policy and adaptation strategies (IPCC, 2023).

Because of their flexibility and applicability, the ETCCDI indices have become one of the widely used tools in climate studies. National meteorological services, research institutions, and international organizations also use them to monitor and prepare climate extreme reports (Peterson et al., 2001). The indices have also been used to validate climate models, assess the impacts of climate change on extreme weather events, and develop climate adaptation strategies for vulnerable regions (Donat et al., 2014; Frich et al., 2002). In many regions, including Europe, Asia, and Africa, ETCCDI indices have provided insights into how climate change is altering the frequency, intensity, and duration of extreme weather events, which has been crucial for improving climate resilience and disaster preparedness (Donat et al., 2014). In this study, 11 indices defined for analyzing extreme precipitation by ETCCDI have been utilized.

2.3 Agro-Ecological Zones

2.3.1 Concept of Agro-Ecological Zoning

Agroecological zoning refers to a scientific approach to land use planning, where land is subdivided into zones based on homogeneous agroecological characteristics (Quiroz et al., 2001). The land is assessed based on its suitability, productive potential, limitations, and environmental impact for major crops and agricultural systems. The optimization of land use with AEZ thus enables efficient and ecologically founded sustainable agricultural development that improves productivity and environmental management. According to (FAO, 1996), AEZ encompasses the division of areas of various agro-climatic along with soil conditions into zones so that effective matching of requirements with the same ecological capability is derived. It can be achieved as an idea of the highest demand for feasible tools to handle land use in developing countries since much depends on agricultural productivity in terms of food security and economic development (Fischer et al., 2006).

Historically, it was first developed in the 1970s when the Food and Agriculture Organization of the United Nations (FAO) launched its global Agro-Ecological Zones Project. It was a way of determining land suitability for crops in developing countries by considering climate, soil, and topographic characteristics to predict agricultural productivity (FAO, 1996). The work fundamentally involved the classification of large tracts of land into zones by agro-climatic and edaphic conditions. With time, it has incorporated new approaches like geographic information systems and remote sensing, thus increasing the scope and accuracy of the same (Fischer et al., 2006). Countries like China, Kenya, Brazil, and Sri Lanka have already applied AEZ for informing national land-use policies with considerable success, thus illustrating the usefulness of the approach in agriculture and resources management (FAO, 1996). The enhancement in AEZ capabilities with sophisticated technologies such as GIS has now made it possible to integrate large data sets for an accurate understanding of land resources and their potential utilization (Fischer et al., 2006).

AEZ cannot be overemphasized in decision-making processes. It gives useful information needed for agricultural planning, optimization of land use, and management of natural resources (Castrignanò et al., 2010). AEZ contributes to policy by providing systematic land suitability assessment that contributes to decision-making on prioritizing areas for agricultural investment, conservation, or other uses of land (FAO, 1996). For example, AEZ can show zones prone to drought or flood in climate change and extreme weather-sensitive zones, and adaptive measures. Therefore, it can be introduced to protect agricultural productivity in such areas, as mentioned by (A. U. Ahmed & Hussain, 2009). In addition, another critical role of AEZ in sustainable land management is the determination of ecological degradations like erosion or fertility reduction of soils, providing opportunities for land managers to switch over to such methods that reduce environmental hazards. By doing so, AEZ shall form a cornerstone in balancing agricultural productivity with the aim of environmental conservation (Fischer et al., 2021).

The AEZ thus plays a critical role In a whole range of sectors like forestry, management of water resources, and biodiversity conservation, aside from agricultural planning. For example, AEZ in forestry enables one to identify those areas that are suitable for afforestation or sustainable timber production with ecological appropriateness of forest resource management (Fischer et al., 2021). In water resource management, AEZ has enlightened the efficient use of water in agriculture through the identification of zones according to their different hydrologic characteristics. Similarly, AEZ can be applied to biodiversity conservation by protecting ecosystems through the identification of high conservation areas, which are vital to maintain ecological balance (FAO, 1996).

In analytical terms, the AEZ approach is supported by a range of analytical tools and techniques, including climatic data analysis, soil mapping, remote sensing, Geographic Information Systems (GIS), and crop simulation models. (Fischer et al., 2006). Analyzing the climatic data on rainfall, temperature, and length of the growing period assesses the land suitability for agricultural use. So, the mapping of soil is another important aspect whereby soil types are rated according to their characteristics, like fertility, texture, and drainage capacity, which affect crop growth (FAO, 1996b). Similarly, remote sensing and satellite imagery are some of the most vital areas in this regard that create land-use patterns, vegetation cover, and change detection over some time for the AEZ process (Fischer et al., 2006). However, in GIS, many data layers can be overlaid to result in high-resolution agroecological mapping that guides land use planning decisions. Crop simulation models reinforce the AEZ framework by expanding the information on crop growth and possible yields in conditions of different ecologies. It gave full coverage of land resources when combined and thus enabled sound decision-making for sustainable agriculture and land management.

Based on the above factors, agroecological zoning is a robust approach to optimizing land use. It is the most appropriate methodology that matches agricultural production with the ecological characteristics of the land. As it evolves further, AEZ is bound to remain one of the key resources toward achieving sustainable development goals by policymakers, land managers, and agricultural planners.

2.3.2 Previous Demarcations in Sri Lanka

Agro-ecological zoning (AEZ) in Sri Lanka has undergone significant changes over the last few decades, to adapt to new agricultural practices, climate, and technological innovations improves. In its very inception, AEZ was broad-based on climatic regions, mainly wet and dry zones demarcated based on rainfall patterns (Zubair, 2000). Early zoning classification focused on distinguishing these zones based on an arbitrary threshold of 75 inches of annual rainfall, a concept that managed to survive for decades (Alles.,1971). After that, in 1960, the Agro-ecological regions in Sri Lanka was re-demarcated again into 7 zones, by considering the climate zones and elevation factor (Punyawardena B.V.R., 2010). As knowledge of the various climates on the island improved, methodology related to AEZ became refined. Based on the updated knowledge in climatology, (Panabokke and Kannangara.,1975) divided the whole Sri Lanka into 24 agroecological regions, five of which are located within the dry zone. It was the demarcation that made the basement the road for the current comprehensive zoning concept in Sri Lanka. In this work, not only rainfall patterns but also soil types and landform characteristics were put into consideration, thereby developing a more comprehensive system of classification.

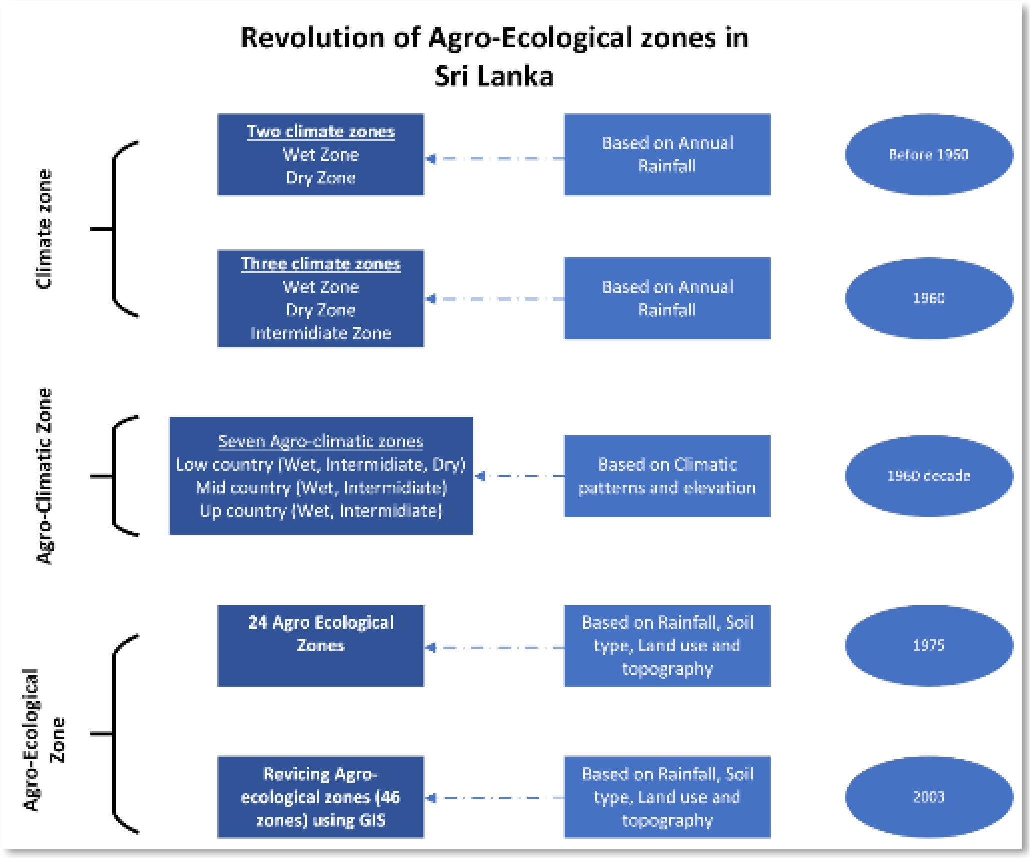


Figure 2-1: Revolution of agroecological zones in Sri Lanka

Source:(Punyawardena B.V.R., 2010)

Sri Lanka's AEZ system has evolved further, largely as a response to the global standards set by the FAO in the 1990s. The guidelines for AEZ of FAO introduce a holistic approach to land-use planning that integrates climate, soil, water resources, and socioeconomic factors in developing sustainable strategies for agriculture (FAO, 1996). With the new concepts of agroecological zoning, it was demarcated into 46 agroecological regions by the Natural Resource Management Center, Sri Lanka in

2003. In that classification, they have considered, the climate zones of Sri Lanka, soil characteristics, elevation patterns in Sri Lanka, and Land use Land cover patterns over the country.

Still, the agroecological regions in Sri Lanka need modification for international compatibility even as they continue to reflect many of the characteristics outlined by (Panabokke., 1996). Irrigation networks provide one of the key areas for modification (Ratnayake et al., 2023a). Considering the ancient and modern irrigation systems of Sri Lanka, especially in dry zones, for example, the areas previously classified as unsuitable for intensive agriculture because of lack of water could now be classified as highly productive areas with stable water sources (Ratnayake et al., 2021). The global guidelines of the FAO do point out that the AEZ maps should be dynamic and adaptive to changes within water management and changeable climate patterns (FAO, 1996). This would most accurately represent the land's suitability for agriculture, especially as the water supply from the irrigation systems becomes more reliable.

2.4 Livelihood Impacts

2.4.1 Socio-Economic Vulnerability Due to Extreme Rainfall Events

Prolonged extreme rainfall causes severe disruption of the socio-economic settings within Sri Lanka (Wahalathanthrighe, 2020). Due to its heavy reliance on agriculture, it is very prone to heavy rainfall, where its smallholder farmers are generally known to incur considerable income losses from the impacts of waterlogging and flooding on crops. The Department of Agriculture conducted a study in 2019 has indicated that floods in 2016 destroyed more than 30% of Sri Lanka's paddy production, thus having a strong detrimental impact on food security and the net income of farmers. These small-scale farmers lack sufficient financial resilience to recover from climatic shocks like these, which, in effect, deepens their economic vulnerabilities (De Silva & Kawasaki, 2018).

One of the major impacts contributed by heavy rains in urban areas is the destruction of infrastructures. For example, flash floods frequently cause damage to roads, bridges, and drainage systems in Colombo and Kandy, increasing the economic burden through repairs and lost productivity (Fernando et al., 2022). The National Building Research Organization (NBRO) in 2018 reported that recurring floods from excessive rainfall have cost the government billions in infrastructure repairs over the past decade. This problem is exacerbated by inadequate urban planning and poor disaster preparedness, particularly in low-income urban settlements (Dassanayake et al., 2023).

Extreme rainfall events enhance the socio-economic vulnerability to health risks. Floods lead to an increased risk of waterborne diseases, such as leptospirosis and dengue fever, which notably increased in the flood season of 2017 (Ministry of Health, 2017). The impact on children, elderly people, and poor families is most devastating as they cannot easily access healthcare or maintain proper sanitation (Alwis et al., 2019). They also involve gender-based vulnerabilities in that rural women is particularly vulnerable because they always bear all the responsibilities related to agriculture, household management, and caregiving (Patel et al., 2020).

Considering the above factors, extreme rainfall occurrences in Sri Lanka enhance socio-economic vulnerabilities, especially for people in agriculture and poorly built urban areas. Vulnerable populations bear a disproportionate share of the consequences, which include long-term harm to vital infrastructure, dangers to health, and direct loss of income.

2.4.2 Adaptation and Mitigation Strategies

The livelihood impacts related to extreme rainfall in Sri Lanka thus make the adaptation and mitigation strategies focus on enhancing community resilience and reducing vulnerability. Adaptation strategies entail the enhancement of agricultural and urban resilience, while mitigation involves the reduction of greenhouse gas emissions to mitigate extreme events related to climate change.

The important adaptation strategies include rainwater harvesting, improvement in drainage systems, and the use of flood-tolerant crops in agriculture. These practices have been promoted by the Ministry of Agriculture and international agencies such as the Food and Agriculture Organization (FAO) to reduce the vulnerability of rural communities (Kadupitiya et al., 2023). In Sri Lanka's Northern and Eastern Provinces, where floods are frequent, farmers have adopted these practices, leading to an observable increase in resilience against erratic rainfall (Ministry of Irrigation and Ministry of Agriculture, 2021). Moreover, it has issued financial aid to the farmers after extreme weather events, and calamities with the Crop Insurance Schemes which was introduced by the government in 2016. It helped stabilize the rural economies a lot.

Urban adaptation strategies have focused on improving flood resilience by upgrading infrastructure. The Colombo Municipal Council (CMC) has implemented flood control projects, including the rehabilitation of drainage networks and the construction of flood retention areas (Fernando et al., 2022). Further, green infrastructures, including urban wetlands, have been adopted in the flood control program to absorb excess rain. Wetland restoration activities in Colombo alone include the rehabilitation of the Bellanwila-Attidiya sanctuary and have contributed to minimizing the flooding in the urban areas (Gayani et al., 2022). Disaster preparedness programs, which include early warning and evacuations, are also being facilitated by the Sri Lankan government and the United Nations Development Programme 2018.

Mitigation strategies have mainly focused on reducing the country's greenhouse gas emissions by enhancing renewable energy sources and reducing deforestation that contributes to flooding (Cookson & Stirk, 2019). Climate-resilient nature-based solutions for flood mitigation, including the restoration of mangroves and coastal ecosystems, also show great prominence, especially in coastal areas. In addition, mangrove reforestation has been effective in reducing the severity of coastal flooding and is also contributing to biodiversity conservation in the District of Kalutara (Das et al., 2022).

It's also crucial to develop community resilience through awareness and education campaigns. Particularly in flood-prone areas like the Kelani River basin, the Disaster Management Centre (DMC) has led several community awareness initiatives to promote flood preparedness. Local response capacity is greatly enhanced by these efforts, which give communities vital knowledge on flood hazards, early warnings, and evacuation procedures (Das et al., 2022).

3. DATA AND METHODOLOGY

3.1 General

This research method is based on a mixed-methods approach, addressing three key objectives. The first objective of assessing climate change with special reference to the temporal variability of extreme rainfall events in Sri Lanka involves statistical analysis of past rainfall data. Because of that, it is based on a quantitative research approach. The second objective, to re-demarcate agroecological zones in Sri Lanka involves a comprehensive GIS analysis with other surveys and suggestions from experts. The final objective is to evaluate the impact of extreme precipitation analysis and new agroecological zoning on agriculture and other decision-making processes based on a questionnaire survey. So the overall research methodology involves a combination of both qualitative and quantitative components in each objective, and it is designed to ensure a comprehensive understanding of the subject matters and to have a proper outcome.

The first objective involves the assessment of climate change through the analysis of extreme rainfall events. A dataset of 30 years of meteorological data with records of daily rainfall was gathered. It was collected from authoritative organizations in Sri Lanka such as the Sri Lanka Meteorological Department, which allowed for better spatial and temporal coverage of the entire nation. Out of these, preprocessing involves cleaning, checking gaps in values, and ensuring consistency. Later, the extreme rainfall indices defined by WMO and the expert team on climate change will be computed with the help of statistical methods using percentiles-based thresholds and established indices. Thus, the trends and patterns of extreme rainfall events with respect to frequency, intensity, and duration can be portrayed. Subsequent steps in the study identified the impacted zones, through spatial analysis using GIS tools, that would be prone to flooding, landslides, or vulnerable agriculture. Further stages of the research focused on highly impacted areas, after which recommendations were given on decision-making about flood risk and agricultural planning.

In the second objective, the meteorological data was integrated with remote sensing data to re-demarcate agroecological zones. The work applied remote sensing techniques to check out land use, vegetation cover, and other environmental factors controlling the AEZs, whereas cluster analysis and spatial classification techniques were conducted to redefine the boundary of AEZ. These new zones were based on the analysis of extreme rainfall events, as well as changing climate patterns identified under the first objective. The re-demarcation of AEZs was validated through field observation, expert feedback, and comparison with the existing AEZ map. In that way, the defined zones would be accurate to represent the current climate conditions, hence developing a climate-resilient zoning system. The proposed zoning system can serve as a more effective tool for agricultural and environmental management in Sri Lanka.

3.2 Methodology Flow Chart

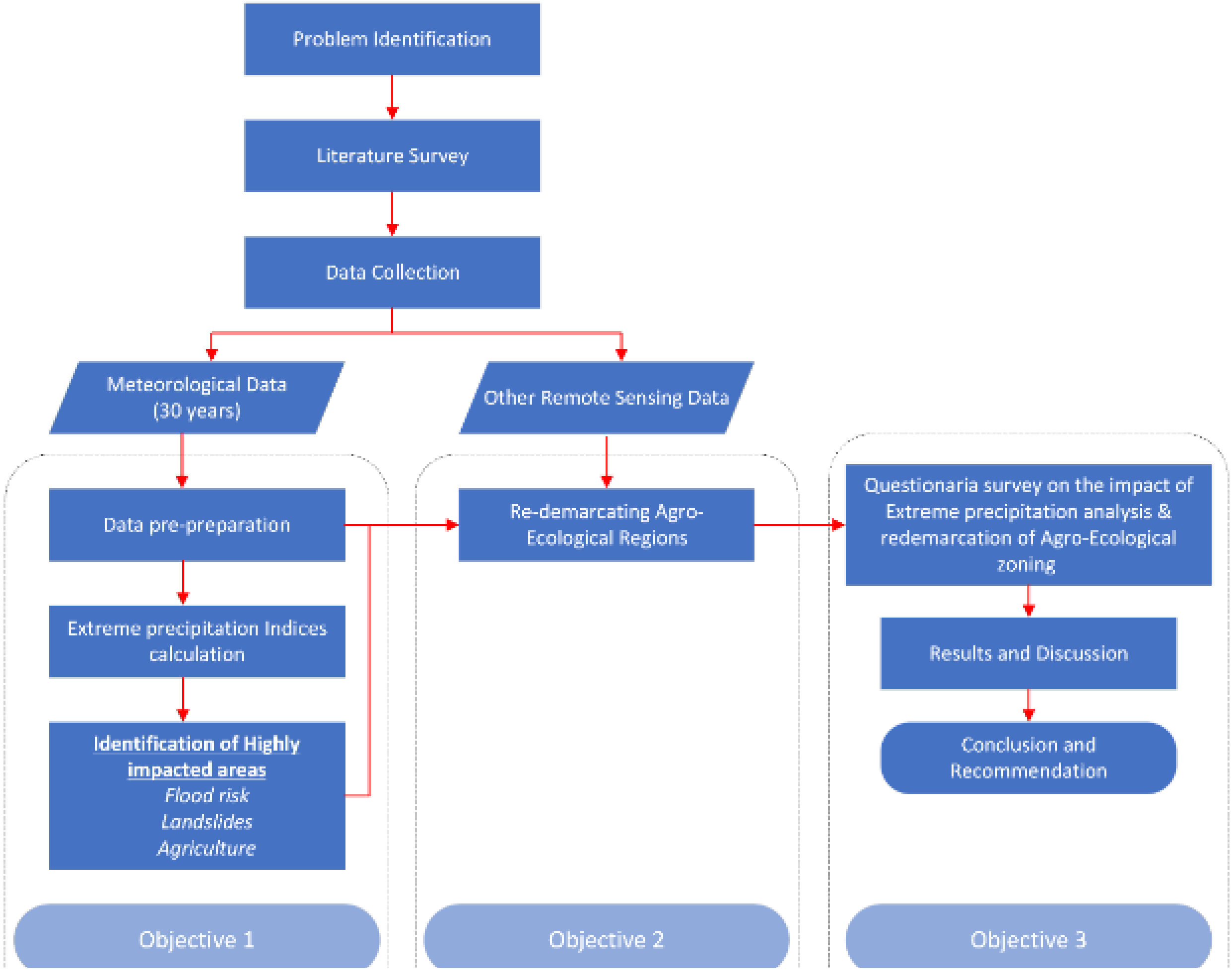


Figure 3-1: Methodology Flowchart

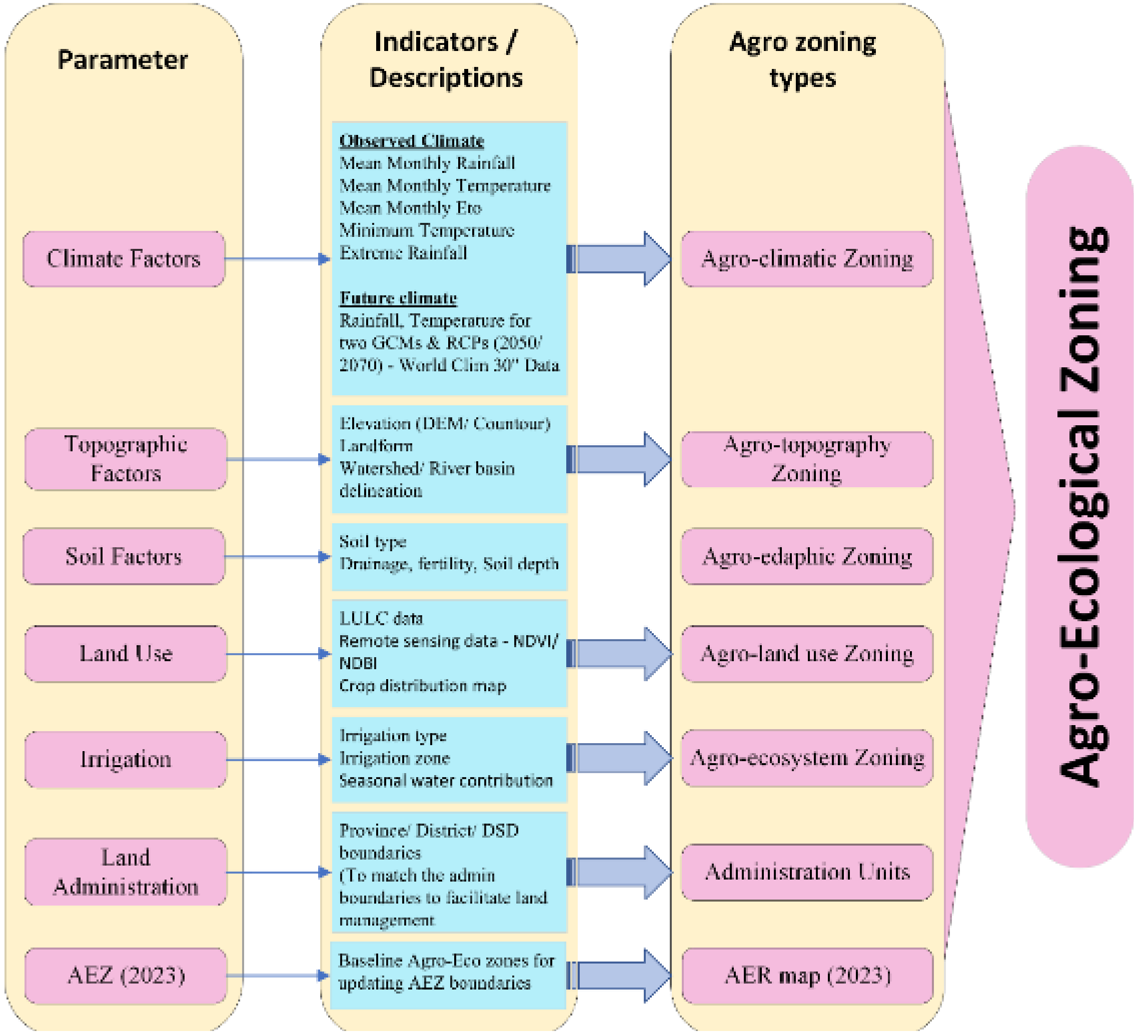


Figure 3-2: Proposed methodology for agroecological zoning

The third objective was to review the analysis of extreme precipitation and newly mapped AEZs in terms of their effect on agriculture and the associated decision-making process. To this effect, structured questionnaire surveys were carried out to obtain qualitative data from farmers, agricultural planners, and members of local governments. That will also raise awareness of the consequences of changed precipitation and new AEZs regarding agricultural activities, crop selection, and strategies to mitigate the involved risks. The survey results were statistically analyzed to identify the common trends from the view of people on their livelihoods and decision-making processes. These findings were compared with the extreme precipitation analysis and AEZ re-demarcation to determine agricultural vulnerability and planning strategies.

Throughout the research, the individual objectives of the research are interlinked. First, the analysis of the meteorological data contributes to the re-marking of AEZs under the second objective, which in turn informs the assessment of the agricultural impacts under the third objective. This integrated analytical framework makes for robust findings, informed by data, and in agreement with practical applications in agricultural planning and climate resilience. This will be in applying the qualitative and quantitative research methodology to bring a holistic framework towards the understanding of the impacts of extreme climate events on Sri Lanka's agriculture, hence useful insight enhancement for scientific research and policy recommendations.

3.3 Study Area

Sri Lanka is an island country in the Indian Ocean of the Indian subcontinent, lying between 6°-10° N latitude and 80°-81° E longitude, with an area of approximately 65,610 square kilometers (Geekiyanage et al., 2015; Punyawardena, 2020) .With this particular geographical setting, combined with the variety of topography of the country, presents a very unique opportunity to study the impacts of climate change on many different aspects, more so on extreme rainfall events. It gives way to the lowland plains and coastal regions, with the central highlands dominated by the peak of Pidurutalagala, 2,524 meters high. Because of the topographical and climatic variety, the country has been divided according to the quantity of annual rainfall into three main zones. They are the dry zone (<1750 mm), the intermediate zone (1750 mm - 2500 mm), and the wet zone (>2500 mm) (Geekiyanage et al., 2015). These climatic zones will be important in deducing how the pattern of extreme rainfall varies from region to region.

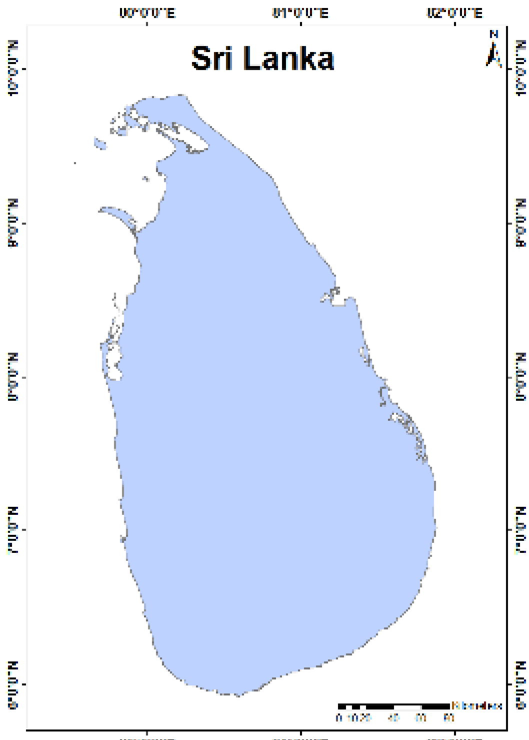


Figure 3-5: Sri Lanka map

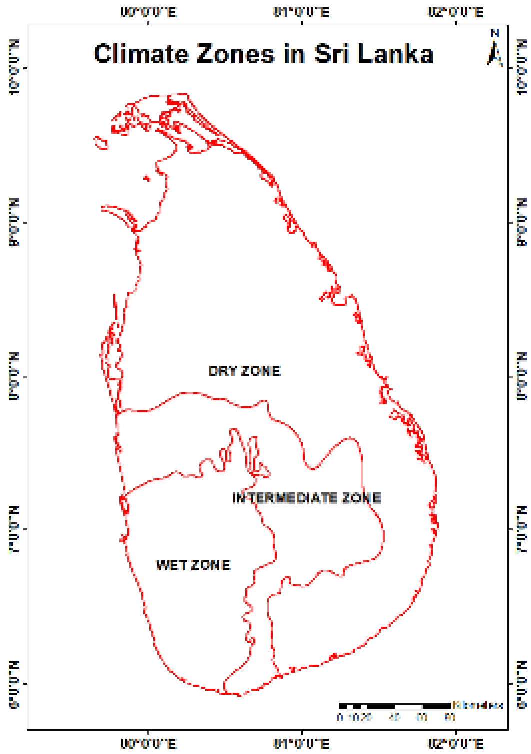


Figure 3-3: Climate Zones in Sri Lanka

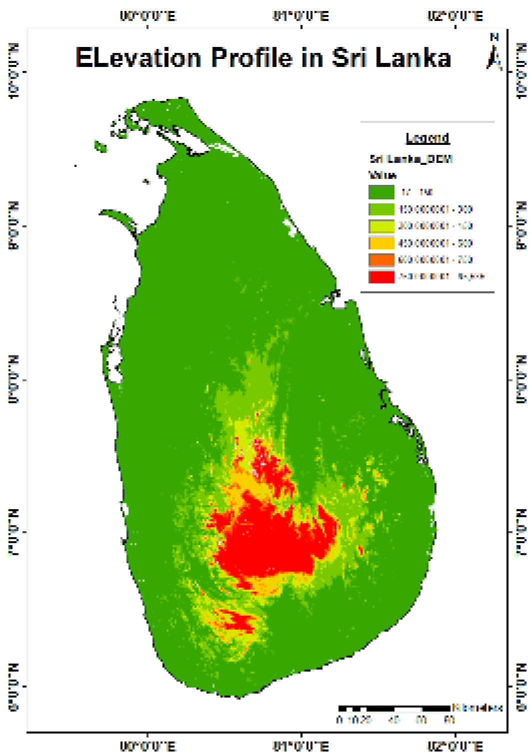


Figure 3-4: DEM of Sri Lanka

Monsoonal seasons further modify the tropical seasons of Sri Lanka. Southwest Monsoon falls with heavy rains over the wet zone between May and September and the Northeast Monsoon falls over dry and intermediate zones from December to February (Marambe et al., 2015). This variability in seasonal rainfall is enhanced by global climate change. The frequency and intensity of such weather events are increasing intensity as in intense like rainfall, flooding events, and droughts (Zubair et al., 2008). All these scales of variability in meteorological cycles lead to an environment given to climate-related hazards and, therefore, to water and agriculture (Eriyagama & Smakhtin, 2010). Average temperatures also vary across the island, with coastal areas experiencing 26°C, while the central highlands see lower temperatures, ranging between 15-19°C due to altitude differences (Geekiyanage et al., 2015; Punyawardena, 2020).

Hydrologically, the innumerable rivers including Mahaweli River and Kelani River arise from its central highland and supply much water to Sri Lankan agriculture. These rivers swell up with heavy rainfall and bring floods, further adding to the risks in the wet and intermediate zones. The extreme rainfall events of the last few years, most notably in the Southwest Monsoon, have brought massive changes in water management, agricultural policies, and disaster preparedness (Chandimala & Zubair, 2007). Understanding this type of climatic variability and its time shift may help comprehend how this extreme rainfall impacts hydrological regimes and water resources management, which is the core of your research focus.

Sri Lanka's agriculture industry, which is extremely susceptible to shifting climatic trends and extreme climate events, is directly integral to the country's socioeconomic framework. Agriculture, one of the major economic engines of Sri Lanka, about more than 25% of the country's total population is engaged in, is mostly dependent on the seasonal monsoons (World Bank, 2023). Districts in the central highlands and Dry zone, like Badulla, Anuradhapura, and Nuwara Eliya, are especially sensitive to the effects of climate change. These areas mostly depend on rainfall for farming, but heavy precipitation events have the potential to disrupt operations through flooding or protracted droughts, which can result in large crop losses (Eriyagama et al., 2010). The South Asian region is becoming more vulnerable to climate-related disasters, as seen by the floods that occurred in 2016 and 2017 and caused thousands of people to be relocated (Disaster Management Centre, 2022).

Climate change poses a threat to Sri Lanka's biodiversity and ecosystems in addition to socioeconomic difficulties. Sri Lanka is home to rich biodiversity, consisting of different types of forests, including lowland rainforests, dry mixed evergreen forests, and tropical thorn forests (Illangasinghe et al., 1999). The ecosystem of the country plays a vital role in controlling the local temperature and water cycles but is threatened by changing patterns of rainfall and an increase in extreme weather events. Among the most sensitive ecosystems that are vulnerable to the impact of climate variability, Horton Plains National Park and a world heritage location named Sinharaja Rainforest are the most important (Gunatilleke et al., 2008).

Sri Lanka is split into 46 agroecological zones based on rainfall, soil, temperature, and land usage (Panabokke & Kannangara, 1996). These zones are essential to preliminary agricultural planning since they establish which crops are suitable for which geographical areas. However, these zones need to be modified due to growing climatic variability, especially concerning heavy rainfall. To enable farmers and policymakers to adjust their farming methods and ensure long-term food security and agricultural output, these AEZs should be re-demarcated in response to climate change (Panabokke & Kannangara, 1996). This can be extremely helpful to Sri Lanka's adaptation plans by concentrating on the evaluation of climate change's effects on extreme rainfall occurrences and the ensuing reclassification of AEZs.

3.4 Data Collection

As mentioned above in Figure 3-2, this study uses several data types. Some are physically measured data from different organizations, and some are remotely sensed data. They are summarized in Table 3-1.

Table 3-1: Required data and available sources

Data type	Source	Used for
Daily rainfall data for 30 year time period	Meteorological Department	Extreme precipitation analysis
World Clim 30” data	Website	Future predictions of rainfall
DEM	USGS Earth Explorer	Agro-ecological Zoning
Updated soil map	Natural Resource Management Centre	Agro-ecological Zoning
LULC data	LUPPD	Agro-ecological Zoning
Irrigation zones	Mahaweli Authority	Agro-ecological Zoning
Administration boundaries of Sri Lanka	Department of Surveying	Agro-ecological Zoning
Previous AEZ map	Natural Resource Management Centre	Agro-ecological Zoning

The collection of these details and the process of imputing missing data are discussed in this section.

3.4.1 Climate Data

Sri Lanka is mainly divided into three climate zones; wet zone, dry zone, and intermediate zone. With the scope of the study, considering the accuracy of the past precipitation data of the country, I have used physically measured data for the analysis of extreme precipitation events over Sri Lanka. To demarcate the trend on a long-term basis, the trend analysis of climate events has to be done for at least 30-year periods. Considering the conditions, climate zones, and data availability of the meteorological department and other relevant organizations, I have selected 39 rainfall stations that can represent the whole of Sri Lanka as shown in Figure 3-6.

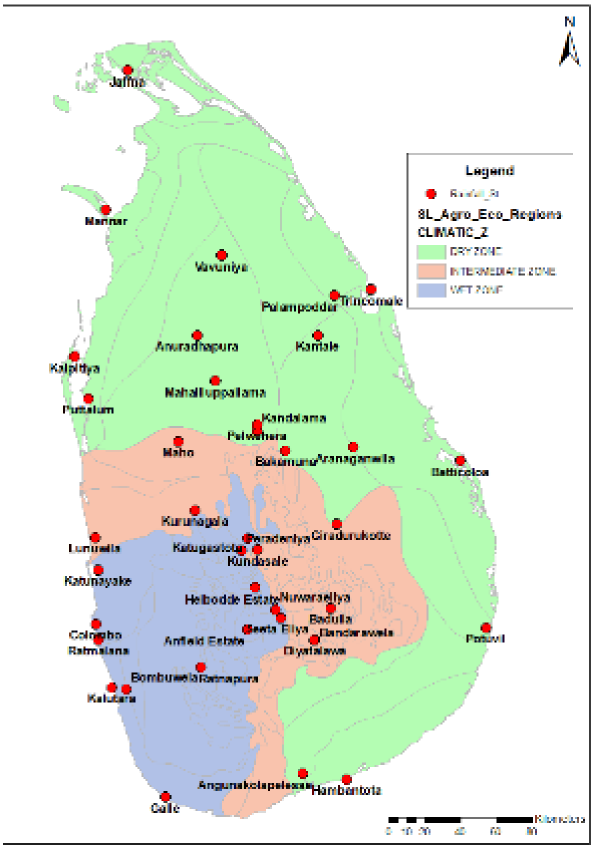


Figure 3-6: Selected rainfall stations

Table 3-2: Rainfall stations in different climate zones

Climatic Zone	Number of Rainfall Stations
Dry Zone	20
Wet Zone	15
Intermediate Zone	4

To get the future predictions of the climate data, there are several models developed by different organizations with different methodologies. Considering the purpose of what the data are used for, and the extent of the study area, we can select a suitable model. Climate models and scenarios that mimic variations in temperature, precipitation, and other variables under various routes of greenhouse gas emissions are usually the basis for future climate projections (Flato et al., 2013).

Among those climate models, the WorldClim dataset is important, it offers high-resolution (about 1 km2) gridded climate data concerning global climate data such as monthly temperature (minimum, maximum, and average), precipitation, solar radiation, wind speed, and vapor pressure. This dataset was created by utilizing thin-plate spline techniques to interpolate weather station data. To increase accuracy, particularly in areas with sparse station networks, satellite-derived variables like cloud cover and land surface temperature were added (Fick & Hijmans, 2017). Because of its great geographic resolution that captures climate fluctuations across different terrains, WorldClim data, which covers a baseline period from 1970 to 2000, is widely used in several scientific domains, including environmental sciences, agriculture, and biodiversity conservation in the South Asian region (Fick & Hijmans, 2017; Kariyawasam et al., 2019). Studies conducted in hilly or steeply varying climate regions, where coarse-resolution datasets might not accurately reflect local circumstances, will find particular use in the data. Assessing the possible effects of climate change requires researchers to analyze historical climate patterns and forecast future changes using downscaled scenarios, which they frequently accomplish using WorldClim data (Kariyawasam et al., 2019).

WorldClim data has been widely used in Sri Lankan agricultural research to examine how climate change affects crop yield, especially in studies pertaining to Village Tank Cascade Systems (VTCS), which facilitate dry zone paddy farming. The Representative Concentration Pathways (RCPs) 4.5 and 8.5, which forecast varied degrees of greenhouse gas concentration trajectories, are two examples of the climate change projections that the dataset helps model (Ratnayake et al., 2023b). It also helps estimate future scenarios of rainfall and temperature trends. To analyze changes in agro-climatic appropriateness, for example, in studies evaluating paddy production, WorldClim data is used to identify sensitive locations where changes in temperature and precipitation patterns potentially affect productivity. Furthermore, the data is essential to methods for modeling species distribution, including the Maximum Entropy (MaxEnt) model, which forecasts the future distribution of ecologically important species, like invasive plants and crops, depending on climatic conditions (Kariyawasam et al., 2019). WorldClim data facilitates a more profound comprehension of climate impacts on agriculture, which in turn aids in the development of adaptable tactics to improve climate resilience and guarantee food security in Sri Lanka's agricultural industry (Ratnayake et al., 2023b).

3.4.2 Handling Missing Data

For the trend analysis of extreme rainfall events, I have taken 40 years of daily precipitation data for all 39 stations. However, after collecting the relevant data from the appropriate authorities, it consisted of some missing data from some time periods throughout the 40 years of the period as shown in Table 3-3. There are several methods to impute missing climate data of a particular area. According to the study (Jayaminda et al., 2023)It mentioned that the MICE missing data imputation method is the most suitable method for rainfall data imputation in Sri Lanka, considering its geography and other parameters.

Table 3-3: Missing rainfall data percentages

Station	Missing Data Percentage (%)	Station	Missing Data Percentage (%)
Anfield Estate	12.41	Katugastota	0.03
Angunakolapelessa	31.74	Katunayake	0.13
Anuradhapura	0.34	Kundasale	18.21
Aranaganwila	31.80	Kurunagala	0.06
Badulla	0.23	Lunuwila	2.80
Bakamuna	14.24	Mahailluppallama	0.96
Bandarawela	5.29	Maho	16.96
Batticoloa	0.79	Mannar	10.01
Bombuwela	32.37	Nuwaraeliya	0.21
Colombo	0.17	Palampoddar	32.73
Diyatalawa	13.79	Pelwehera	14.64
Galle	0.08	Peradeniya	33.87
Giradurukotte	34.51	Potuvil	31.47
Hambantota	0.23	Puttalum	0.07
Helbodde Estate	11.40	Ratmalana	0.03
Jaffna	26.30	Ratnapura	0.41
Kalpitiya	21.32	Sita Eliya	5.13
kalutara	46.77	Trincomale	2.26
Kandalama	22.11	Vauniya	6.00
Kantale	46.96		

The Multiple Imputation by Chained Equations (MICE) method is a prevalent statistical technique for addressing missing data, particularly in climatological research, such as rainfall time series reconstruction (Stuart et al., 2010). Several complete datasets are created by the MICE method. All the missing values are substituted with values that have similar characteristics and patterns in the observed datasets. This method is helpful for time series analysis with gaps because it helps account for the uncertainty that comes with missing data (Buuren & Oudshoorn, 2011).

MICE imputes missing values in the context of rainfall data using regression models that combine data from nearby stations and the target variable itself. The predictive mean matching (PMM) technique, which is frequently applied in MICE, imputes missing values by utilizing the mean of like observations. This preserves the original data's distribution and lowers the possibility of imputed values that are extremely high or low (Jayaminda et al., 2023; Michot et al., 2019).

MICE has been used to handle missing precipitation data across different climatic zones in research focusing on Sri Lanka, and the results reveal lower error rates when the PMM approach is applied. The method works well for high temporal scale analysis, like monthly or daily rainfall, and it works especially well for datasets with random complete missing data (Jayaminda et al., 2023).

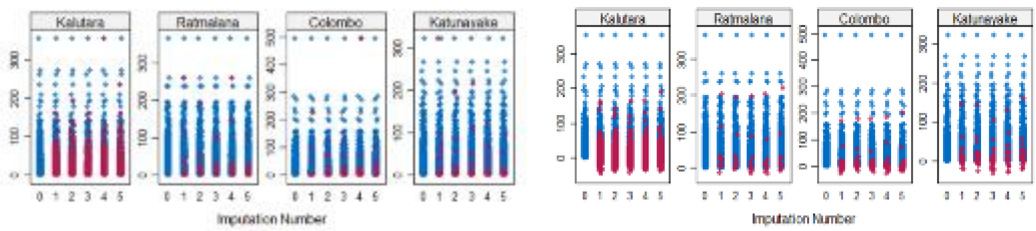


Figure 3-7: Imputation data for some selected stations - Pmm (predictive imputation) method and Norm (normal imputation) method

3.4.3 Calculation of Extreme Rainfall Indices

The Expert Team on Climate Change Detection and Indices (ETCCDI) has recommended extreme precipitation indices, which are extensively utilized for evaluating changes in the frequency, intensity, and duration of extreme climate events. The ETCCDI has defined 27 climate indices, of which 11 of them are specifically focused on extreme precipitation and the rest of them are related to extreme temperature identification (Zhang et al., 2011). The definitions and details of extreme precipitation indices are mentioned in Table 3-4.

Table 3-4: Extreme rainfall indices

Index	Indicator Name	Definition	Units
CDD	Consecutive dry days	Number of maximum consecutive days with RR < 1 mm	Days

CWD	Consecutive wet days	Number of maximum consecutive days with RR > 1 mm	Days
R10mm	Number of heavy precipitation days	Number of days when RR ≥ 10 mm	Days
R20mm	Number of heavy precipitation days	Number of days when RR ≥ 20 mm	Days
R25mm	Number of heavy precipitation days	Number of days when RR ≥ 25 mm	Days
RX1day	Maximum 1-day precipitation amount	Maximum 1-day precipitation	mm
RX5day	Maximum 5-day precipitation amount	Maximum consecutive 5-day rainfall amount	mm
PRCPTOT	Annual total wet day precipitation	Annual total RR in wet days (when RR ≥ 1 mm)	mm
SDII	Dimple daily intensity index	Annual Total RR divided by the number of total wetdays	mm/day
R95p	Very wet days	Annual total rainfall when r > 95th percentile of daily rainfall	mm
R99p	Extremely wet days	Annual total rainfall when r > 99th percentile of daily rainfall	mm

These indicators assist in understanding of changes in precipitation patterns, which is important for evaluating the effects of climate change on hydrological cycles and associated socioeconomic activities.

RClimDex Software

A specific software program called RClimDex is used to calculate climate indices, including those established by ETCCDI. It is an R-based package designed to process daily precipitation and temperature data while guaranteeing homogeneity checks and quality control. By computing the ETCCDI indices automatically, the software provides a consistent method for analyzing climate change. Climate experts choose it because of its automatic handling of missing variables and statistical tools for trend analysis (Zhang et al., 2011).

3.5 Multi-Criteria Analysis

A decision-support method called multi-criteria analysis (MCA) is frequently used in place of benefit-cost analysis to assess options according to a variety of criteria (Gillespie, 2001). MCA has been challenged for its subjectivity and potential for misuse by special interests while widely used in environmental impact assessments in different countries (Dobes & Bennett, 2010; Janssen, 2001)According to critics, MCA's absence of a well-established theoretical framework permits analysts to use diverse criteria and ranking systems, which could produce arbitrary conclusions (Gillespie, 2001). In spite of these reservations, MCA is becoming increasingly popular among academics and professionals across a range of disciplines, including planning and transportation policy (Dean, 2020).

In this study, the multi-criteria analysis approach was used to compare extreme precipitation indices, to identify the areas that are most affected by extreme climate events over different climate seasons in Sri Lanka. The impacts of excessive precipitation across different locations were systematically and robustly evaluated through the use of the analytical hierarchy process (AHP), which also facilitated the comparison of the indices and determined the factor weights for each indicator.

3.5.1 AHP Pairwise Comparison

The Analytic Hierarchy Process (AHP) is a commonly used multi-criteria decision-making method that uses pairwise comparison to identify priorities among the factors that engage with the analysis (Nedashkovskaya, 2022). AHP is criticized for being subjective and inconsistent in weight assignment, despite being appreciated for its simplicity and flexibility (Zarour et al., 2019). Researchers have investigated several strategies to deal with these problems, such as fuzzy pairwise and interval methods (Nedashkovskaya, 2022) and algorithms for automatic weight generation (Zarour et al., 2019). According to simulation experiments comparing the exact eigenvector (EEV) and approximate eigenvector (AEV) approaches, EEV is better for calculating priority vectors (Vinod Kumar & Ganesh, 1996). AHP has been effectively utilized to rank important success variables in a variety of fields, including healthcare management information systems (Hussain M, 2014).

In this study, the pairwise comparison method was used to compare the priorities among the extreme rainfall indices to identify the highly impacted areas from extreme rainfall events in Sri Lanka over different periods, because almost all the other similar studies in the past have only calculated the indices and identified the trends of different indices in particular areas, and haven't done any calculation with combining all the indices like this. This pairwise comparison was done by taking advice from experts, researchers, and people who are engaging in different sectors that can be affected by extreme precipitation events. Therefore, the results from this pairwise comparison are more reliable than the auto-generated comparisons and can get a clear overview regarding the effect of extreme climate events in the country in different sectors.

3.5.2 Identification of Highly Impacted Areas

In this study, highly impacted areas from rainfall are calculated by using extreme precipitation indices established by ETCCDI. With the suggestions from the experts and researchers, and considering the extreme precipitation index values for the last 40 years, identified the most affected parameters which can be affected to agriculture, disasters, and the livelihood of the people. Then, using a pairwise comparison approach, recognized the importance of each of the selected parameters by giving them a weightage.

As the next step in identifying highly impacted areas by extreme precipitation events, raster files were created for each index in the selected period by considering the rainfall seasons of Sri Lanka. Then, using multi-criteria analysis in GIS along with the generated weights by pairwise comparison, relevant maps were created for each climate season. In this analysis, time series modeling in ArcGIS and Python coding were used.

3.6 Re-demarcation of Agro-Ecological Zones

The current agroecological zoning (AEZ) standards in Sri Lanka are based on several important factors, as was covered in earlier sections. These factors include elevation, soil properties, annual rainfall, and patterns of land use and land cover. Compared with the zoning criteria in other countries and agro-ecological zoning guidelines provided by the Food and Agriculture Organization of the United States (FAO), it is shown that some other additional factors need to be considered to enhance the decision-making process of different organizations and individuals.

Comprehensive geographical data were collected which are mentioned in Table 3-1 as part of the process for re-demarcating Sri Lanka's present AEZ, led by the parameters determined by a literature survey (Figure 3-2). To create a more accurate and useful zoning framework, this method guarantees that the new agroecological classification takes into account a wider variety of elements in addition to filling in the gaps and limits in the current system. The resulting classification is intended to increase its usefulness in assisting with well-informed decision-making in a variety of fields, including policy-making, agriculture, and natural resource management.

Six steps will be used for this re-demarcating process, first to develop an agro-climatic zoning map of Sri Lanka by determining the climate indices, the mean temperature, and mean rainfall for each month will be developed taking 75% probability values for 30 years. The agro-climatic zone will be demarcated based on the criteria illustrated in Figure 3-8 & Figure 3-9. The zoning will be done using temporal climate profile analysis and spatial zoning in r-modelling software.

The second step of the study is to determine the agro-topographic classification map of Sri Lanka by using important indicators of slope, aspect and elevation from sea level. The third step is to define the soil zones considering the common soil characteristics.

The fourth step is to study the land use status of the country in terms of key indicators of land use type and land cover, and by matching the desirable areas and removing non-planting regions to consider different types of crop zoning.

In the step five (05), the irrigation potential based agro-ecosystem will be demarcated for cultivation management detailing.

Finally, in step six (06), by integrating different zones in the form of varying raster and vector layers in GIS, with raster calculator tool and vector overlay operations in ArcGIS all layers take the weight and the desired agro-ecological zones will be determined. Resulted AEZ map will be supper imposed over AEZ map of 2003 for finalizing AER map.

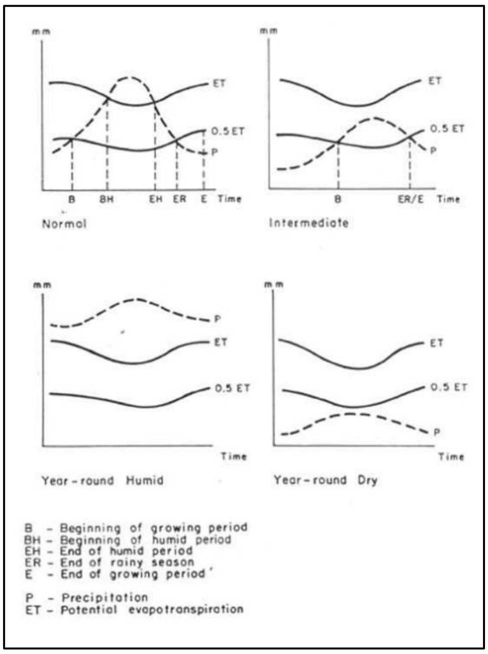


Figure 3-9: Seasonal water availability criteria

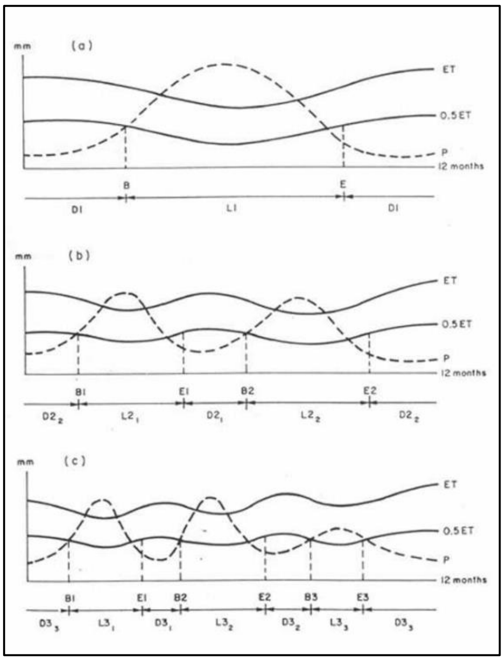


Figure 3-8: Number of rainy season criteria

3.7 Evaluation of Livelihood Impacts

The third and final objective of this study focuses on evaluating the effects on both livelihood and ecosystems of different regions by identifying extreme precipitation-prone regions across various climate zones of Sri Lanka and the re-demarcation of agro-ecological zones. To achieve this task, a comprehensive questionnaire survey was conducted, targeting different groups of stakeholders, including researchers in the agricultural sector, regional agricultural officers, disaster management experts, farmers, and specialists in climate change and agriculture. The survey was conducted through Google Sheets and data was collected from various regions across the country. To evaluate the wider socio-economic and ecological effects of extreme precipitation events, the collected replies were compiled and examined. The findings from this questionnaire survey serve as a basis for offering recommendations on future research opportunities and policy approaches, specifically concerning adaptative methods and sustainable farming practices.

4. RESULTS AND DISCUSSION

4.1 Temporal Variability of Extreme Rainfall Events

The data in Table 3-3 clearly shows that some rainfall stations are missing several rainfall data in the selected period. To overcome this issue, the missing data was imputed using the MICE method combined with the nearby stations with similar rainfall patterns. After preparing the daily rainfall data for 40-year periods, the trend values of each index in all the selected stations were calculated using the RClimDex software package. In this R package, once the indices are calculated, the Mann-Kendell test was used to calculate the significance of the trends at stations over time, and Sen's slope equations were used to calculate the trend values. Therefore, we could get a more reliable outcome through the analysis of this RClimDex package.

4.1.1 Trends Analysis and Regional Differences

Trend values of each index and how they are distributed over Sri Lanka are summarized below.

Consecutive Dry Days

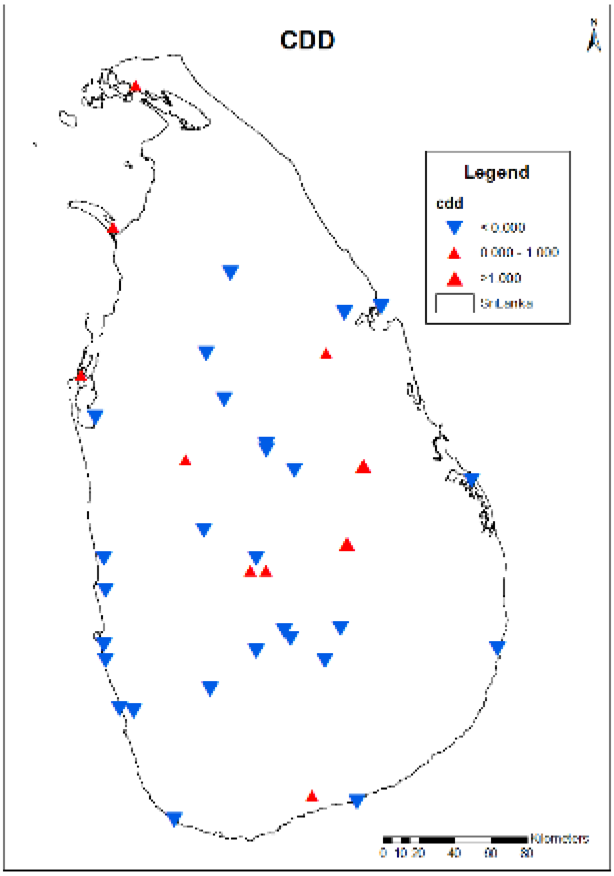


Figure 4-1: Trend analysis of Consecutive Dry Days

Table 4-1: Trend analysis of Consecutive Dry Days

Station	Trend Value	P-value	Station	Trend Value	P-value
Anfield Estate	-0.657	0	Katugastota	-0.225	0.138
Angunakolapelessa	0.535	0	Katunayake	-0.638	0.033
Anuradhapura	-0.158	0.555	Kundasale	0.083	0.762
Aranaganwila	1.353	0	Kurunagala	-0.337	0.101
Bakamuna	-0.817	0.044	Lunuwila	-0.412	0.21
Badulla	-0.128	0.441	Mahailluppallama	-0.115	0.613
Bandarawela	-0.03	0.851	Maho	0.286	0.322
Batticoloa	-0.123	0.671	Mannar	0.898	0.048
Bombuwela	-0.199	0.094	Nuwaraeliya	-0.491	0.006
Colombo	-0.371	0.088	Palampoddar	-0.28	0.459
Diyatalawa	-0.181	0.206	Pelwehera	-0.283	0.351
Galle	-0.23	0.071	Peradeniya	0.113	0.594
Giradurukotte	1.058	0	Potuvil	-0.175	0.567
Hambantota	-0.421	0.076	Puttalum	-0.407	0.2
Helbodde Estate	-0.637	0.002	Ratmalana	-0.231	0.12
Jaffna	0.062	0.842	Ratnapura	-0.231	0.112
Kalpitiya	0.184	0.694	Sita Eliya	-0.326	0.06
Kalutara	-0.784	0	Trincomale	-0.047	0.822
Kandalama	-0.908	0.012	Vavuniya	-0.205	0.431
Kantale	0.609	0.063			

There is clear regional heterogeneity in the patterns of consecutive dry days (CDD) in Sri Lanka during the previous 40 years, with some parts witnessing an increase in dry spells and others seeing a decrease. The spatial distribution of these trends is graphically depicted on the map, with red triangles denoting stations with increasing trends (trend value > 0) and blue triangles representing stations with falling trends (trend value < 0). It is clear that the areas in central regions such as Aranaganwila and Giradurukotte, notably those closer to Anuradhapura and Polonnaruwa districts, tend to exhibit moderate to high increases in CDD. Coastal areas, especially those in the southwest and north, exhibit a combination of increasing and decreasing trends.

Important insights can be gained by closely examining the trend values and statistical significance. The declining trends at Anfield Estate, Bakamuna, Helbodde Estate, Kalutara, and Kandalama are among the stations that show statistically significant reductions in CDD. There aren't as many dry days in a row in certain places, which might mean there is more water available. On the other hand, major increases in CDD are observed at stations such as Aranaganwila, Giradurukotte, and Mannar, suggesting that dry conditions are getting worse and may make drought, agricultural, and water resource issues in these areas worse.

However, not every trend that has been noticed is statistically significant. Although there are changes in CDD in stations like Anuradhapura, Colombo, and Badulla, they are not significant enough to be statistically significant over 40 years. These non-significant patterns imply that although dry spells are changing, they might be more erratic or impacted by regional climate factors.

Consecutive Wet Days (CWD)

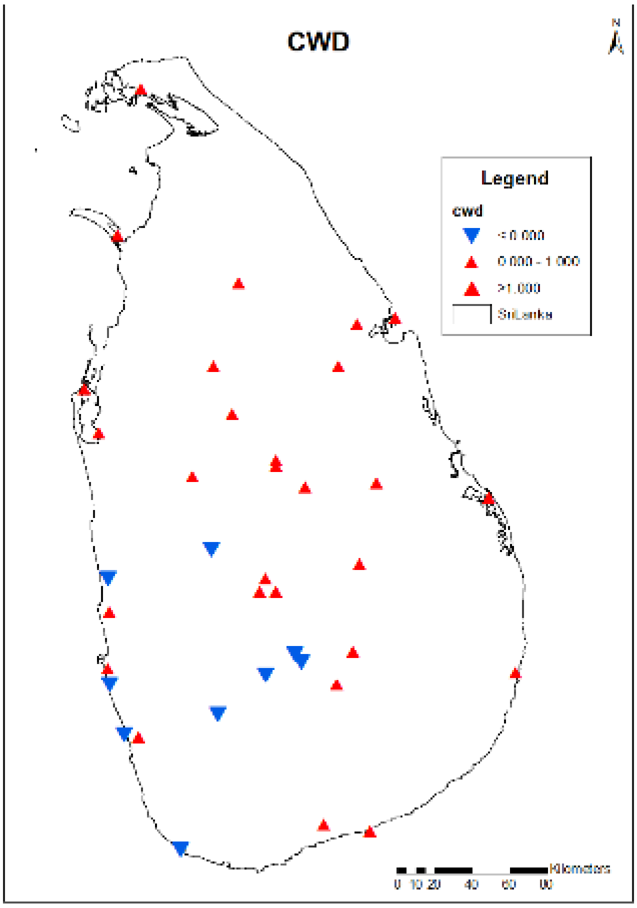


Figure 4-2: Trend analysis of Consecutive Wet Days

Red triangles on the associated map indicate that numerous stations, especially in the country's central and eastern regions, are characterized by rising trends in CWD. This implies that these regions are having longer streaks of precipitation, which could raise the possibility of flooding or agricultural waterlogging. Conversely, stations with declining CWD trends shown by blue triangles are mostly found in coastal locations in the southwest, where wet seasons are getting shorter.

The increase in CWD is shown by statistically significant positive trends at certain stations. For example, there are notable increases in consecutive wet days in Aranaganwila, Anuradhapura, Giradurukotte, Kantalai, and Peradeniya. This could

Table 4-2: Trend analysis of Consecutive Wet Days

Station	Trend Value	P-value
Anfield Estate	-0.292	0
Angunakolapelessa	0.07	0.001
Anuradhapura	0.09	0.014
Aranaganwila	0.244	0
Bakamuna	0.035	0.468
Badulla	0.029	0.577
Bandarawela	0.07	0.268
Batticoloa	0.064	0.314
Bombuwela	0.059	0.326
Colombo	0.065	0.197
Diyatalawa	0.092	0.161
Galle	-0.027	0.485
Giradurukotte	0.162	0.002
Hambantota	0.06	0.012
Helbodde Estate	-0.107	0.135
Jaffna	0.065	0.231
Kalpitiya	0.911	0.098
Kalutara	-0.132	0.055
Kandalama	0.034	0.413
Kantale	0.193	0.001

Station	Trend Value	P-value
Katugastota	0.062	0.089
Katunayake	0.073	0.054
Kundasale	0.047	0.213
Kurunagala	-0.025	0.568
Lunuwila	-0.078	0.169
Mahailluppallama	0.001	0.988
Maho	0.1	0.045
Mannar	0.036	0.267
Nuwaraeliya	-0.134	0.007
Palampoddar	0.081	0.064
Pelwehera	0.052	0.234
Peradeniya	0.214	0
Potuvil	0.133	0.018
Puttalum	0.042	0.295
Ratmalana	-0.017	0.68
Ratnapura	-0.017	0.465
Sita Eliya	-0.039	0.448
Trincomale	0.032	0.531
Vavuniya	0.085	0.045

result in more water being available, but it could also present problems like a higher danger of flooding or crops that are flooded. Though the improvements are modest, some stations, including Angunakolapelessa, also exhibit encouraging trends. On the other hand, a few of stations, like Anfield Estate and Nuwara Eliya, have notable negative trends, suggesting shorter consecutive wet spells. This decline in CWD points to more erratic rainfall patterns in these regions, which could result in water shortages during crucial agricultural times. Although not exhibiting statistically significant changes, areas such as Kalutara are about to experience a large decline in CWD.

When Sri Lanka's trends for continuous dry days (CDD) and consecutive wet days (CWD) are compared, clear regional patterns emerge that point to different climate impacts. Both CDD and CWD are rising in a number of areas, including Aranaganwila and Giradurukotte, suggesting a move toward more extreme weather patterns with longer dry spells interspersed with protracted wet spells. Managing water supplies and reducing the dangers of floods and droughts may be particularly difficult in these locations. As a result of less drought stress and more regular rainfall, locations such as Bakamuna and Anuradhapura are witnessing declines in CDD and rises in CWD, indicating more suitable conditions for agriculture.

Reductions in both dry and wet periods are being observed in some areas, such as Kalutara and Nuwara Eliya, suggesting more dispersed rainfall patterns. Shorter periods of consecutive dry and wet days could result in less severe but more frequent weather changes in certain regions, which could have an effect on crop planning and water storage techniques. Concerns regarding protracted drought conditions and inadequate rainfall to support agriculture and water supplies are further raised by the fact that some areas, like Mannar and Peradeniya, are seeing an increase in dry spells without appreciable increases in rainy periods.

It is significant to remember that seasonal variations, such as monsoons and inter-monsoon periods, have a significant impact on Sri Lanka's climate and rainfall patterns. However, following the Expert Team on Climate Change Detection and Indices' (ETCCDI) recommendations, all of the trend values for CDD and CWD were computed annually for this analysis. The finer intricacies of how seasonal variations affect the frequency and duration of dry and wet spells may be obscured, even though this gives a general idea of changes over time. Therefore, it is essential to perform a seasonal study of these changes to conduct a more comprehensive and clear comparison between CDD and CWD.

R10mm (Number of heavy precipitation days)

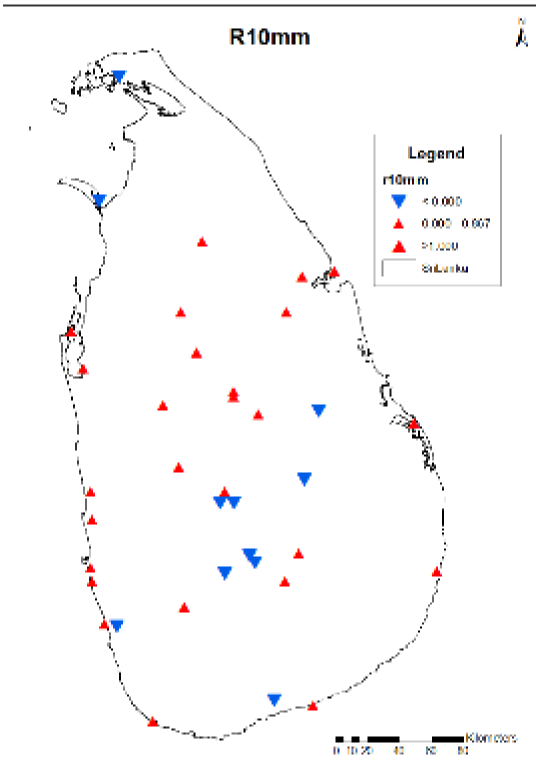


Figure 4-3: Trend analysis of R10mm

Table 4-3: Trend analysis of R10mm

Station	Trend Value	P-value
Anfield Estate	-0.128	0.609
Angunakolapelessa	-1.082	0
Anuradhapura	0.226	0.024
Aranaganwila	-0.983	0
Bakamuna	0.38	0.006
Badulla	0.222	0.103
Bandarawela	0.236	0.104
Batticoloa	0.193	0.145
Bombuwela	-0.047	0.757
Colombo	0.231	0.065
Diyatalawa	0.145	0.242
Galle	0.136	0.3
Giradurukotte	-0.253	0.094
Hambantota	0.155	0.104
Helbodde Estate	0.732	0.004
Jaffna	-0.087	0.481
Kalpitiya	0.867	0.106
Kalutara	0.621	0.001
Kandalama	0.345	0.001
Kantale	0.305	0.012
Katugastota	0.026	0.797
Katunayake	0.001	0.996
Kundasale	-0.065	0.622
Kurunagala	0.028	0.811
Lunuwila	0.063	0.569
Mahailluppallama	0.147	0.114
Maho	0.239	0.044
Mannar	-0.042	0.677
Nuwaraeliya	-0.048	0.732
Palampoddar	0.38	0.164
Pelwehera	0.286	0.006
Peradeniya	-0.161	0.209
Potuvil	0.334	0.003
Puttalum	0.073	0.435
Ratmalana	0.198	0.1
Ratnapura	0.198	0.432
Sita Eliya	-0.015	0.93
Trincomale	0.173	0.141
Vavuniya	0.184	0.07

R20mm (Number of heavy precipitation days)

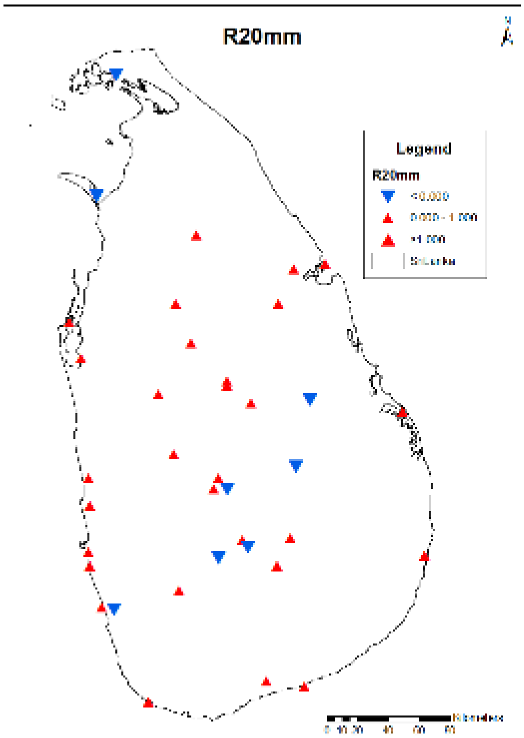


Figure 4-4: Trend analysis of R20mm

Table 4-4: Trend analysis of R20mm

Station	Trend Value	P-value
Anfield Estate	-0.267	0.192
Angunakolapelessa	0.106	0.046
Anuradhapura	0.175	0.032
Aranaganwila	-1.061	0
Bakamuna	0.3	0.004
Badulla	0.153	0.108
Bandarawela	0.163	0.066
Batticoloa	0.209	0.044
Bombuwela	-0.016	0.874
Colombo	0.176	0.068
Diyatalawa	0.094	0.195
Galle	0.132	0.163
Giradurukotte	-0.033	0.776
Hambantota	0.036	0.501
Helbodde Estate	0.645	0.001
Jaffna	-0.058	0.538
Kalpitiya	0.063	0.361
Kalutara	0.692	0
Kandalama	0.252	0.002
Kantale	0.196	0.072
Katugastota	0.036	0.656
Katunayake	0.017	0.846
Kundasale	-0.044	0.596
Kurunagala	0.001	0.994
Lunuwila	0.106	0.203
Mahailluppallama	0.141	0.075
Maho	0.097	0.296
Mannar	-0.032	0.623
Nuwaraeliya	0.001	0.992
Palampoddar	0.326	0.197
Pelwehera	0.161	0.029
Peradeniya	0.018	0.834
Potuvil	0.213	0.008
Puttalum	0.048	0.503
Ratmalana	0.22	0.024
Ratnapura	0.22	0.759
Sita Eliya	-0.003	0.976
Trincomale	0.129	0.164
Vavuniya	0.08	0.278

R25mm (Number of heavy precipitation days)

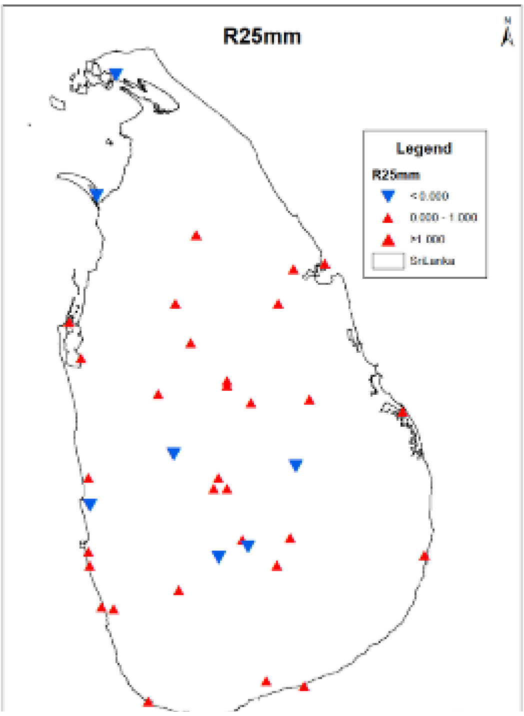


Figure 4-5: Trend analysis of R25mm

Table 4-5: Trend analysis of R25mm

Station	Trend Value	P-value	Station	Trend Value	P-value
Anfield Estate	-0.179	0.293	Katugastota	0.016	0.813
Angunakolapelessa	0.051	0.324	Katunayake	-0.006	0.933
Anuradhapura	0.174	0.013	Kundasale	0.02	0.779
Aranaganwila	0.092	0.288	Kurunagala	-0.018	0.833
Bakamuna	0.27	0.004	Lunuwila	0.069	0.302
Badulla	0.143	0.058	Mahailluppallama	0.125	0.038
Bandarawela	0.121	0.14	Maho	0.067	0.351
Batticoloa	0.163	0.082	Mannar	-0.045	0.424
Bombuwela	0.048	0.607	Nuwaraeliya	0.032	0.678
Colombo	0.193	0.013	Palampoddar	0.294	0.217
Diyatalawa	0.122	0.061	Pelwehera	0.141	0.04
Galle	0.159	0.036	Peradeniya	0.069	0.382
Giradurukotte	-0.103	0.32	Potuvil	0.173	0.01
Hambantota	0.024	0.642	Puttalum	0.096	0.156
Helbodde Estate	0.565	0.001	Ratmalana	0.163	0.047
Jaffna	-0.039	0.591	Ratnapura	0.163	0.857
Kalpitiya	0.035	0.538	Sita Eliya	-0.003	0.968
Kalutara	0.686	0	Trincomale	0.128	0.098
Kandalama	0.218	0.003	Vavuniya	0.1	0.124
Kantale	0.203	0.038			

The majority of stations show positive increases across all three indicators, suggesting an overall rise in rainfall events of various intensities. For R10mm, R20mm, and R25mm, Sri Lanka's central, southern, and western regions continuously exhibit positive trends, indicating that moderate to extremely strong rainfall events are occurring more frequently in these regions. However certain stations exhibit minor increases or negative trends, especially for the more heavy rainfall events recorded by R20mm and R25mm, especially in the country's north and northeast.

Particularly, all three indices exhibit steady and significant increases at stations like Kalutara, Helbodde Estate, and Kandalama, with trend values increasing in parallel with an increase in rainfall intensity. As an example, Kalutara shows the highest trend in all three indices, with values of 0.686 for R25mm and 0.692 for R20mm. In the same way, Helbodde Estate shows notable and statistically significant increases in every index, indicating that rainfall events are becoming significantly more severe in these areas. However, stations like Aranaganwila, Girandurukotte, and Jaffna exhibit negative or marginally positive trends, particularly for R10mm and R20mm, suggesting that there may be fewer days with moderate to heavy rainfall in these places. Aranaganwila specifically exhibits notable declines in R10mm and R20mm, although R25mm trends are less impacted.

Different difficulties can arise in the northern and eastern regions, where there are negative trends or marginal increases in rainfall. Particularly in stations like Aranaganwila and Jaffna, declining patterns in moderate and strong rainfall could indicate water constraints and stress on agricultural systems. To adapt to the shifting rainfall patterns, these regions will need to implement drought-resilient farming methods and water-saving technologies.

Although the ETCCDI (Expert Team on Climate Change Detection and Indices) has established R10, R20, and R25 mm as extreme precipitation indices, it is essential to understand that not all regions may regard rainfall amounts of 10 mm, 20 mm, and 25 mm to be extreme. It is important to carefully consider the unique features of the regions under study when determining the threshold values for high precipitation occurrences, including soil characteristics, land use patterns, local livelihoods, and topography, . Therefore, any conclusions made from these trends must consider the regional context and seasonal fluctuations throughout the year, even if these trend values were computed using the indices developed by the World Meteorological Organization (WMO). The interpretation of trends in rainfall extremes may not accurately reflect the effects on certain locations if these local features are not taken into account. Therefore, additional research should incorporate these specifics to offer a more comprehensive and situation-specific comprehension of rainfall patterns and their consequences.

RX1day (Maximum 1-day precipitation amount)

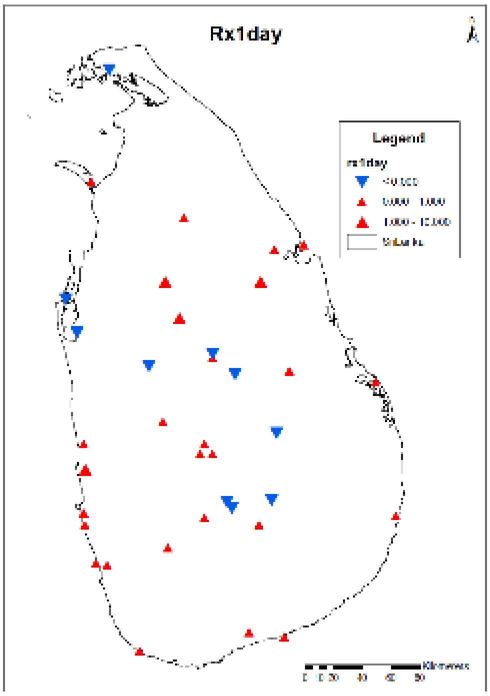


Figure 4-6: Trend analysis of Rx1day

Table 4-6: Trend analysis of Rx1day

Station	Trend Value	P-value
Anfield Estate	0.21	0.744
Angunakolapelessa	0.168	0.695
Anuradhapura	1.395	0
Aranaganwila	0.794	0.22
Bakamuna	-0.163	0.742
Badulla	-0.292	0.545
Bandarawela	0.607	0.093
Batticoloa	0.931	0.204
Bombuwela	0.787	0.236
Colombo	0.385	0.74
Diyatalawa	0.068	0.828
Galle	0.462	0.468
Giradurukotte	-0.432	0.4
Hambantota	0.375	0.355
Helbodde Estate	-0.372	0.745
Jaffna	-0.565	0.628
Kalpitiya	-0.856	0.093
Kalutara	0.871	0.194
Kandalama	0.21	0.649
Kantale	1.39	0.064
Katugastota	0.209	0.592
Katunayake	1.15	0.121
Kundasale	0.308	0.441
Kurunagala	0.8	0.169
Lunuwila	0.361	0.637
Mahailluppallama	1.044	0.081
Maho	-0.022	0.955
Mannar	0.191	0.809
Nuwaraeliya	-0.252	0.47
Palampoddar	0.05	0.913
Pelwehera	-0.5	0.256
Peradeniya	0.15	0.767
Potuvil	0.504	0.463
Puttalum	-1.315	0.039
Ratmalana	0.156	0.861
Ratnapura	0.156	0.471
Sita Eliya	-0.23	0.484
Trincomale	0.463	0.345
Vavuniya	0.898	0.19

RX5day (Maximum 5-day precipitation amount)

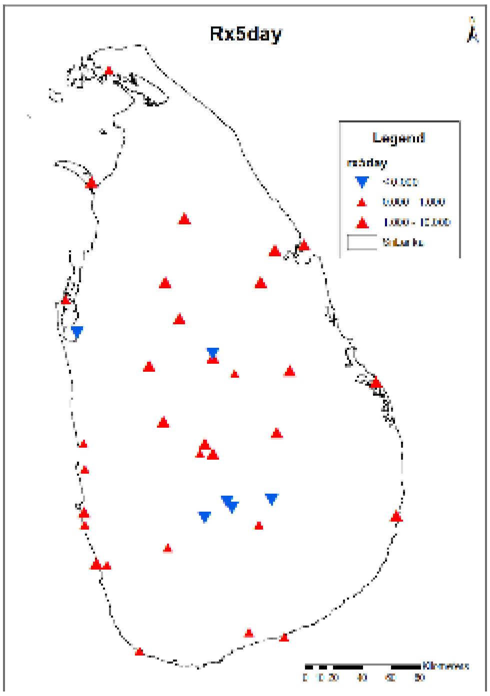


Figure 4-7: Trend analysis of Rx5day

Table 4-7: Trend analysis of Rx5day

Station	Trend Value	P-value
Anfield Estate	-0.526	0.634
Angunakolapelessa	0.865	0.14
Anuradhapura	2.624	0.001
Aranaganwila	2.849	0.005
Bakamuna	0.758	0.44
Badulla	-0.425	0.738
Bandarawela	0.491	0.464
Batticoloa	5.068	0.004
Bombuwela	0.919	0.345
Colombo	1.093	0.327
Diyatalawa	0.014	0.982
Galle	0.69	0.504
Giradurukotte	1.314	0.242
Hambantota	0.577	0.303
Helbodde Estate	1.045	0.476
Jaffna	0.59	0.738
Kalpitiya	0.36	0.653
Kalutara	1.46	0.127
Kandalama	1.265	0.151
Kantale	2.974	0.053

Station	Trend Value	P-value
Katugastota	1.285	0.07
Katunayake	0.756	0.505
Kundasale	1.166	0.113
Kurunagala	1.207	0.254
Lunuwila	0.429	0.73
Mahailluppallama	2.043	0.045
Maho	1.003	0.184
Mannar	1.103	0.278
Nuwaraeliya	-0.852	0.277
Palampoddar	1.602	0.136
Pelwehera	-1.068	0.293
Peradeniya	0.926	0.367
Potuvil	1.943	0.113
Puttalum	-0.606	0.539
Ratmalana	0.408	0.737
Ratnapura	0.408	0.83
Sita Eliya	-0.801	0.33
Trincomale	1.903	0.065
Vavuniya	1.481	0.126

The RX1day and RX5day indices, computed annually using daily rainfall data, reveal significant spatial and temporal diversity in extreme rainfall patterns in Sri Lanka. The RX1day index is essential for detecting flash floods since it shows each station's highest annual single-day rainfall event. The RX5day index, on the other hand, provides information about the probability of flooding and landslides in the areas by displaying the highest total rainfall over five days in a row. Both indices are measured in days as units.

According to the trend values given in Table 4-6, Anuradhapura, Mahailuppallama, and Kantale are among the stations that show positive and statistically significant increases in the RX1day trends, suggesting that the frequency of extreme one-day rainfall events is increasing, especially in the dry and intermediate zones. On the other hand, statistically significant drops are seen at several stations, including Puttalam, indicating a decline in intense rainfall events in these regions. Particularly in areas exhibiting increasing trends, the spatial dispersion emphasizes the necessity of localized adaptation methods.

Similar to that, the RX5day index study shows that many stations, including Batticaloa, Anuradhapura, Kantale, and Aranaganwila, have notable positive trends, suggesting an increase in extended periods of heavy rainfall. This pattern emphasizes the need for improved flood control measures, particularly in areas where such circumstances are common. Although there are negative tendencies in some places, such as Pelwehera and Nuwara Eliya, these are not statistically significant, meaning that more observation is required to confirm any significant changes.

A seasonal analysis is necessary to properly comprehend the obvious influence of these variables because Sri Lanka has seasonal change in rainfall, with different regions receiving varying amounts throughout the year. A more thorough understanding of extreme rainfall patterns and their impacts could be obtained by seasonal analysis, enabling more accurate and successful mitigation and adaptation plans.

PRCPTOT (Annual Total Precipitation)

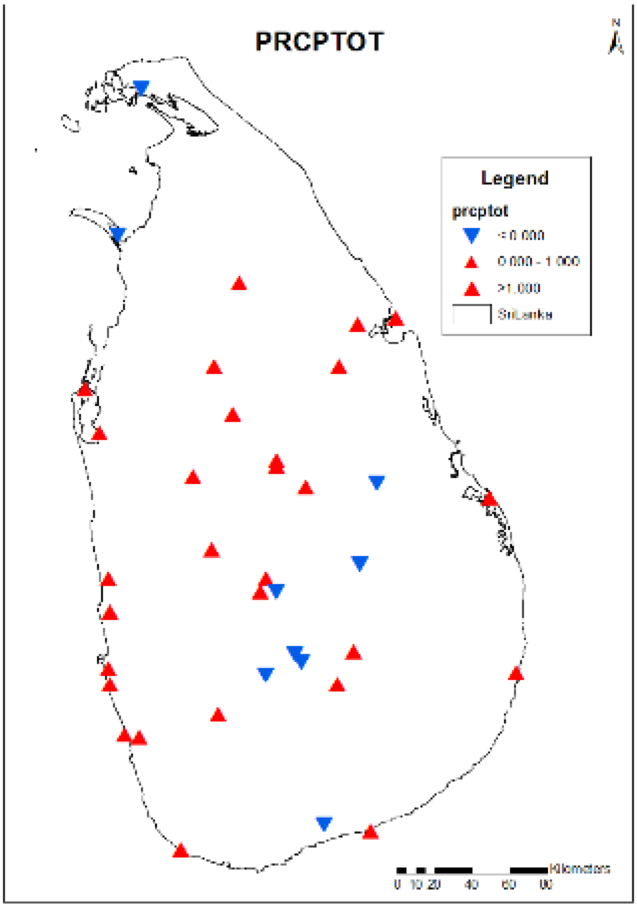


Figure 4-8 : Trend analysis of PRCPTOT

A varied pattern of variations can be seen when the rainfall trend figures from different Sri Lankan stations are analyzed. Rainfall has significantly increased at a number of stations, with very high positive trend values shown at places like Kalutara (30.081), Potuvil (13.367), and Palampoddar (25.281). Increased rainfall patterns are also shown by other stations, such as Pelwehera (8.804), Trincomalee (9.253), and Batticoloa (17.008), indicating that precipitation levels are noticeably rising in these regions.

Table 4-8: Trend analysis of PRCPTOT

Station	Trend Value	P-value
Anfield Estate	-5.934	0.534
Angunakolapelessa	-9.633	0.006
Anuradhapura	12.001	0.006
Aranaganwila	-18.576	0.006
Bakamuna	16.376	0.007
Badulla	5.742	0.203
Bandarawela	7.474	0.097
Batticoloa	17.008	0.016
Bombuwela	3.175	0.595
Colombo	10.474	0.032
Diyatalawa	5.7	0.116
Galle	9.485	0.062
Giradurukotte	-7.819	0.248
Hambantota	3.976	0.201
Helbodde Estate	27.617	0.006
Jaffna	-1.806	0.75
Kalpitiya	10.679	0.103
Kalutara	30.081	0
Kandalama	15.834	0.001
Kantale	16.337	0.021

Station	Trend Value	P-value
Katugastota	2.395	0.529
Katunayake	1.983	0.688
Kundasale	-0.719	0.859
Kurunagala	1.924	0.667
Lunuwila	2.878	0.492
Mahailluppallama	7.124	0.066
Maho	3.461	0.47
Mannar	-2.202	0.555
Nuwaraeliya	-1.8	0.66
Palampoddar	25.281	0.174
Pelwehera	8.804	0.04
Peradeniya	1.092	0.797
Potuvil	13.367	0.003
Puttalum	1.206	0.765
Ratmalana	7.619	0.145
Ratnapura	7.619	0.906
Sita Eliya	-0.923	0.841
Trincomale	9.253	0.085
Vavuniya	7.829	0.058

Not only that, several stations show tendencies of declining rainfall. Anfield Estate (-5.934) and Giradurukotte (-7.819) also show negative trends, while Angunakolapelessa (-9.633) and Aranaganwila (-18.576) show notable reductions. some declines could indicate possible issues with drought or decreasing water supplies in some areas.

With a P-value of 0, stations such as Kalutara exhibit the most significant trend when assessing the statistical significance of these trends. This confirms a strong rise in rainfall. Significant positive trends are also seen at other sites, including Potuvil (P = 0.003), Helbodde Estate (P = 0.006), Anuradhapura (P = 0.006), and Kantale (P = 0.021). On the other hand, significant negative trends with low P-values are shown by Angunakolapelessa, Aranaganwila, and Batticoloa, further supporting the observed alterations. The high P-values of certain stations, such as Katugastota, Kurunegala, and Nuwara Eliya, indicate that the variations in rainfall patterns at these sites are not statistically significant. This suggests that the patterns seen in these domains within the examined time frame might not be significant or accurate.

The data shows a varied pattern of rainfall variations throughout Sri Lanka, with some locations, particularly coastal and central areas like Kalutara and Potuvil, seeing increases in rainfall while others, such as Aranaganwila, show declining patterns. Since the regions with the biggest changes may need focused intervention to address the effects of these changing rainfall patterns, these findings have substantial ramifications for agriculture, water resource management, and disaster preparedness.

SDII (Simple Daily Intensity Index)

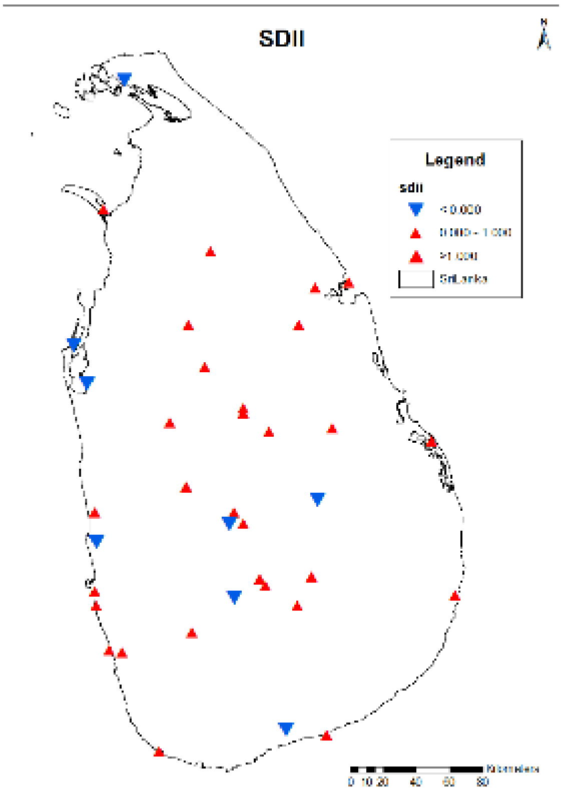


Figure 4-9: Trend analysis of SDII

The Simple Daily Intensity Index (SDII), which is normally computed annually, calculates the average intensity of precipitation on wet days (Days that have precipitation greater than 1mm) over a given period. Here the analysis is done considering that the stations are experiencing similar rainfall variation throughout the year. It is a crucial statistic for comprehending precipitation patterns and evaluating possible flood threats since it offers information on the typical amount of rainfall every rainy day.

According to the statistics, there is a noticeable rise in the intensity of the daily rainfall at stations such as Aranaganwila (trend value of 0.149 and p-value of 0.001) and

Batticaloa (trend value of 0.158 and p-value of 0.004). The decline is not statistically significant, however, as other stations, such as Anfield Estate, display a negative trend (-0.064) with a p-value of 0.153. Furthermore, the dependability of these trends is confirmed by stations with low p-values, like Kalutara (trend value of 0.106 and p-value of 0.001), which indicate a persistent pattern of increasing rainfall intensity in those places.

Table 4-9: Trend analysis of SDII

Station	Trend Value	P-value	Station	Trend Value	P-value
Anfield Estate	-0.064	0.153	Katugastota	0.023	0.271
Angunakolapelessa	-0.027	0.221	Katunayake	-0.005	0.881
Anuradhapura	0.09	0.012	Kundasale	0.035	0.061
Aranaganwila	0.149	0.001	Kurunagala	0.026	0.323
Bakamuna	0.12	0.003	Lunuwila	0.043	0.2
Badulla	0.03	0.187	Mahailluppallama	0.047	0.1
Bandarawela	0.043	0.061	Maho	0.112	0.011
Batticoloa	0.158	0.004	Mannar	0.047	0.211
Bombuwela	0.003	0.931	Nuwaraeliya	0.006	0.729
Colombo	0.047	0.137	Palampoddar	0.103	0.436
Diyatalawa	0.035	0.085	Pelwehera	0.001	0.989
Galle	0.044	0.105	Peradeniya	-0.016	0.644
Giradurukotte	-0.006	0.877	Potuvil	0.038	0.531
Hambantota	0.004	0.893	Puttalum	-0.018	0.605
Helbodde Estate	0.128	0.033	Ratmalana	0.027	0.367
Jaffna	-0.028	0.574	Ratnapura	0.027	0.777
Kalpitiya	-0.027	0.564	Sita Eliya	0.018	0.421
Kalutara	0.106	0.001	Trincomale	0.081	0.058
Kandalama	0.063	0.108	Vavuniya	0.075	0.045
Kantale	0.048	0.461			

R95p (Very wet days)

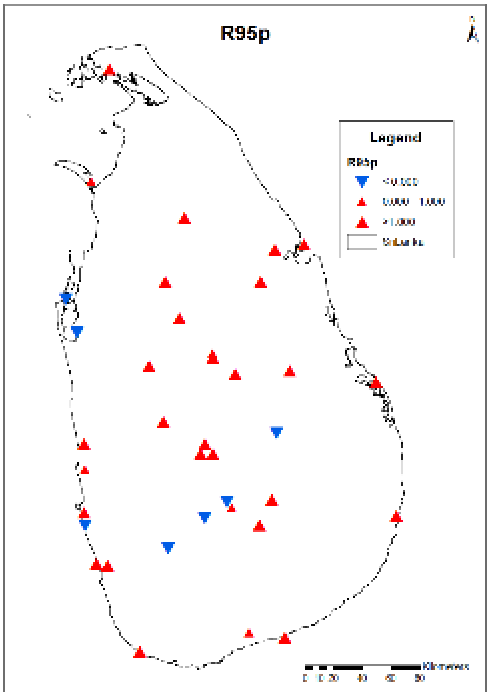


Figure 4-10: Trend analysis of R95p

Table 4-10: Trend analysis of R95p

Station	Trend Value	P-value
Anfield Estate	-6.27	0.237
Angunakolapelessa	0.648	0.781
Anuradhapura	7.422	0.011
Aranaganwila	6.814	0.061
Bakamuna	5.508	0.048
Badulla	1.493	0.543
Bandarawela	5.015	0.029
Batticoloa	12.921	0.004
Bombuwela	3.393	0.395
Colombo	4.273	0.302
Diyatalawa	4.558	0.046
Galle	6.777	0.11
Giradurukotte	-0.264	0.944
Hambantota	1.914	0.364
Helbodde Estate	11.482	0.063
Jaffna	1.76	0.56
Kalpitiya	-1.464	0.537
Kalutara	4.45	0.239
Kandalama	7.83	0.013
Kantale	8.362	0.048

Station	Trend Value	P-value
Katugastota	2.627	0.367
Katunayake	0.296	0.931
Kundasale	3.502	0.124
Kurunagala	1.977	0.379
Lunuwila	2.331	0.4
Mahailluppallama	2.584	0.287
Maho	3.246	0.203
Mannar	0.5	0.812
Nuwaraeliya	-1.001	0.669
Palampoddar	3.143	0.481
Pelwehera	0.776	0.775
Peradeniya	3.289	0.325
Potuvil	5.341	0.073
Puttalum	-2.01	0.466
Ratmalana	-0.152	0.969
Ratnapura	-0.152	0.7
Sita Eliya	0.791	0.782
Trincomale	4.464	0.166
Vavuniya	4.267	0.114

R99p (Extremely Wet Day Rainfall)

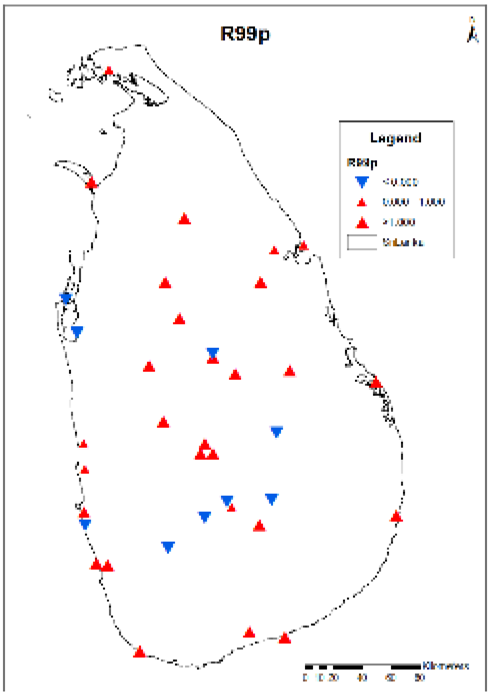


Figure 4-11: Trend analysis of R99p

Table 4-11: Trend analysis of R99p

Station	Trend Value	P-value
Anfield Estate	-0.531	0.846
Angunakolapelessa	1.242	0.425
Anuradhapura	5.584	0.001
Aranaganwila	3.922	0.084
Bakamuna	1.641	0.36
Badulla	-0.491	0.793
Bandarawela	1.903	0.115
Batticoloa	4.109	0.149
Bombuwela	4.063	0.16
Colombo	3.206	0.321
Diyatalawa	0.938	0.482
Galle	1.896	0.448
Giradurukotte	-2.034	0.316
Hambantota	1.181	0.343
Helbodde Estate	3.401	0.26
Jaffna	0.518	0.832
Kalpitiya	-1.935	0.14
Kalutara	2.298	0.369
Kandalama	2.478	0.091
Kantale	2.639	0.276

Station	Trend Value	P-value
Katugastota	2.735	0.172
Katunayake	0.725	0.742
Kundasale	1.777	0.142
Kurunagala	2.796	0.131
Lunuwila	0.916	0.659
Mahailluppallama	3.529	0.036
Maho	1.86	0.237
Mannar	1.218	0.521
Nuwaraeliya	-0.15	0.93
Palampoddar	0.232	0.923
Pelwehera	-0.065	0.968
Peradeniya	2.57	0.217
Potuvil	1.385	0.492
Puttalum	-2.441	0.151
Ratmalana	-0.109	0.969
Ratnapura	-0.109	0.818
Sita Eliya	0.633	0.693
Trincomale	0.592	0.788
Vavuniya	2.106	0.225

The R95p and R99p indices are important indices in analyzing extreme rainfall events. They quantify cumulative precipitation above the 95th and 99th percentile thresholds from a chosen baseline period to calculate the trend value for the selected period. The trend values determined using these indices aid in locating regions where the frequency or severity of extreme rainfall events is changing. The technique offers a systematic way to analyze patterns of excessive precipitation by adhering to the ETCCDI (Expert Team on Climate Change Detection and Indices) methodology.

For the R95p index, stations like Batticaloa (12.921, p-value = 0.004), Anuradhapura (7.422, p-value = 0.011), and Kandalama (7.83, p-value = 0.013) show notable increases in extreme rainfall. certain stations show an increasing trend of intense rainfall events, which may exacerbate infrastructure issues and flooding in certain areas. Aranaganwila (6.814, p-value = 0.061) and Helbodde Estate (11.482, p-value = 0.063) also show moderate increases. However, these patterns are not statistically significant at the 5% level, indicating the need for additional research. On the other hand, stations like Kalpitiya (-1.464, p-value = 0.537) and Anfield Estate (-6.27, p-value = 0.237) show declines in extreme rainfall. The absence of statistical significance suggests that natural variability rather than regular patterns may cause these declines.

Similar trends can be detected in the R99p index, with notable increases observed in Mahailuppallama (3.529, p-value = 0.036) and Anuradhapura (5.584, p-value = 0.001). These findings point to a higher likelihood of heavy rainfall occurrences in these areas, which could affect infrastructure and nearby residents. Positive trends are also seen at other stations, such as Aranaganwila (3.922, p-value = 0.084) and Kandalam (2.478, p-value = 0.091); however, their p-values suggest that these increases are not statistically significant, indicating the need for further research. While certain stations show declining patterns, including Giradurukotte (-2.034, p-value = 0.316) and Puttalam (-2.441, p-value = 0.151), the lack of statistical significance indicates that these declines may not be a persistent pattern.

The frequency and precise timing of these incidents within the year are not taken into consideration by the trend values in the R95p and R99p indices, although they offer important insights into the spatial distribution of extreme rainfall. The seasonal timing and frequency of extreme precipitation, which are crucial for comprehending the hazards and effects of these patterns, are not included in the ETCCDI methodology. To improve readiness, implement focused mitigation initiatives, and gain a better understanding of the overall climatic impact on various regions of Sri Lanka, seasonal analysis is therefore required to ascertain when and how frequently extreme rainfall events occur.

When all of these extreme precipitation indices are taken into account, R95p and R99p indices are directly associated with disasters brought on by extreme rainfall events. Records of landslides, floods, and flash floods show that the frequency of these natural disasters has risen over time as a result of global climate change. Knowing the frequency of these catastrophic events as well as the time frame in which they occur is crucial for performing a thorough investigation of these disasters and their connection to excessive precipitation. However, this specific information is not provided by the ETCCDI calculations.

Therefore, results derived using the RClimDex software for both the R95p and R99p indices were used in a different analysis. In this investigation, the number of extreme precipitation events that occurred was calculated, together with the threshold values for the 95^{th} and 99^{th} percentiles at each rainfall station. A thorough decadal analysis was also conducted, and the data were compiled based on Sri Lanka's rainfall seasons for simpler presentation and further analyses. Below is a summary of the computed outcomes.

Decadal and seasonal analysis of R95p

Figure 4-13 shows a comprehensive analysis of extreme precipitation occurrences over 40 years. It clearly shows the number of rainfall occurrences in each decade and how they vary over all selected stations. In addition to that, the spatial distribution of the same analyzed data is shown Figure 4-12, providing a clear visual representation of how the extreme events have changed over selected time in geographically in Sri Lanka. According to the values in this analysis, some specific stations like Anuradhapura, Aranaganwila, and Badulla show a significant increment in extreme rainfall events, particularly in the first inter-monsoon period. This trend suggests a changing seasonal rainfall pattern, underscoring the significance of comprehending regional climate variability and its possible effects on these regions.

Decadal and seasonal analysis of R99p

Similar to the R95 analysis, the same decadal and seasonal analysis was done on all the stations to identify the occurrences of extreme precipitation events, in which the precipitation is greater than the 99^{th} percentile of the selected baseline period. According to the analysis results, it shows that most of the stations have not experienced such a huge rainfall in some decades, and almost all stations show the total number of occurrences is less than 10 (Figure 4-14). These results only show the variation of extreme precipitation occurrences during the first inter-monsoon period. Comparing the values given in the table with R95p values, it can be concluded that R95p has given much weightage to disasters that happened due to extreme precipitation events in recent decades compared to the past.

Likewise, this analysis was done for all rainfall seasons of Sri Lanka and this analysis results were taken into consideration for the identification of impacted areas from extreme rainfall events, instead of directly using the trend values extracted by RClimDex software.

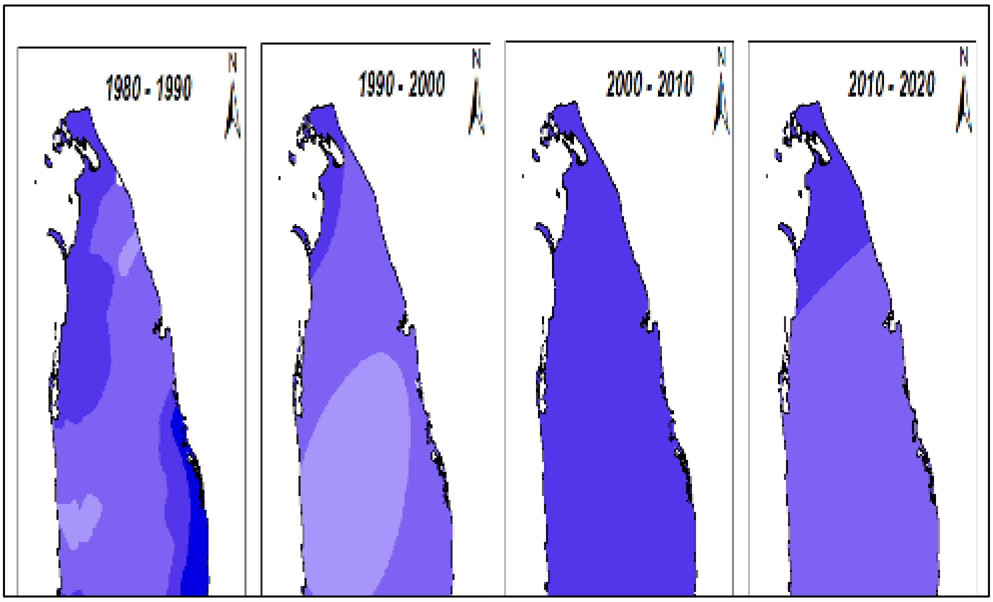


Figure 4-12: Decadal heavy rainfall maps in FIM

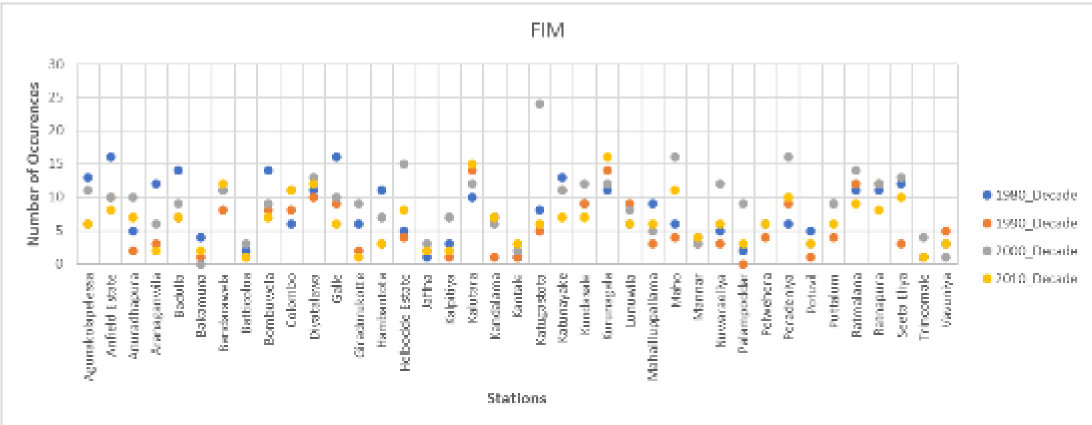


Figure 4-13:Decadal heavy rainfall distribution of all rainfall stations

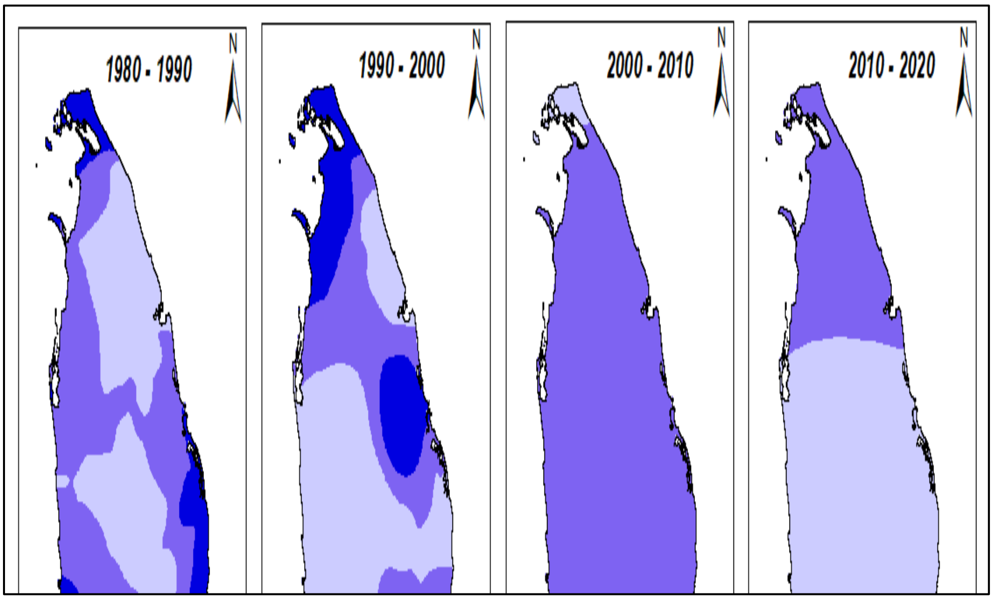


Figure 4-15: Decadal extreme rainfall maps in FIM

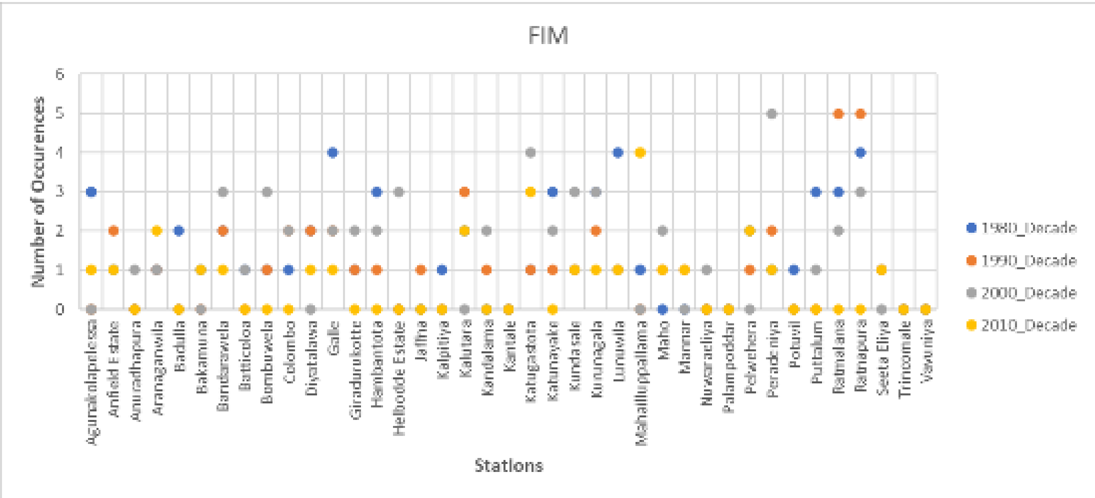


Figure 4-14: Decadal extreme rainfall distribution of all rainfall stations

4.1.2 Identification of Highly Impacted Areas

Similar research on trend analysis of extreme rainfall indices was conducted in Sri Lanka in past years considering data from different periods and using different stations (Jayawardena et al., 2018; Premalal et al., 2020; Thevakaran et al., 2019). In all those studies, they have given the trend values of all the indices in each selected station as their outcome. However, there is a need to identify the overall impact of these extreme precipitation indices, to the easiness of the decision-making process of different organizations and different people.

Considering the trend value and p-value given from the trend analysis using RClimDex software, we can see that, most of the stations are not showing significant increases or decreases in their trends. Therefore, making decisions by analyzing those trend values will not be given an accurate outcome. With the guidance of the expertise of the related fields, I have proposed a multi-criteria analysis to combine all these index values and get one result, that can identify the areas that are highly affected by the extreme precipitation during different climate seasons of the year.

As the first step, I have identified the most affected extreme rainfall indices for agriculture, occurring disasters, and livelihood of the people with the discussions of the expertise and the analysis of recorded climate data for the past 40 years. During that analysis, seven indices were identified to do the multi-criteria analysis. To calculate the factor values of the selected factors, an AHP pair-wise comparison method was used, and collected the values for comparison from experts and researchers from different sectors, like agriculture, climate change, and disaster management through a small questionnaire survey (Figure 4-16).

Primary Questionnaire sheet: Effective criteria and pair wise comparison (AHP)										
Factor	More Importance than				Equal	Less importance than				Factor
R99p	5	4	3	2	1	2	3	4	5	PRCPTOT
R99p	5	4	3	2	1	2	3	4	5	R10mm
R99p	5	4	3	2	1	2	3	4	5	R20mm
R99p	5	4	3	2	1	2	3	4	5	R25mm
R99p	5	4	3	2	1	2	3	4	5	R95p
R99p	5	4	3	2	1	2	3	4	5	RX5day
R95p	5	4	3	2	1	2	3	4	5	PRCPTOT
R95p	5	4	3	2	1	2	3	4	5	R10mm
R95p	5	4	3	2	1	2	3	4	5	R20mm
R95p	5	4	3	2	1	2	3	4	5	R25mm
R95p	5	4	3	2	1	2	3	4	5	RX5day
RX5day	5	4	3	2	1	2	3	4	5	PRCPTOT
RX5day	5	4	3	2	1	2	3	4	5	R10mm
RX5day	5	4	3	2	1	2	3	4	5	R20mm
RX5day	5	4	3	2	1	2	3	4	5	R25mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R10mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R20mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R25mm
R25mm	5	4	3	2	1	2	3	4	5	R10mm
R25mm	5	4	3	2	1	2	3	4	5	R20mm
R20mm	5	4	3	2	1	2	3	4	5	R10mm

Figure 4-16: Priliminary questionnaire sheet

After the collection of the values from the questionnaire survey, the final factor values were calculated with a series of matrix calculations. Complete details of the questionnaire survey and calculation process is attached in Appendix D – Questionnaire survey on Extreme rainfall and new Agroecological zones.

Table 4-12: Final Factor values from AHP pairwise comparison

Index	Weightage
R99p	0.24
R95p	0.2
RX5day	0.27
PRCPTOT	0.12
R25mm	0.08
R20mm	0.06
R10mm	0.04

After the weightage calculation of each factor, multi-criteria analysis was done using ArcGIS 10.8 software, as the raster analysis. For this analysis, the data extracted by RClimDex software and the raw data from the meteorological department were re-classified on a monthly basis, and monthly spatial distribution maps for all the indices were created for 40 years. The spatial distribution of maps was created using the Kriging interpolation method, which was recommended as the best method for rainfall interpolation in Sri Lanka considering the geography of the country (Wijemannage et al., 2016).

The multi-criteria analysis was conducted for each set of raster files every month, and the monthly affected area map was created for each month over 40 years. While doing this analysis, the raster files were reclassified based on the criteria mentioned in Table 4-13.

Table 4-13: Re-classification criteria of extreme rainfall indices

Index	Criteria used for re-classification	Re-classification method (5 classes)
R99p	Based on the range of incidents that happened in Sri Lanka in the particular month	Natural break (Jenks)
R95p	Based on the range of incidents that happened in Sri Lanka in the particular month	Natural break (Jenks)
RX5day	Based on the range of values and the 95^{th} percentile as the threshold	Manual
PRCPTOT	Based on the range of monthly rainfall cumulative in Sri Lanka and the monthly rainfall threshold (150mm)	Manual
R25mm	Based on the range of values in Sri Lanka at a particular month	Natural break (Jenks)

R20mm	Based on the range of values in Sri Lanka at a particular month	Natural break (Jenks)
R10mm	Based on the range of values in Sri Lanka at a particular month	Natural break (Jenks)

After creating all the monthly maps for all indices, created a seasonal-wise average map of the highly affected areas from extreme precipitation events as shown in the Figure 4-17.

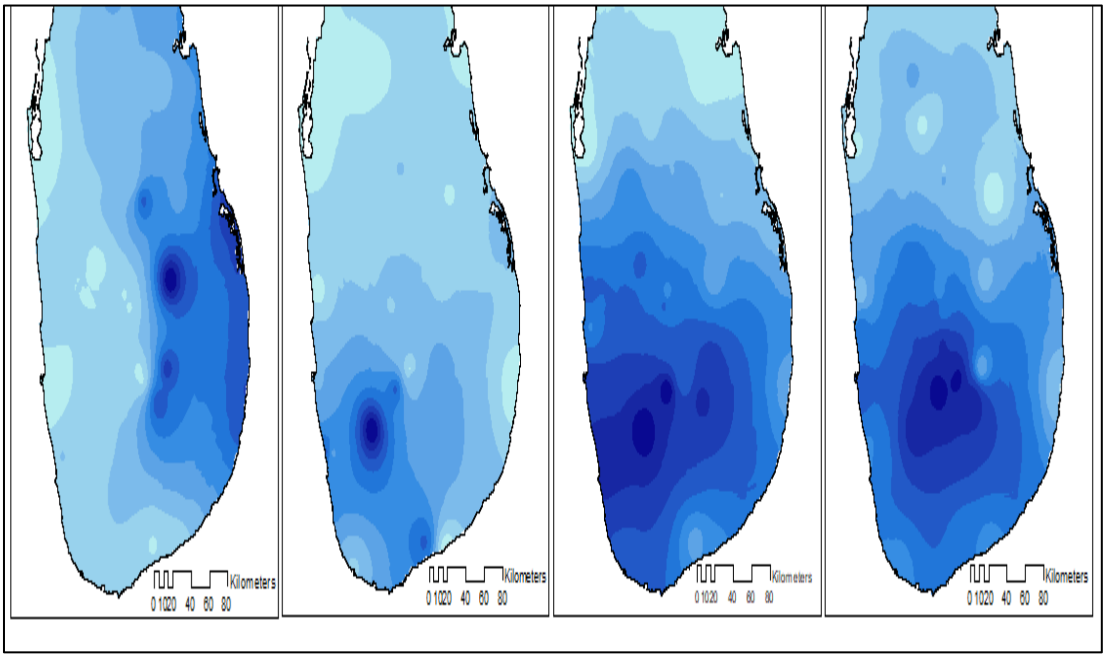


Figure 4-17: Final high risk zone map by extreme precipitation

Compared to the trend analysis values of each index, we can get a clear understanding of the effect of extreme rainfall events from this analysis and it is easy to understand the spatial distribution of the analyzed data over Sri Lanka in different time scales. According to the extreme rainfall-affected area map, we can see that during the northeast monsoon season, the eastern part of the country has a higher probability of facing extreme precipitation events. When it moves to the first inter-monsoon and southwest monsoon periods, the probability of having extreme rainfall events moves to the western and central parts of the country. During the second inter-monsoon period, extreme rainfall events mostly happened around the central highlands of Sri Lanka.

4.2 Historical and Future Climate of Sri Lanka

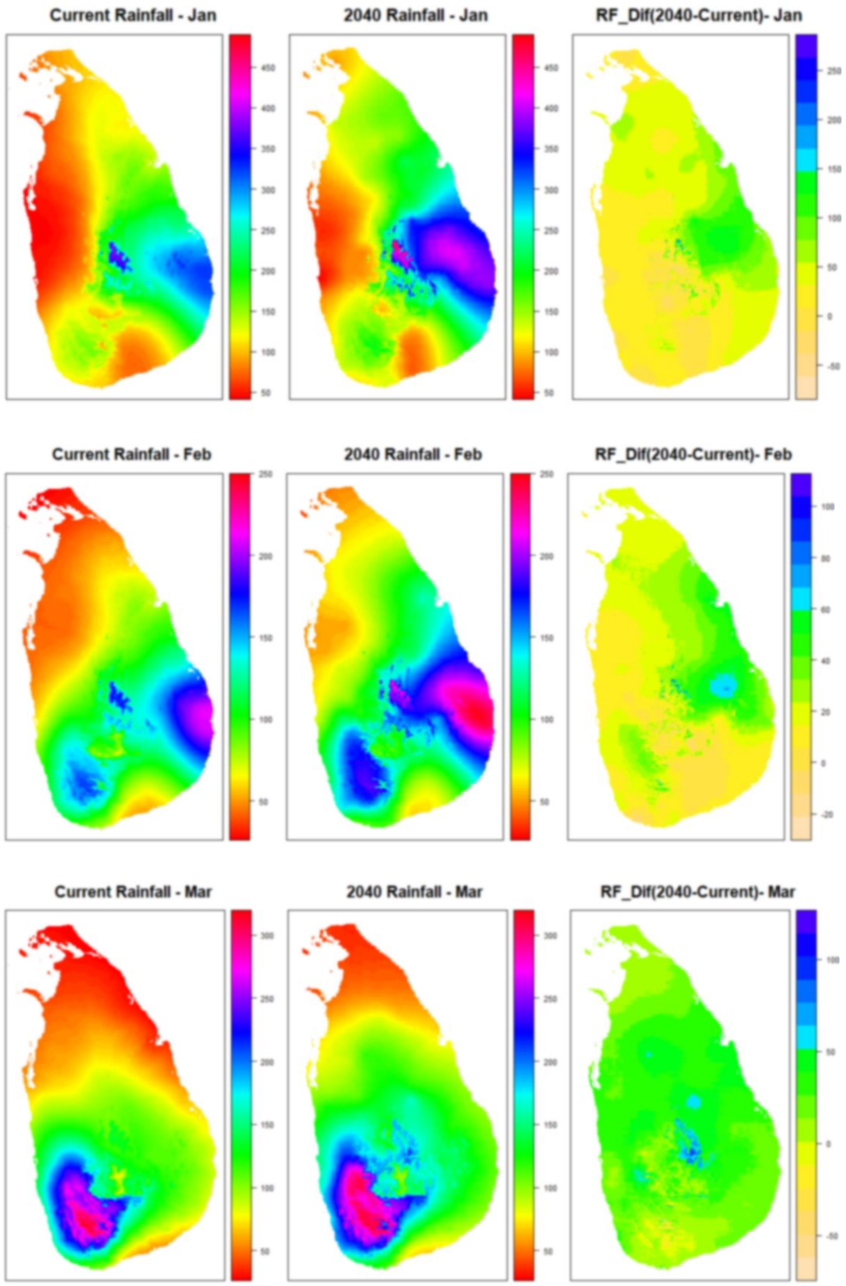
The climate of Sri Lanka has undergone significant changes over time, influenced by both natural variability and human-induced factors. As a tropical island, Sri Lanka experiences a monsoonal climate, with distinct wet and dry seasons that have shaped its agricultural practices, ecosystems, and water resources. Long-term monthly historical climate maps show spatial and temporal patterns of temperature, changing rainfall variability, and shifting monsoonal behavior, all of which have significant implications for critical sectors such as agriculture. In particular, crop-wise vulnerability to climate change has emerged as a pressing concern, with key crops like paddy, plantation or perennial crops (coconut, tea, rubber, fruits, cinnamon, ect.) and seasonal crops (vegetables, other field crops, etc.) showing varying levels of sensitivity to changing agro-climatic conditions. Looking to the future, climate projections indicate further shifts in temperature, precipitation, and the frequency of extreme weather events, which will intensify the challenges faced by agriculture and food security. Understanding both historical trends and future projections, as well as their specific impacts on crop vulnerability, is essential for formulating targeted adaptation strategies. This section explores these dynamics, drawing from climate models and regional assessments to emphasize the need for proactive and crop-specific adaptation measures.

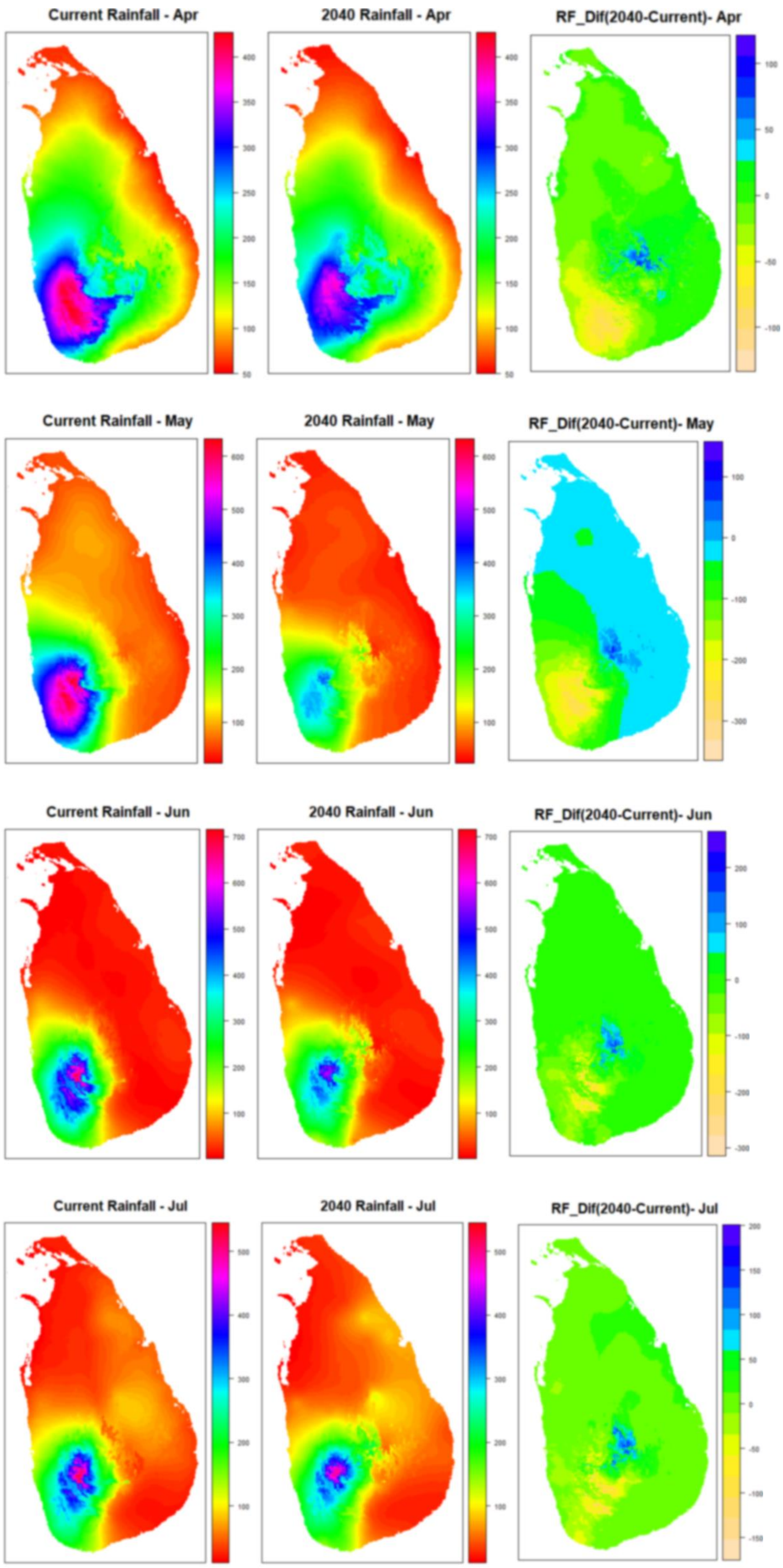
4.2.1 Historical/ Current Climate

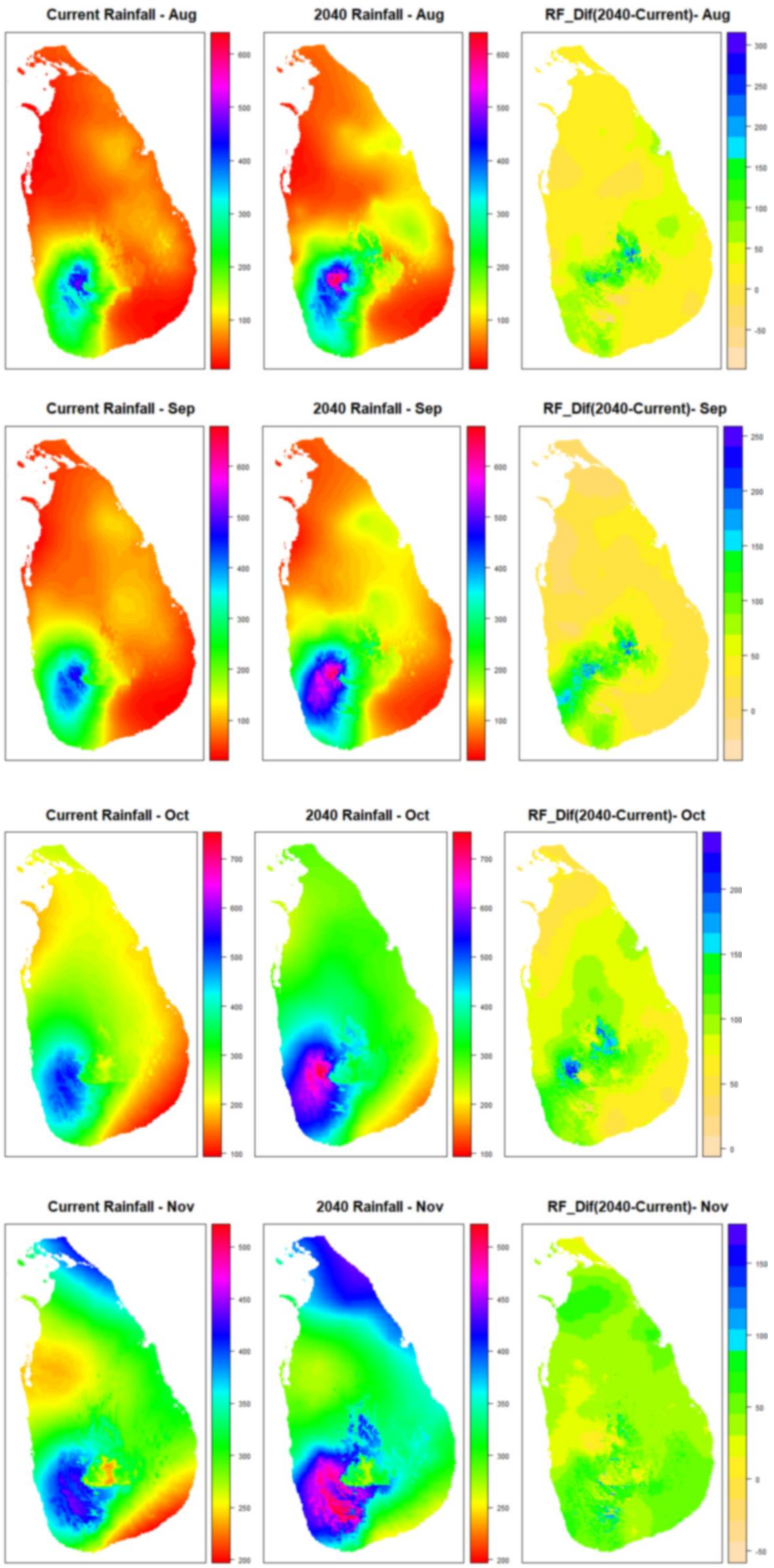
Sri Lanka's climate is predominantly tropical, influenced by monsoonal patterns that have historically driven the island's weather systems. The southwest monsoon (May to September) and northeast monsoon (December to February) dictate rainfall distribution, which is critical for agriculture and water resources. Over the past century, historical climate data has revealed a gradual increase in average temperatures, fluctuations in seasonal rainfall patterns, and a rise in the frequency of extreme weather events such as floods and droughts. Additionally, shifts in the timing and intensity of monsoons have created uncertainty in agricultural planning. The current climate, marked by warmer temperatures and more erratic rainfall, exacerbates water scarcity and soil degradation, especially in semi-arid regions. Importantly, historical and current temperature data serve as a baseline for assessing crop growth potential when considering projected climate changes. By establishing this baseline, it becomes possible to evaluate the impacts of future climate shifts on crop yields, pest pressures, and growing seasons, enabling the development of more targeted and effective adaptation strategies. Maps developed for historical/current climate are given in next chapters.

The above-mentioned monthly rainfall and temperature GIS raster map layers with other map layers such as elevation, soil, slope, etc. were further processed for crop potential growth analysis in the vulnerability mapping and agro-ecological zone demarcating process. Those climate map layers were further processed to get perfectly aligned GIS with other GIS data sets by processing for grid snapping, grid aligning, and value format adjustments by using r-modeling software to develop stacked raster data set development for vulnerability assessment with MaxEnt software.

4.2.2 Rainfall distribution over Sri Lanka – Current (2024) vs Predicted (2040)




Current Rainfall - Apr
2040 Rainfall - Apr
RF_Dif(2040-Current)- Apr
Current Rainfall - May
2040 Rainfall - May
RF_Dif(2040-Current)- May
Current Rainfall - Jun
2040 Rainfall - Jun
RF_Dif(2040-Current)- Jun
Current Rainfall - Jul
2040 Rainfall - Jul
RF_Dif(2040-Current)- Jul


Current Rainfall - Aug
2040 Rainfall - Aug
RF_Dif(2040-Current)- Aug
Current Rainfall - Sep
2040 Rainfall - Sep
RF_Dif(2040-Current)- Sep
Current Rainfall - Oct
2040 Rainfall - Oct
RF_Dif(2040-Current)- Oct
Current Rainfall - Nov
2040 Rainfall - Nov
RF_Dif(2040-Current)- Nov

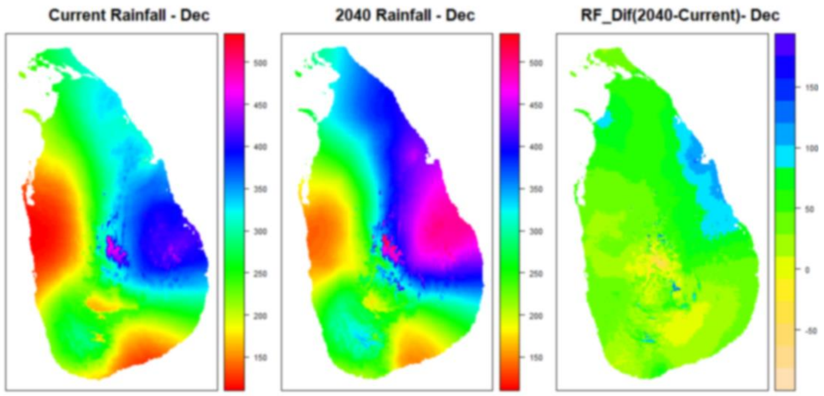
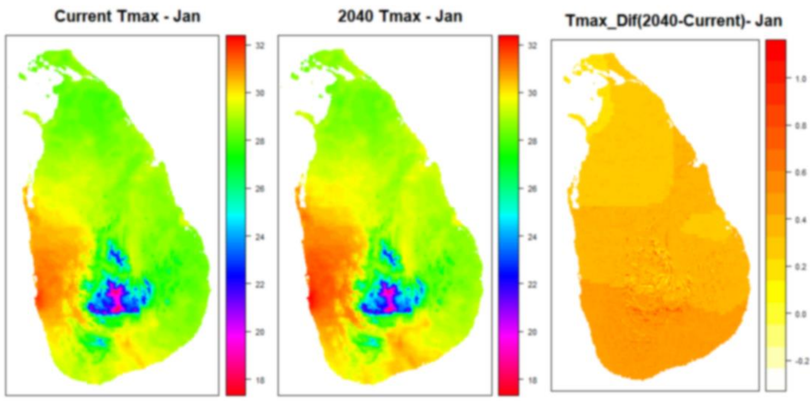


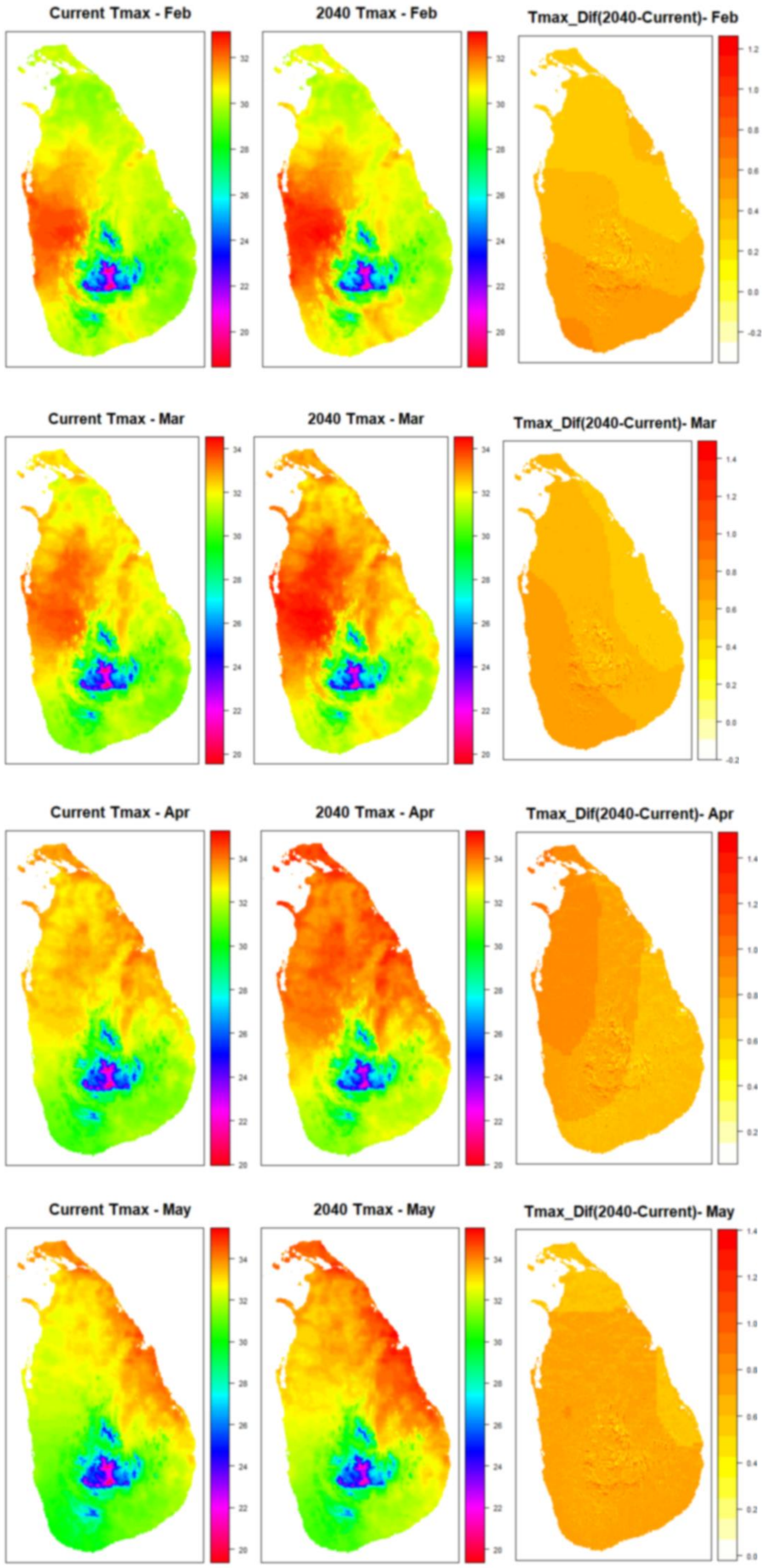
Figure 4-18: Current vs Predicted rainfall distribution over Sri Lanka

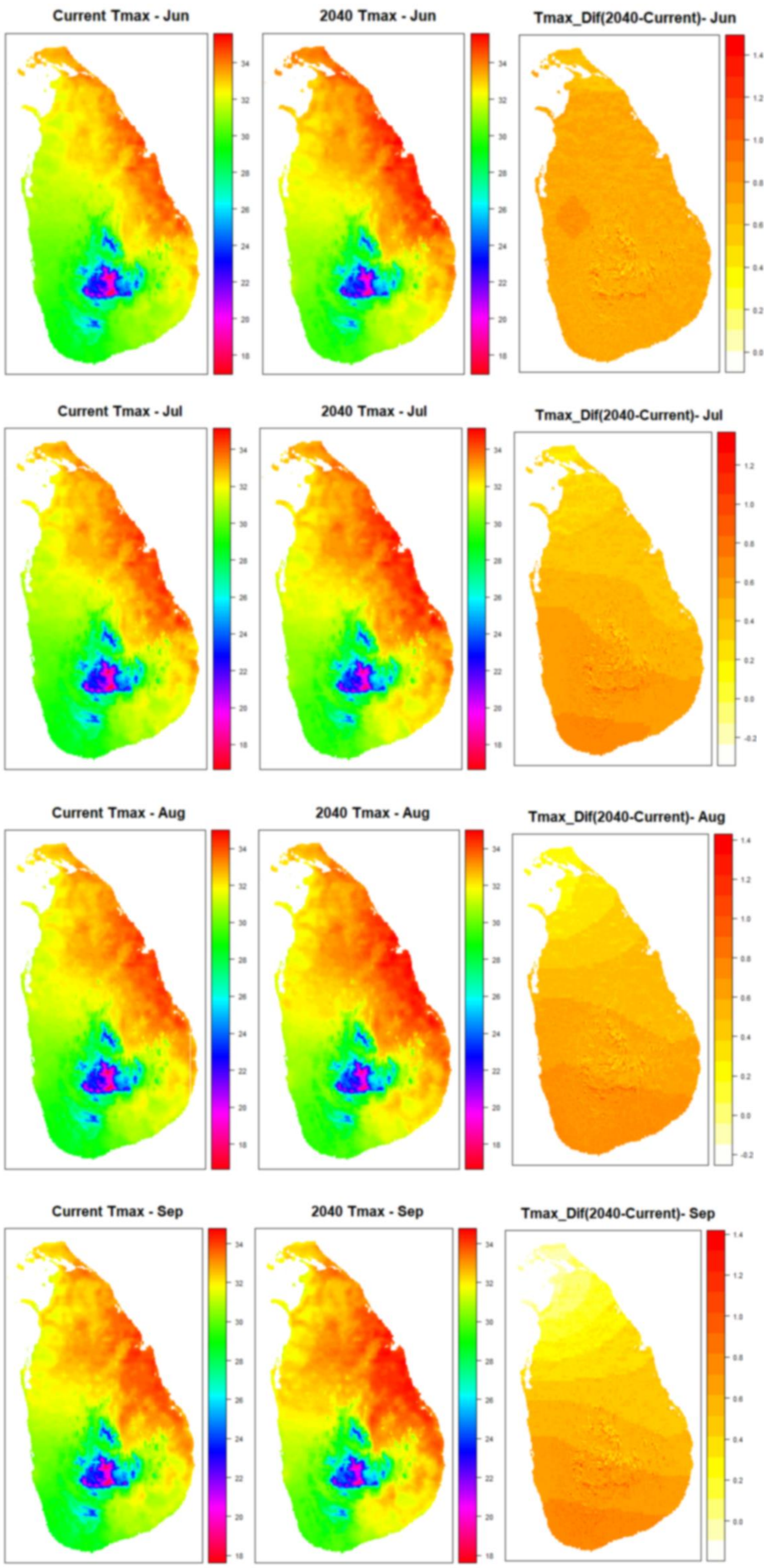
The current rainfall distribution, the rainfall forecast for 2040 based on WorldClim data, and the associated changes in rainfall whether an increase or decrease by 2040 are the three main visualizations that show the spatial distribution of rainfall over Sri Lanka in Figure 4-18. The current rainfall variability map was also created using WorldClim data in order address the lack of ground-based rainfall data, which is limited to 39 stations throughout. A more comprehensive overview of rainfall dynamics throughout Sri Lanka was made possible by this method, which guaranteed improved geographical coverage and improved the precision of detecting increases or declines in rainfall.

According to the values in these maps, it can be clearly seen that the rainfall of Sri Lanka is increasing by 2040 in a considerable amount. More increment of rainfall can be experienced in central highlands and north-east areas of Sri Lanka.

4.2.3 Maximum Temperature Distribution over Sri Lanka – Current (2024) vs Predicted (2040)




Current Tmax - Feb
2040 Tmax - Feb
Tmax_Dif(2040-Current)- Feb
Current Tmax - Mar
2040 Tmax - Mar
Tmax_Dif(2040-Current)- Mar
Current Tmax - Apr
2040 Tmax - Apr
Tmax_Dif(2040-Current)- Apr
Current Tmax - May
2040 Tmax - May
Tmax_Dif(2040-Current)- May


Current Tmax - Jun
2040 Tmax - Jun
Tmax_Dif(2040-Current)- Jun
Current Tmax - Jul
2040 Tmax - Jul
Tmax_Dif(2040-Current)- Jul
Current Tmax - Aug
2040 Tmax - Aug
Tmax_Dif(2040-Current)- Aug
Current Tmax - Sep
2040 Tmax - Sep
Tmax_Dif(2040-Current)- Sep

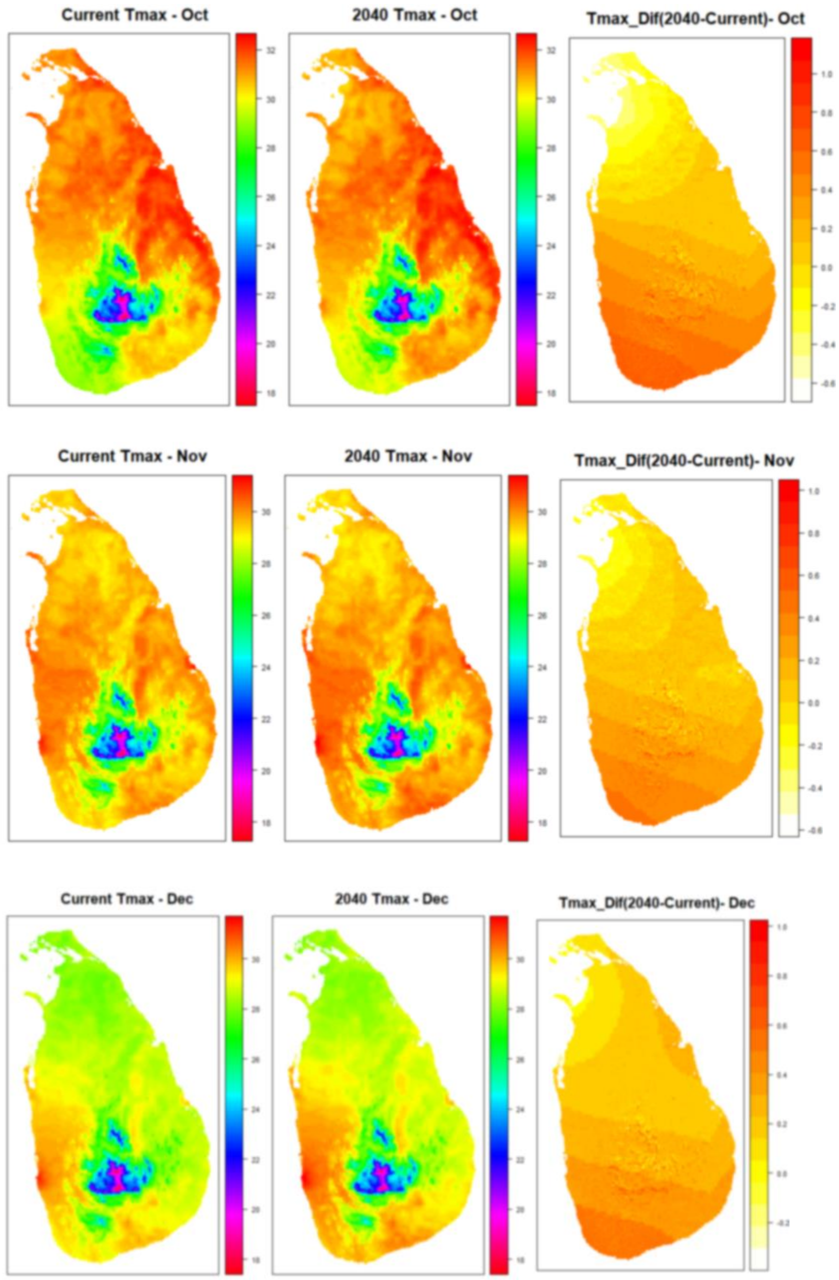
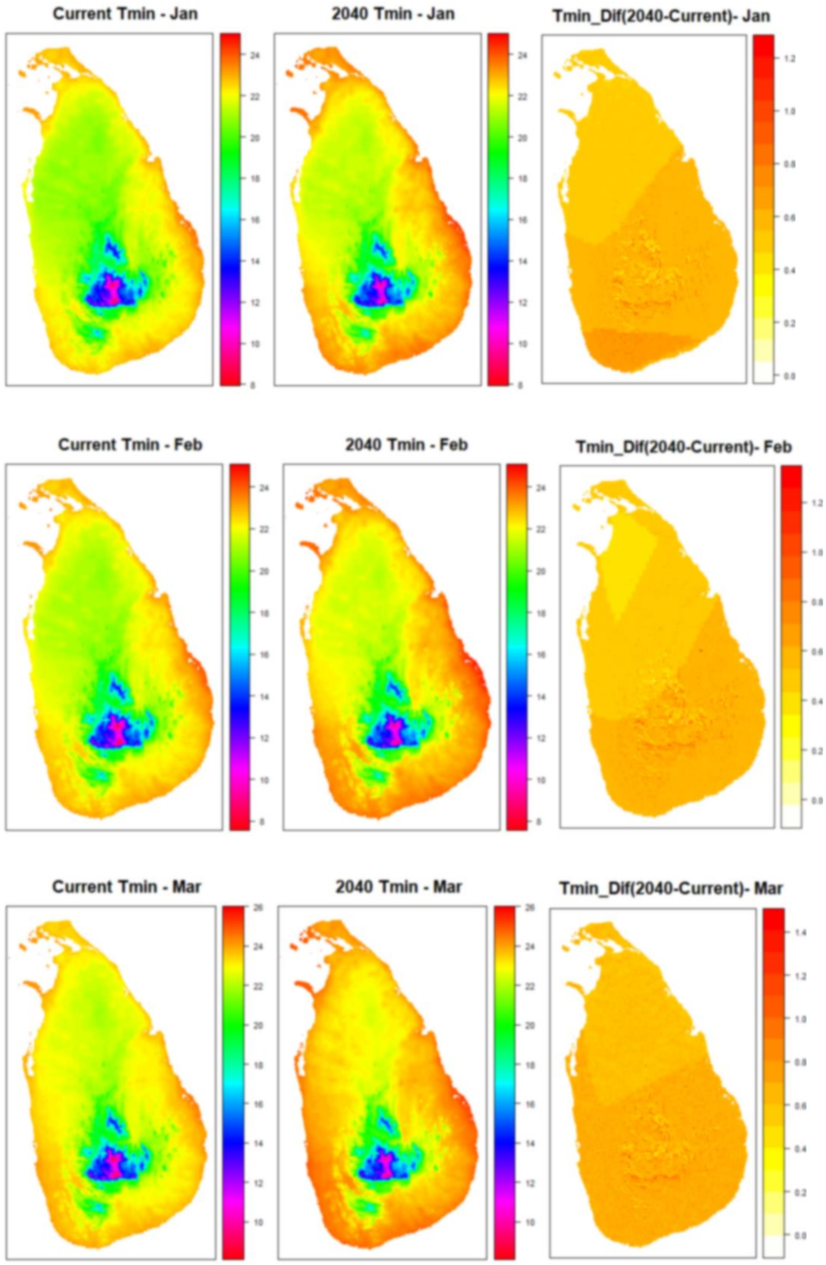
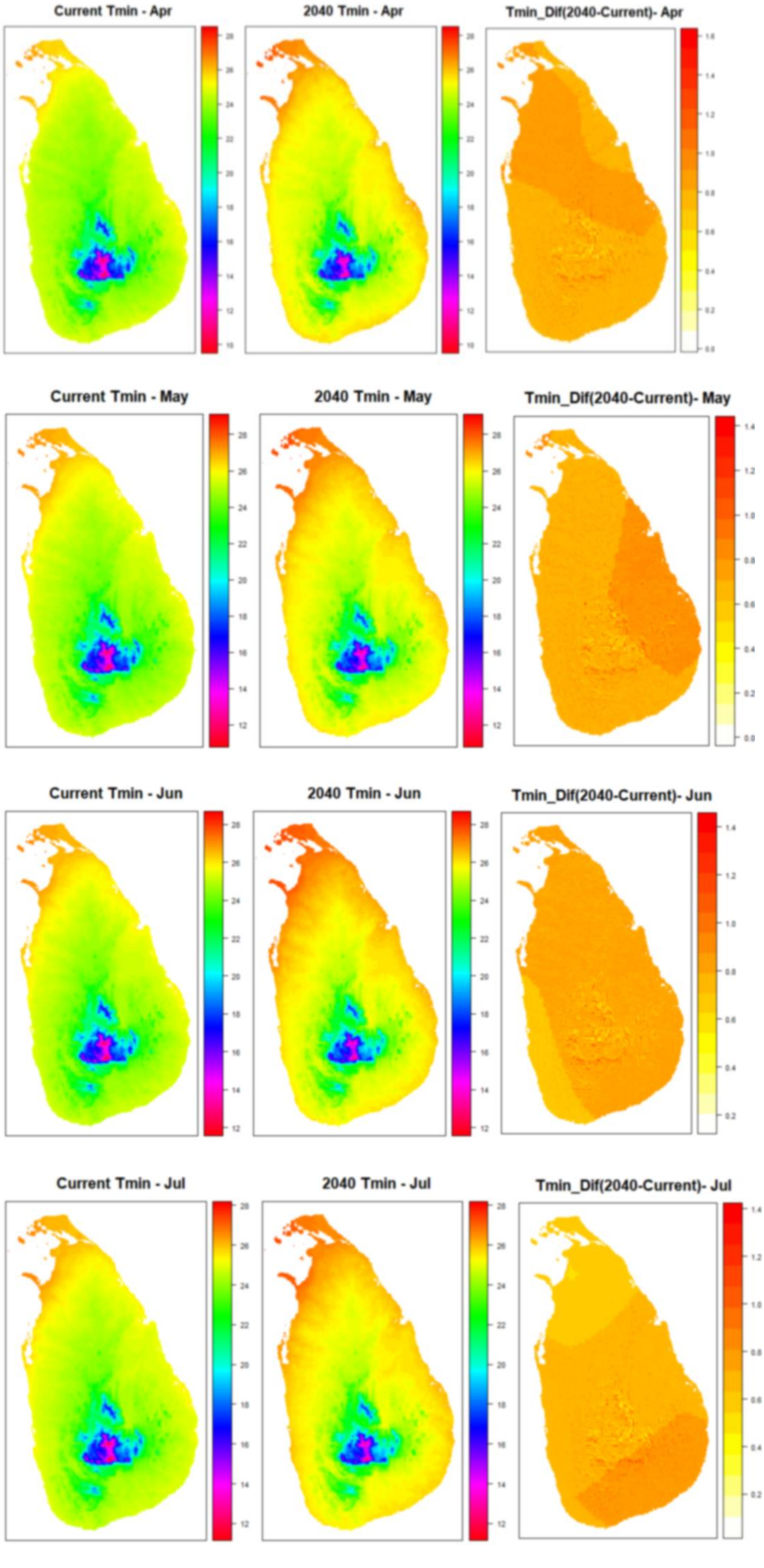


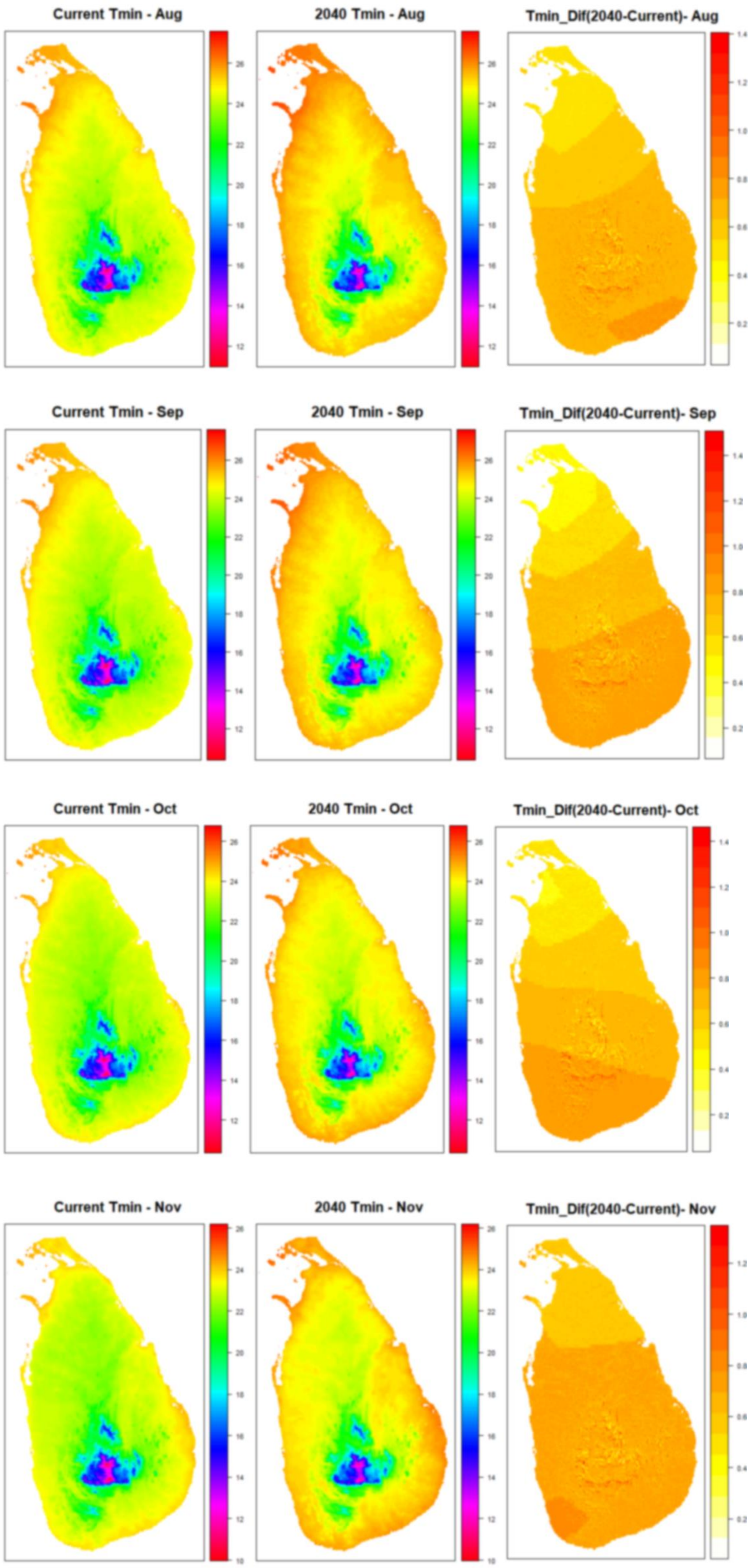
Figure 4-19: Current vs Predicted Maximum Temperature distribution over Sri Lanka

Maximum temperature maps were created to examine the present and projected temperature distributions, much like the rainfall variability maps. These maps offer important new information about the spatial trends of temperature variations in Sri Lanka. The findings indicate that by 2040, the maximum temperature is expected to rise by an average of about 0.6°C over the country. This slight increase draws attention to the slow warming trend, which may have significant consequences for the nation's water supplies, agriculture, and ecosystem stability. Better planning and adaption techniques for the effects of climate change are made possible by the maps' clear representation of these changes.

4.2.4 Minimum Temperature distribution over Sri Lanka – Current (2024) vs Predicted (2040)




Current Tmin - Apr
2040 Tmin - Apr
Tmin_Dif(2040-Current)- Apr
Current Tmin - May
2040 Tmin - May
Tmin_Dif(2040-Current)- May
Current Tmin - Jun
2040 Tmin - Jun
Tmin_Dif(2040-Current)- Jun
Current Tmin - Jul
2040 Tmin - Jul
Tmin_Dif(2040-Current)- Jul


Current Tmin - Aug
2040 Tmin - Aug
Tmin_Dif(2040-Current)- Aug
Current Tmin - Sep
2040 Tmin - Sep
Tmin_Dif(2040-Current)- Sep
Current Tmin - Oct
2040 Tmin - Oct
Tmin_Dif(2040-Current)- Oct
Current Tmin - Nov
2040 Tmin - Nov
Tmin_Dif(2040-Current)- Nov

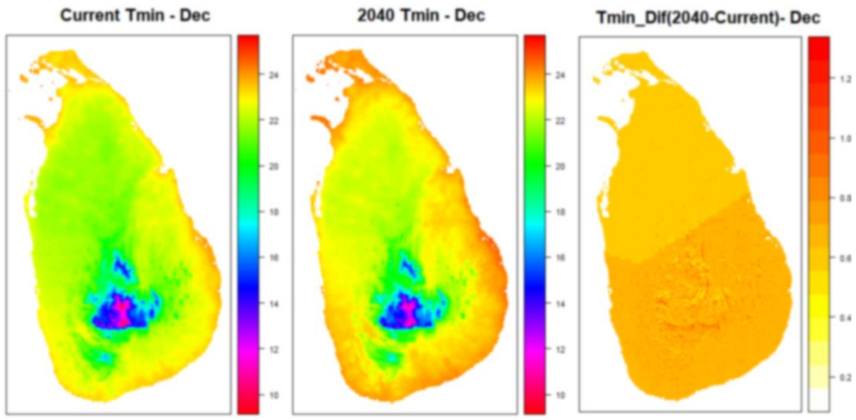


Figure 4-20: Current vs Predicted Minimum Temperature distribution over Sri Lanka

In order to understand the spatial variability and trends, a similar methodology was used to evaluate the minimum temperature distribution, producing both present and predicted maps. The findings show that by 2040, the minimum temperature will have increased by an average of about 0.5°C. When compared to trends in maximum temperatures, this slow increase indicates a general warming tendency in Sri Lanka. The necessity for adaptive solutions to lessen the consequences of rising temperatures is highlighted by the potential significant implications that these changes in maximum and minimum temperatures may have on ecosystems, agricultural growth cycles, and agriculture.

4.2.5 Spatial Variability of Rainfall Over Sri Lanka: Projected 2050 (CGM 4.5) vs. Historical or Current Climate

Rainfall distribution across Sri Lanka has always exhibited considerable spatial variability, driven primarily by the island's unique topography and its interaction with the southwest and northeast monsoons. Historically, the central highlands have received the highest annual rainfall, while the northern and eastern dry zones experience relatively lower precipitation. However, with projected climate changes under the CGM 4.5 scenario for 2040, significant shifts in the spatial and temporal distribution of rainfall are expected. Future climate models suggest that some regions may experience increased rainfall intensity during the wet season, while others, particularly in the dry zone, could face longer periods of drought and water scarcity. This projected variability could have serious implications for water resource management and agricultural practices, particularly for rain-fed crops such as paddy, which rely heavily on seasonal rains. The expected variability of Rainfall over Sri Lanka, Projected 2040 (CGM 4.5) vs. Historical or Current Climate in each month is given in Figure 4-25.

Comparing spatial and temporal patterns of future projections with historical and current rainfall data highlights emerging risks and underscores the need for localized adaptation strategies to manage both water excess and deficits. A detailed analysis of the projected spatial variability in rainfall for 2050 under the CGM 4.5 scenario, and how it differs from past and present climate trends, will focus on key agricultural regions and their vulnerability to changes in rainfall patterns.

An integrated evaluation and analysis of the spatial distribution of agricultural production landscapes considering factors such as landscape management, land use, water management, and topography may create opportunities for more holistic planning to address the impacts of climate change. Such comprehensive assessments can help identify vulnerable areas, optimize resource allocation, and implement sustainable practices that enhance resilience to climate-related challenges. By understanding the interplay between these factors, stakeholders can develop targeted strategies that not only mitigate the adverse effects of climate change but also promote sustainable agricultural productivity and environmental conservation. Moreover, engaging local communities in this planning process ensures that adaptation measures are context-specific, culturally appropriate, and supported by those directly affected. In this way, integrated landscape management can play a pivotal role in fostering climate resilience and ensuring the long-term viability of agricultural systems in the face of ongoing environmental change.

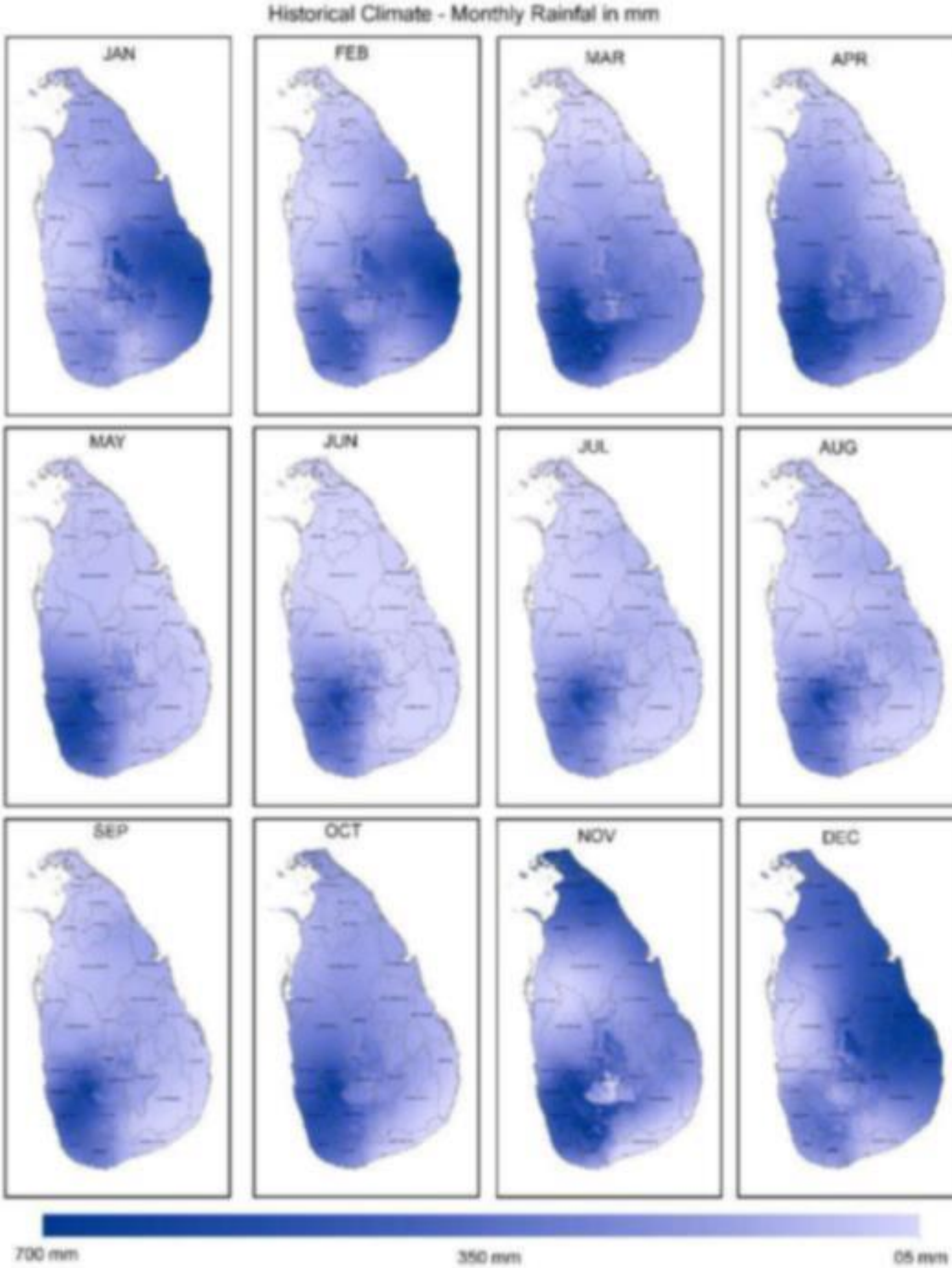


Figure 4-21: Historical monthly rainfall distribution (WorkClim Data)

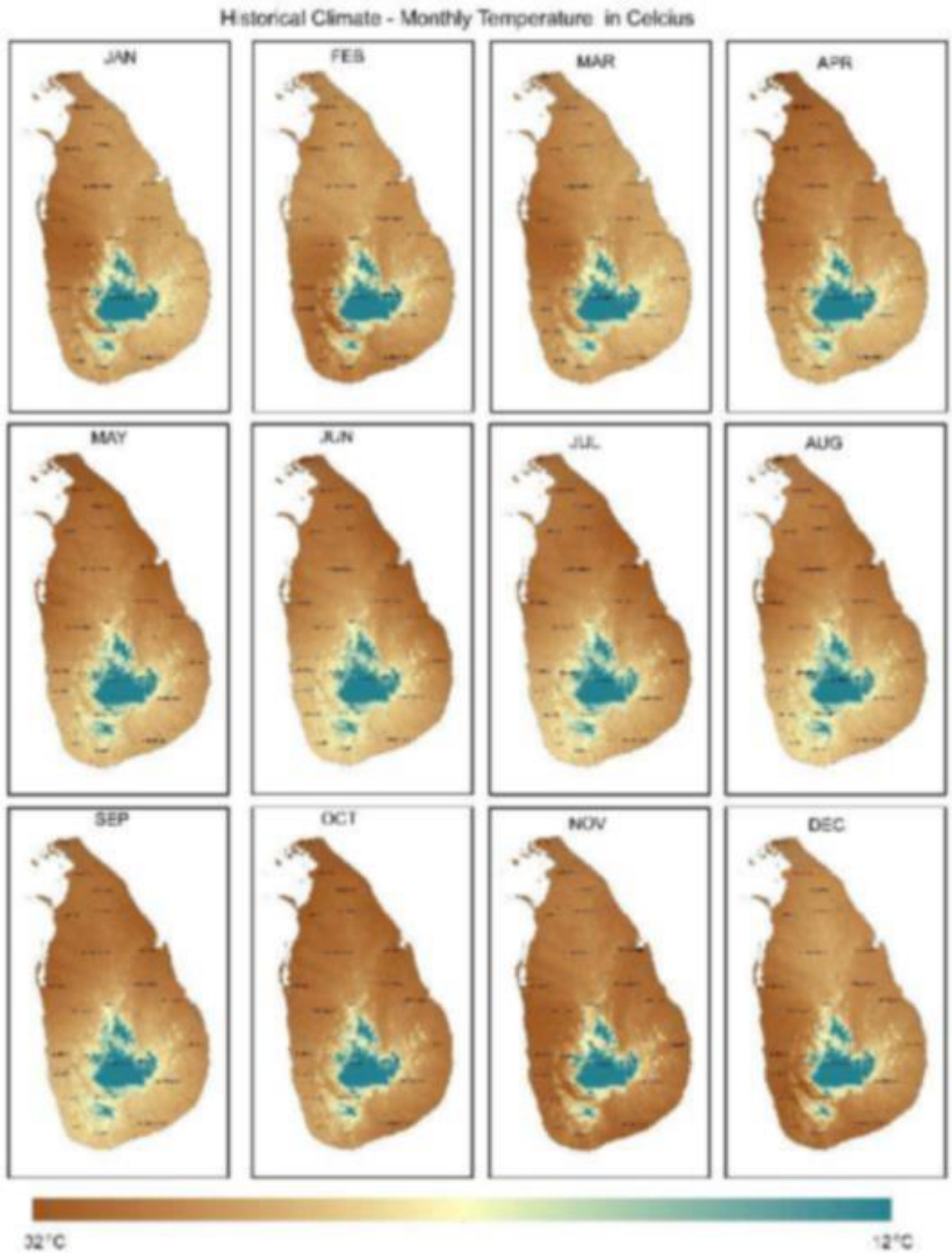


Figure 4-22: Historical monthly temperature distribution (WorkClim Data)

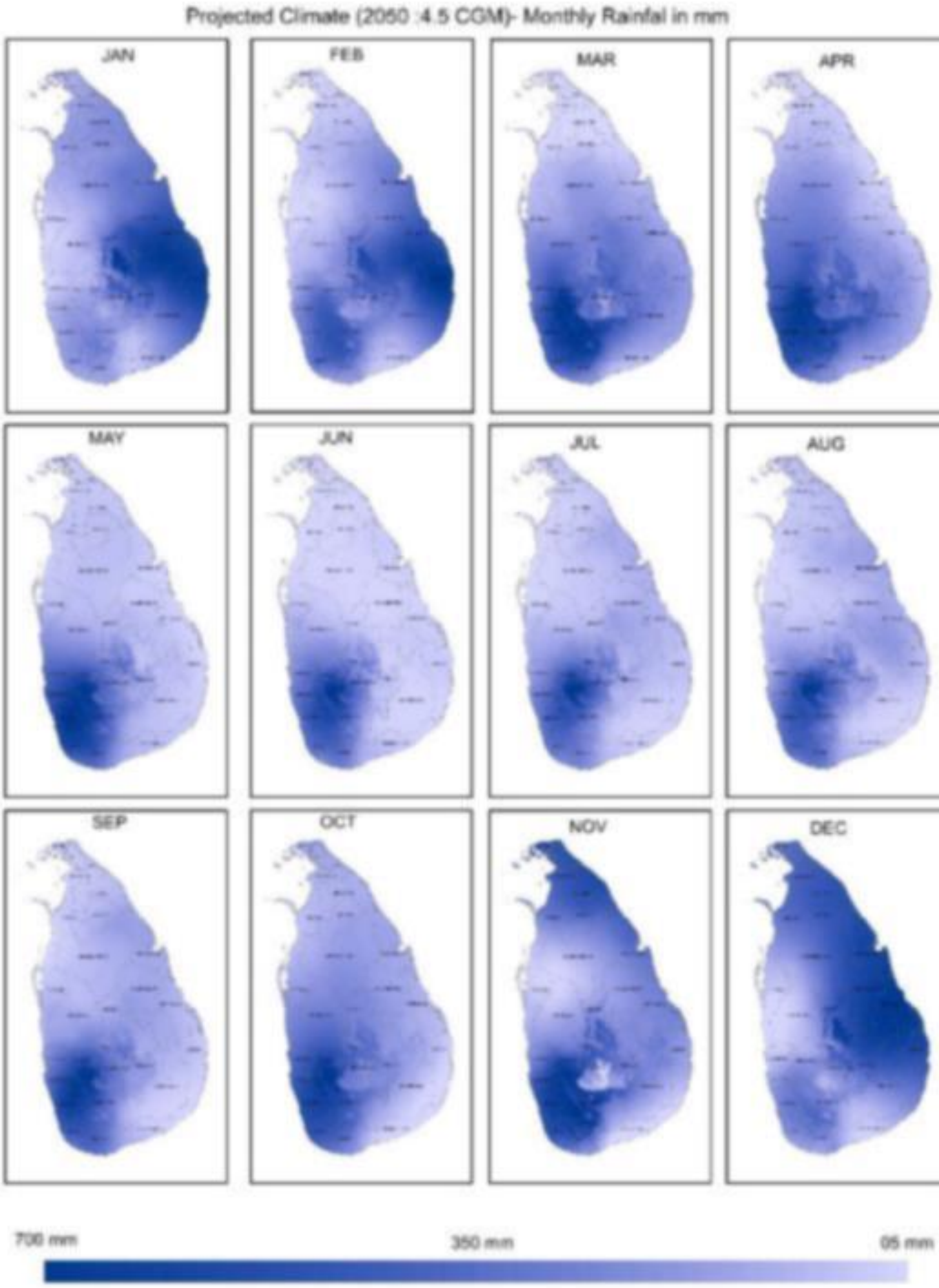


Figure 4-23: Projected Rainfall (2050: RCP 4.5)- Monthly Rainfall distribution

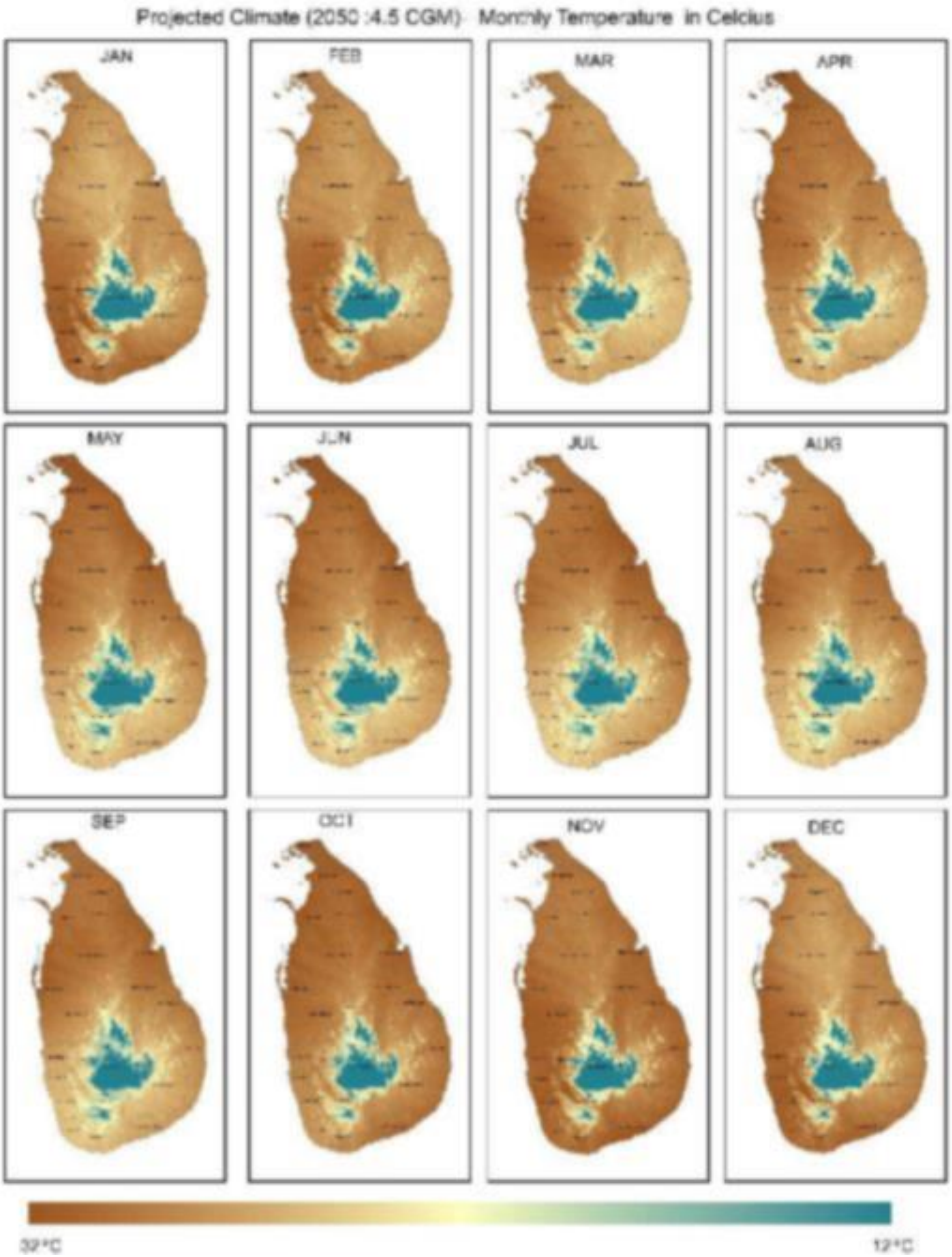


Figure 4-24: Projected Temperature in 2050

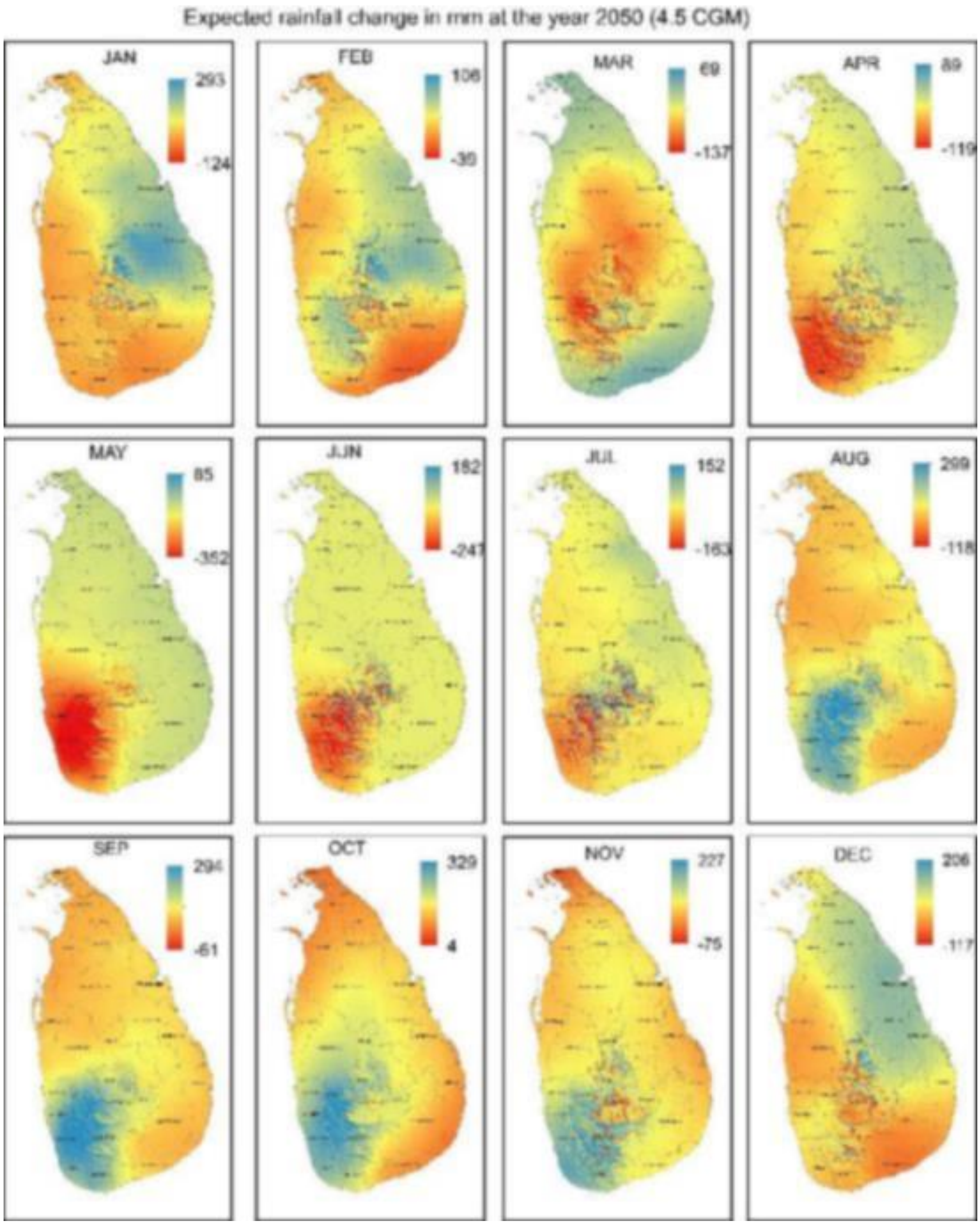


Figure 4-25: Rainfall change in 2050 (According to RCP 4.5 scenario)

4.3 Re-demarcation of Agro-Ecological Zones

Agroecological zoning is used for decision-making purposes in different fields, especially in agriculture. The current agroecological zoning was created by the Natural Resource Management Center of Sri Lanka in Peradeniya, guided by Dr.

Punyawardhana. The current agroecological zoning map consists of 46 zones, as shown in Figure 4-26.

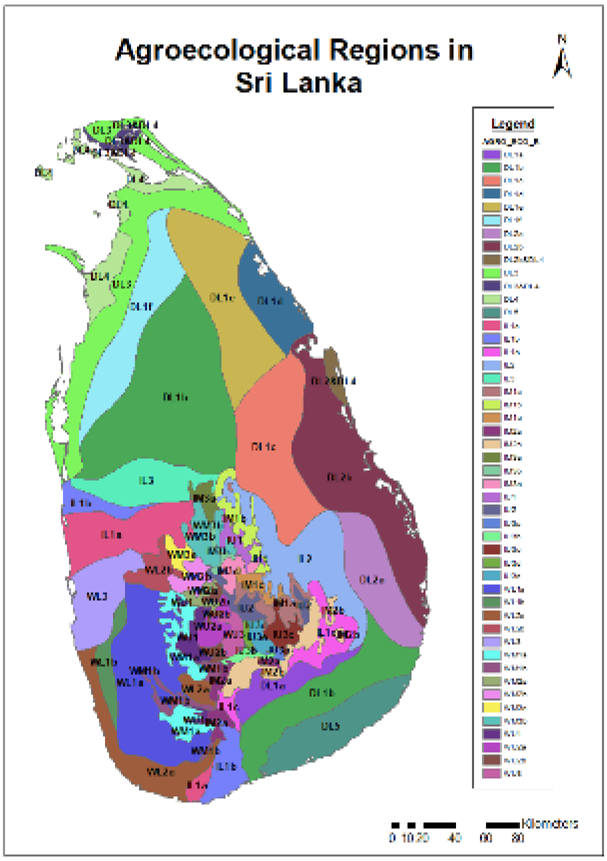


Figure 4-26: Agroecological Region map of Sri Lanka

The zoning criteria are mainly based on 4 parameters, annual rainfall, elevation, soil properties, and climate zone variation of Sri Lanka. The names of the zones reflect all these parameters in their name as mentioned in Table 4-14.

Table 4-14: Current AEZ criteria

WL1a		
Climate Zone	W	Wet zone
	D	Dry zone
	I	Intermediate zone
Elevation	L	Low Country
	M	Mid Country
	U	Up Country

Degree of wetness (Soil category)	1 - 5	‘1’ represents the most favorable
Rainfall and other physical environmental factors	a - f	The degree of wetness decreases from ‘a’ – ‘f’

4.3.1 Identified issues of the current zoning map

The World Agroecological Zoning standards state that while dividing agroecological zones, several criteria should be taken into account. Even though these factors are not mandatory, it is important to include the geological and environmental factors that affect agriculture in the particular region. All pertinent information about these areas should be included in the zoning system since these agroecological zones are utilized for research and decision-making. However, many problems and restrictions can be found when assessing the current demarcation criteria. Therefore, several other factors need to be taken into consideration when considering the Sri Lankan agriculture sector.

Administration Boundaries of Sri Lanka

In Sri Lanka, Agrarian Service Centers and Agriculture Development Officers serving in each DS Division advise farmers and small estate holders on the best agriculture practices. That means all the relevant officers are working based on administration divisions for the easiness of their operations and planning processes. The officers who advise consider the soil distribution, rainfall, and other geological aspects relevant to their area. Consequently, the selecting criteria relevant to the agroecological zoning becomes a relevant factor. However, the available agroecological zones do not fall within the administration divisions. As a result, most of the DS divisions encompass two or more agroecological zones Figure 4-27. While the local agrarians are familiar with the exact nature of their individual areas due to experience, the higher levels of decision-makers have been using the details of agroecological zoning for planning and making policies. To increase the usability value of these zones, the administrative boundaries also need to be considered while demarcating the agroecological regions.

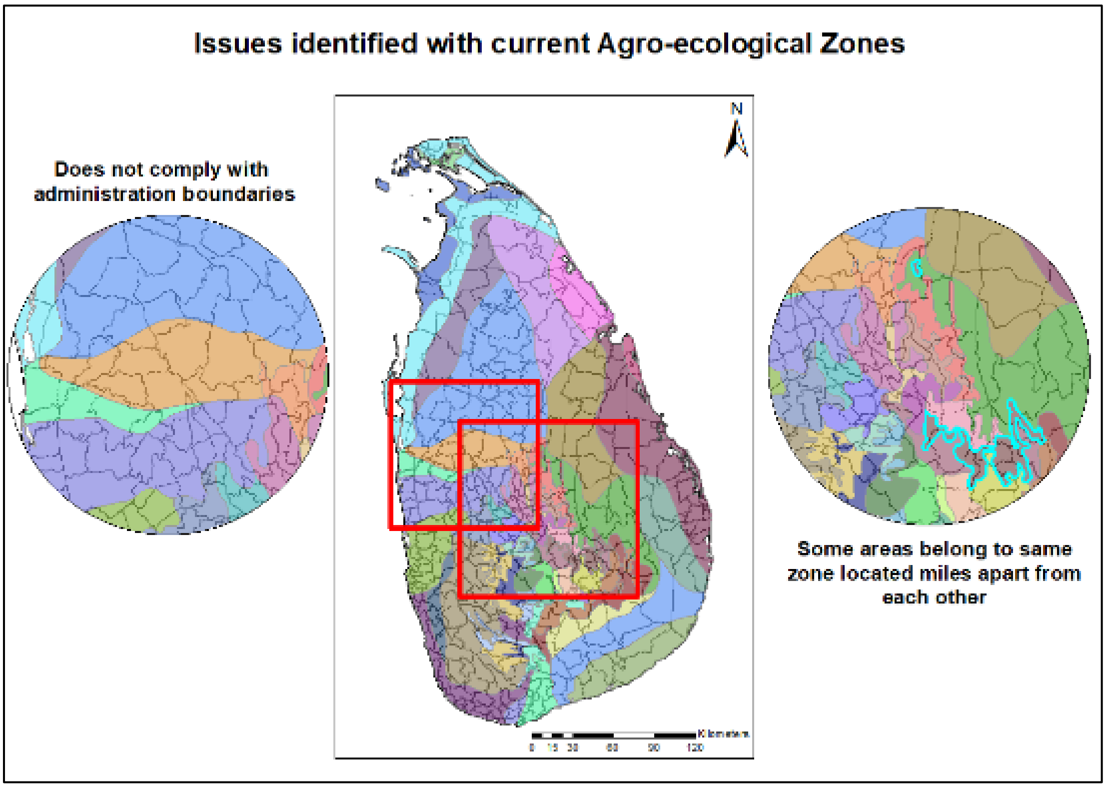


Figure 4-27: Problem map of the current zoning

Geographical location and extent of the zones

A zone-by-zone examination of the current agroecological zones in Sri Lanka reveals that some of the zones around the central highlands cover only small and scattered areas, with their respective patches located far apart (Figure 4-27). Such fragmentary zones make decision-making more difficult because it becomes really complicated to apply a single policy or practice across these scattered areas. This problem has to be addressed to bring in more efficiency regarding the usability of the zone for agricultural planning and resource management.

4.3.2 Parameters to re-demarcate agroecological zones in Sri Lanka

As shown in Figure 3-2, several factors have been extracted from the literature that affected the agricultural sector in Sri Lanka.

Climate Factor

Current criteria for agroecological zoning in Sri Lanka consider historic rainfall data from approximately 300 rainfall stations over a 30-year period. However, using past rainfall data and regional topography, several predictive models have more recently been developed to predict trends in rainfall for the future. In agricultural research covering South Asia, many recent studies consider the application of WorldClim data in predicting future climate events of rainfall, temperature, and other bioclimatic variables. This therefore, becomes necessary, especially when one is predicting the future distribution of certain crops and agricultural products (Amarasinghe et al., 2021; Ratnayake et al., 2020).

This WorldClim data package includes both regional Climate Models (RCM) and Global Climate Models (GCM) data under various Representative Concentration Pathway (RCP) scenarios (Fick & Hijmans, 2017). For this analysis, future climate predictions are used for the year 2070. Since there are no clearly defined climate zones in Sri Lanka, these future rainfall predictions will be used only in the classification of sub-agroecological zones. This research does not alter the main climatic zones such as the dry zone, wet zone, and intermediate zone of Sri Lanka.

Topographic factors

7Topography in Sri Lanka's landscape includes several sub-factors: elevation, landforms, and watersheds. Within the existing agroecological zoning, elevation has already been included as a major factor. Other landforms and river basins, however, also largely determine the productivity of agriculture and therefore need inclusion in zoning criteria. Most areas depend not solely on rainfall for cultivation but rather upon water resources stemming from nearby river basins. The inclusion of these other topographic factors into the zoning system would make it more effective in highlighting the variability in water sources feeding agriculture around the country.

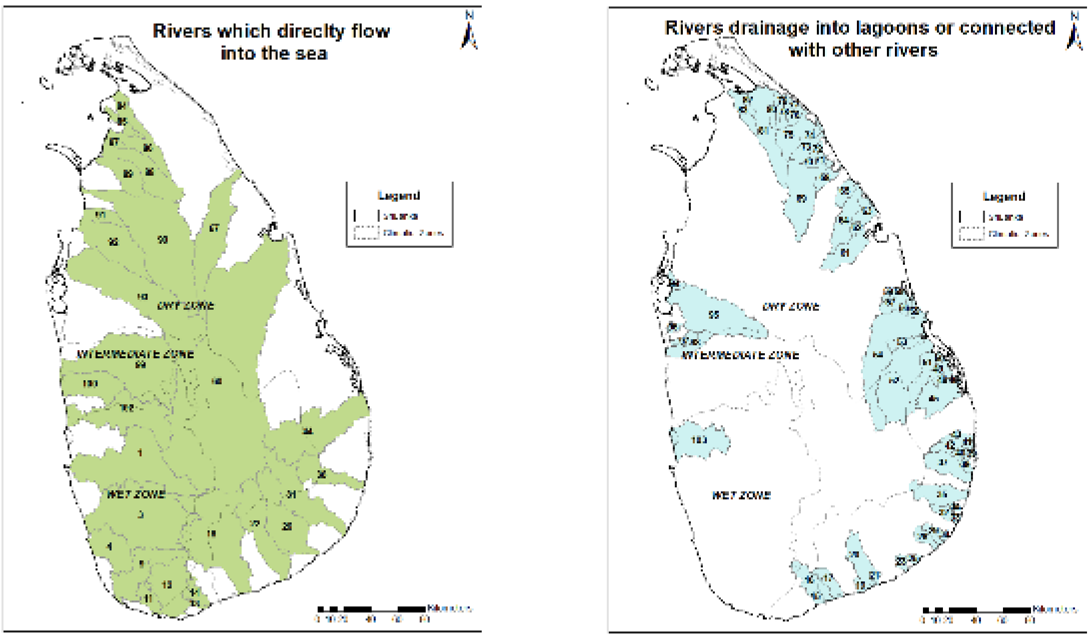


Figure 4-28: River basins of Sri Lanka

According to (Katupotha & Gamage, 2020), there are 103 different river basins in Sri Lanka. Figure 4-28 illustrates 29 rivers entering the sea directly from their point of origin, although many do not originate from the central highlands. Rivers originating in the central highlands, that part of the country where rainfall is uniform throughout the year, have maintained a continuous flow to support catchment areas rich in biodiversity. Therefore, agricultural lands in such regions receive high supplies of water even during low rainfall seasons. Equally, there are identified drainage basins where the rivers and streams normally flow into lagoons, lakes, or any other major rivers, especially in the dry zone. These also help to determine agricultural activities in their respective regions. However, present zoning criteria do not consider this factor. Therefore, we can mention that the inclusion of river basin influences in the zoning process would emphasize better agricultural planning and sustainability.

Soil factors

The soil types of Sri Lanka already represent an input in the process of existing agroecological zoning. Knowledge of prevailing soil types would facilitate precise decisions in the sector, directly influencing the suitability of various crops, irrigation requirements, and land management methods. This would lead to having the information on soil type included in the criteria of zoning, thus rendering agricultural planning suitable and appropriate for different regions, fostering an intelligent and environmentally friendly approach.

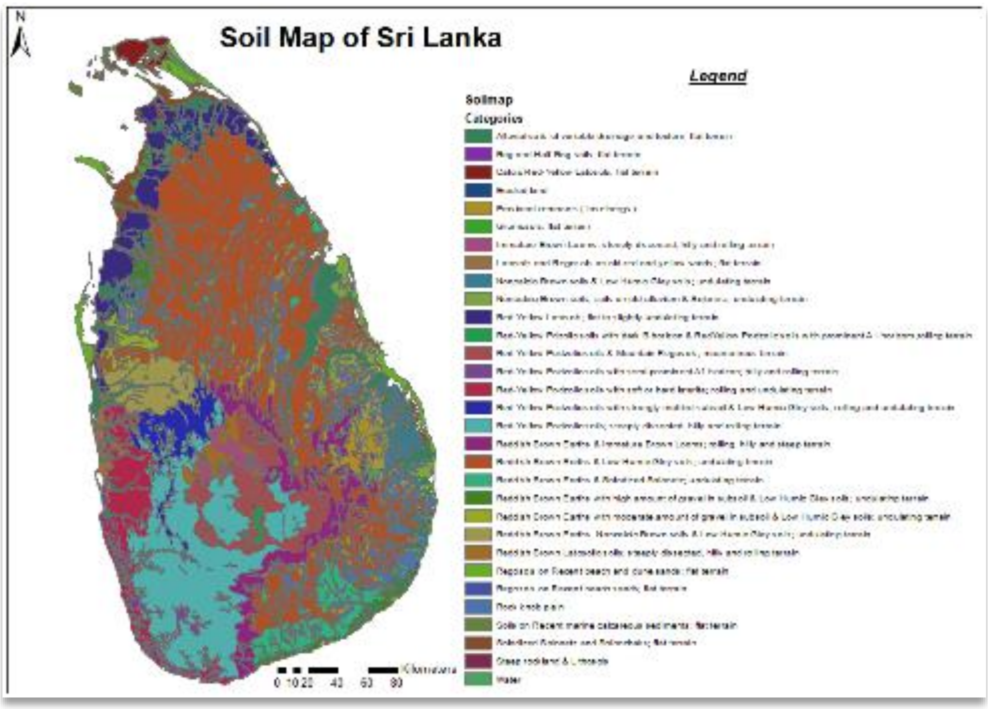


Figure 4-29: Soil map of Sri Lanka

Land use and Land cover

Land use type is one of the critical variables in agroecological zoning. The existing zoning has listed major land use categories under each zone but does not incorporate land use patterns into the zoning process. Some of the zones mostly consist of urban areas or even dense forests that are not suitable for large-scale agriculture. Identifying and incorporating the percentage of non-agricultural areas within each zone will improve decision-making in the agricultural sector. As an example, in the central highlands, land use is dominated by large areas devoted to tea cultivation, while the remaining lands are dominated by built-up areas. With the incorporation of land use criteria, zones in the central highlands that are distinguished based on rainfall patterns alone could be combined and the zoning system simplified and made less unwieldy.

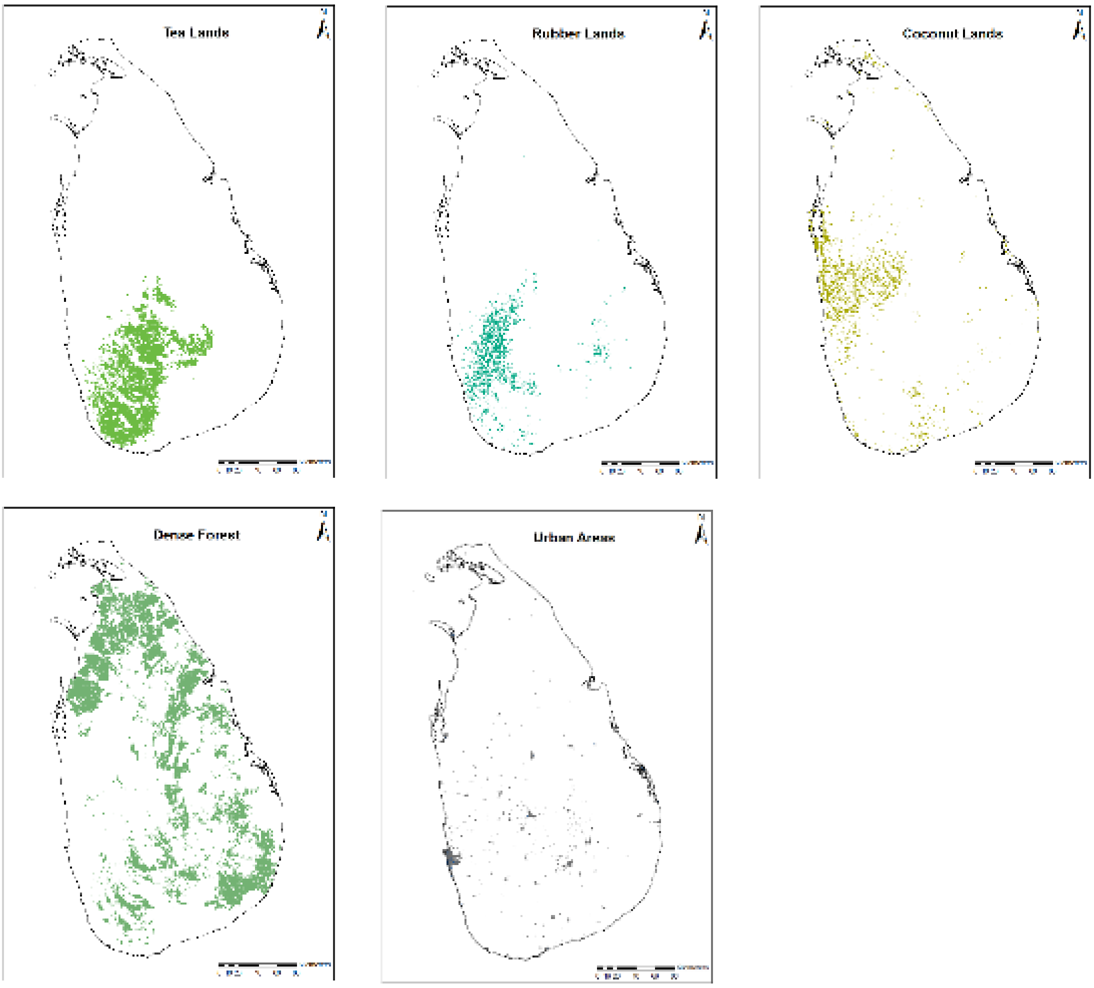


Figure 4-30: LULC maps of selected features

Irrigation

Irrigation has been the backbone of agriculture in Sri Lanka since ancient times. In earlier times, thousands of lakes, tanks, and canals were built to support agricultural development, especially in the dry zone of the country, which receives comparatively less rainfall throughout the year. As shown in Figure 4-31, Sri Lanka has over 10,000 large and small cascade systems that are important for sustaining agriculture, most specifically paddy cultivation. This cascade system thus greatly contributes to agricultural sectors in regions where mere rainfall is insufficient to sustain crop growth. The integration of the effects of such irrigation systems into agroecological zoning criteria would enhance the relevance of zoning for agricultural planning and sustainability.

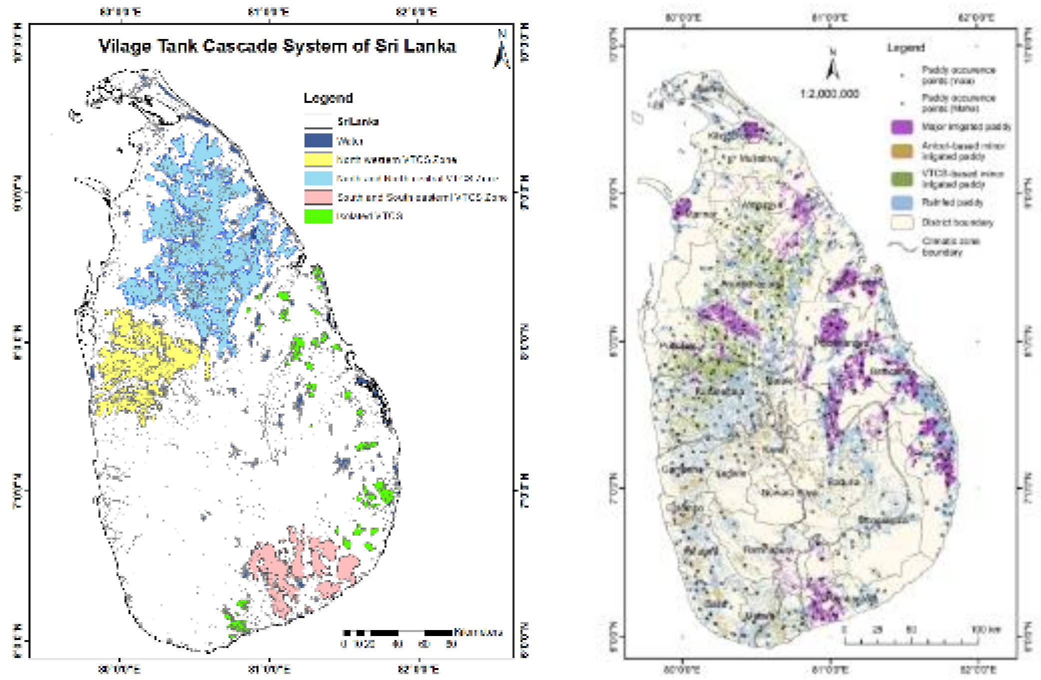


Figure 4-31: VTCS and paddy distribution map of Sri Lanka

4.3.3 New zoning criteria and map

Considering the above-mentioned factors, new zoning criteria have been established. The new method of agroecological zoning is done without completely changing the current zoning pattern because almost all the sectors have already been adapted to the existing zoning system for several years now and it is difficult to change all current ongoing scenarios. This re-demarcated map consists of more details that are important to agriculture, and disaster management sectors. The new zoning system and naming system are mentioned in the Table 4-15.

In this new criteria, some of the current zones combined together and created one new zone by comparing the land use patterns, and some zones were distributed into a few parts. After the all analysis, new AEZ map is presented in Figure 4-32.

Table 4-15: New AEZ criteria

Major Factor	Description	Symbol	Criteria
Climate Zone	Wet Zone	W	> 2500mm
	Intermediate Zone	I	1750mm – 2500mm
	Dry Zone	D	<1750mm
Elevation	Low Country	L	<300m
	Mid Country	M	300m – 600m
	Up Country	U	> 600m
Degree of wetness (Soil Category)		1 - 5	'1' represents the most favorable
Rainfall (Extreme) and other physical environmental factors		a - f	The degree of wetness decreases from 'a' – 'f'
Yearly runoff of the river basins	High runoff	R_1	River basins started from the central highland and percentage of the AEZ area > 50%
	Moderate runoff	R_2	River basins started from the central highland and percentage of the AEZ area < 50%
	Low runoff	R_3	River basins directly flow to the sea & runoff > 1000 per year
	Combined runoff	R_0	Affected by river basins starting from the central highland and not starting there
Village Tank Cascade System Influence		t_1	VTCS area in the AEZ > 20%
		t_2	VTCS area in the AEZ < 20%
Land Use	Tea	T	Highest Land use area percentage of the category compared to others
	Rubber	r	
	Coconut	C	
	Paddy	P	

	Urban Area	LU	
	Dense Forest	LF	

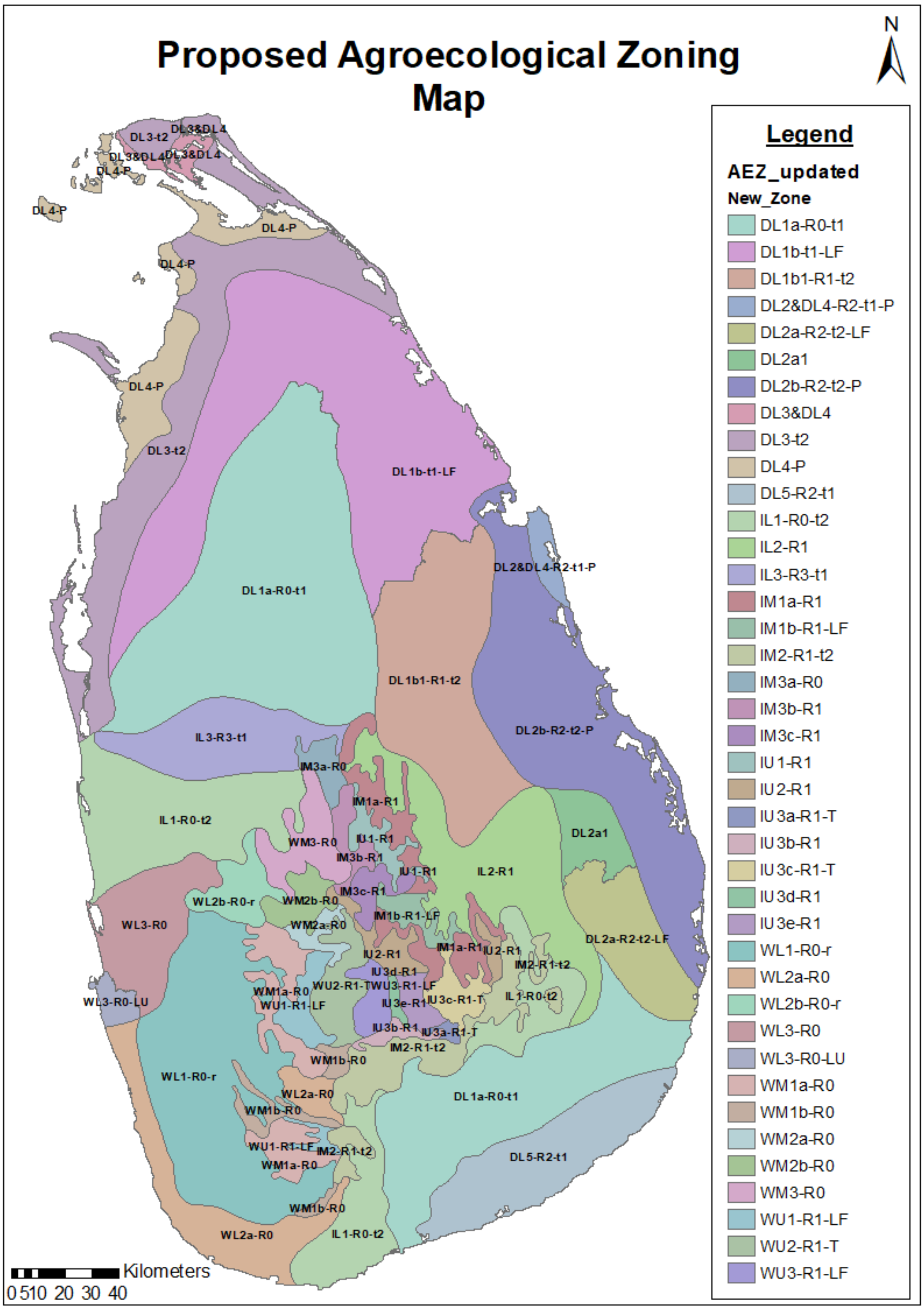


Figure 4-32: New Agro-Ecological Zone map

In the new criteria, the degree of wetness is integrated with extreme precipitation maps. This factor categorizes regions based on their degree of wetness, with classes ranging from 'a' (extremely wet) to 'f' (extremely dry). It reflects the intensity and frequency of extreme rainfall events, directly influencing soil moisture availability, vegetation patterns, and agricultural suitability. By incorporating this gradient, the zoning system more effectively captures the variability of water resources and climate-driven risks, such as floods and droughts, across different parts of the country.

Yearly runoff is classified based on the source and intensity of river flows within each AEZ. High runoff (R1) areas are characterized by rivers originating from the central highlands, with more than 50% of the AEZ area influenced, resulting in strong water availability. Moderate runoff (R2) areas also receive water from the central highlands but cover less than 50% of the AEZ, providing moderate yet less reliable water sources. Low runoff (R3) regions involve rivers that flow directly to the sea with high runoff rates (>1000 mm/year), indicating distinct hydrological behavior with limited catchment-based water control. Combined runoff (R0) zones are influenced by both highland and coastal river systems, leading to more complex water dynamics. Differentiating runoff types enables a better understanding of flood risks, irrigation potential, and water resource management.

The VTCS factor identifies the impact of traditional tank (reservoir) networks on water availability and land management. Category t1 refers to AEZs where VTCS systems cover more than 20% of the area, highlighting regions where ancient water harvesting structures continue to significantly regulate microclimates, support agriculture, and enhance drought resilience. Category t2 represents areas with less than 20% VTCS coverage, where such systems have a reduced influence or are absent. This factor is crucial for recognizing how indigenous water management practices continue to shape agricultural potential and community resilience across different zones.

Land use classification identifies the dominant type of land cover within each AEZ. Tea (T), Rubber (r), Coconut (C), and Paddy (P) represent the major agricultural land uses, each associated with specific soil, climate, and management requirements. Urban Area (LU) denotes zones that are heavily built-up, influencing natural processes such as infiltration and surface runoff. Dense Forest (LF) areas contribute to ecosystem stability, carbon sequestration, and biodiversity conservation. Recognizing the predominant land use is essential for aligning zoning decisions with economic activities, environmental protection objectives, and sustainable development goals within each region.

Table 4-16: New Agro-ecological Zoning Criteria

ZONE	ANNUAL_RF	Starting from CH (>500) (%)	Code	Other catchment (%)	Code	Irrigation areas (VTCS) (%)	Code	Tea (%)	Rubber (%)	Coconut (%)	Paddy (%)	Urban area (%)	Dense forest (%)	Code	Final Name
WU1	>3100	94.70	R1	5.30		0.00		19.11	0.00	0.00	0.02	0.01	55.20	LF	WU1-R1-LF
WU2	>2200	100.00	R1	0.00		0.00		51.76	0.00	0.00	0.28	0.38	15.84	T	WU2-R1-T
WU3	>1800	100.00	R1	0.00		0.00		16.78	0.00	0.00	0.00	0.10	57.17	LF	WU3-R1-LF
WM1a	>3300	76.34	R1	23.66	R3	0.00		24.61	4.61	0.11	1.52	0.00	29.30		WM1a-R0
WM1b	>2900	85.08	R1	14.79	R3	0.00		26.46	4.35	0.20	3.50	0.02	35.11		WM1b-R0
WM2a	>2200	84.04	R1	15.96	R3	0.00		24.99	0.43	0.03	4.37	0.07	6.11		WM2a-R0
WM2b	>1800	55.97	R1	44.03	R3	0.00		8.69	8.59	0.24	6.27	1.76	2.43		WM2b-R0
WM3	>1600	43.47	R2	56.53	R3	0.00		2.59	10.27	5.83	8.35	1.49	1.22		WM3-R0
WL1	>2800	61.26	R1	31.49	R3	0.00		12.78	25.89	1.27	7.97	0.22	9.77	r	WL1-R0-r
WL2a	>2400	18.69	R2	38.70	R3	0.00		12.17	7.89	2.69	8.85	1.71	2.54		WL2a-R0
WL2b	>2200	25.51	R2	71.78	R3	0.00		0.24	29.73	5.04	10.09	0.70	0.33	r	WL2b-R0-r
WL3_1	>1700	0.00	R2	0.00	R3	0.00		0.00	0.00	0.00	0.00	57.00	0.00	LU	WL3-R0-LU
WL3	>1700	29.20	R2	26.88	R3	0.00		0.00	2.47	15.91	11.10	9.14	0.15		WL3-R0
IU1	>2400	100.00	R1	0.00		0.00		16.21	0.00	0.00	0.54	0.01	32.68		IU1-R1
IU2	>2100	100.00	R1	0.00		0.00		29.94	0.18	0.05	2.12	0.52	9.17		IU2-R1
IU3a	>1900	100.00	R1	0.00		0.00		43.58	0.00	0.00	0.36	3.24	14.72	T	IU3a-R1-T
IU3b	>1700	100.00	R1	0.00		0.00		20.58	0.26	0.00	0.89	0.71	36.64		IU3b-R1
IU3c	>1600	100.00	R1	0.00		0.00		32.06	0.25	0.00	6.34	2.63	4.02	T	IU3c-R1-T
IU3d	>1300	100.00	R1	0.00		0.00		7.12	0.00	0.00	2.45	0.04	34.80		IU3d-R1
IU3e	>1400	100.00	R1	0.00		0.00		10.15	0.00	0.00	8.27	3.37	2.63		IU3e-R1
IM1a	>2000	94.51	R1	0.00		0.00		2.99	0.30	0.05	6.64	0.18	25.95		IM1a-R1
IM1b	>1300	100.00	R1	0.00		0.00		0.00	0.03	0.01	3.34	0.01	48.56	LF	IM1b-R1-LF
IM2	>1600	95.53	R1	0.00		1.32	t2	7.06	4.20	0.88	4.17	0.26	20.81		IM2-R1-t2
IM3a	>1400	66.88	R1	16.84	R3	0.27		0.00	5.65	14.05	7.59	0.04	0.17		IM3a-R0
IM3b	>1200	100.00	R1	0.00		0.00		13.91	2.69	1.28	7.32	0.45	1.02		IM3b-R1
IM3c	>1100	100.00	R1	0.00		0.00		1.35	0.00	1.33	9.63	0.45	3.78		IM3c-R1
IL1	>1100	20.58	R2	38.06	R3	13.63	t2	0.13	1.78	18.96	14.89	0.47	2.96		IL1-R0-t2
IL2	>1600	62.19	R1	0.00		0.13		0.00	0.55	0.09	14.66	0.13	21.13		IL2-R1
IL3	>1100	0.22		71.67	R3	49.47	t1	0.00	0.00	15.28	22.96	0.09	1.05		IL3-R3-t1
DL1a	>900	24.33	R2	23.95	R3	55.44	t1	0.00	0.05	1.16	17.79	0.20	17.63		DL1a-R0-t1
DL1b	>800	0.02		3.69		51.82	t1	0.00	0.00	0.15	12.77	0.01	50.83	LF	DL1b-t1-LF
DL2a	>1300	46.67	R2	0.00		17.56	t2	0.00	0.00	0.07	10.73	0.06	42.68	LF	DL2a-R2-t2-LF
DL2b	>1100	26.69	R2	0.00		7.64	t2	0.00	0.01	0.70	33.33	0.90	11.53	P	DL2b-R2-t2-P
DL3	>800	0.00		2.16		9.13	t2	0.00	0.00	6.39	7.12	0.40	38.15		DL3-t2
DL4	>750	0.00		4.86		0.46		0.00	0.00	0.39	26.67	0.00	13.50	P	DL4-P
DL5	>650	47.41	R2	0.00		35.63	t1	0.00	0.00	0.59	11.00	0.39	21.23		DL5-R2-t1
DL3&DL4		0.00		0.00		0.00		0.00	0.00	0.67	29.29	0.32	0.00		DL3&DL4
DL2&DL4		25.89	R2	0.00		21.13	t1	0.00	0.00	0.49	33.40	0.00	6.90	P	DL2&DL4-R2-t1-P
DL1b1	>800	83.76	R1	0.00		3.31	t2	0.00	0.00	0.09	25.14	0.09	26.89		DL1b1-R1-t2
DL2a1	>1300	0.00		0.00		0.00		0.00	1.30	0.43	6.93	0.00	26.50		DL2a1

Table 4-17: River basins and soil categories of AEZ

New Zone	River Basins	Major soil Categories
WU1-R1-LF	Kalu, Mahaweli, Kelani, Walawe	Red Yellow Podzolic (RYP), Mountain Regsol & Lithosol Soils
WU2-R1-T	Mahaweli, Kelani, Walawe	Red Yellow Podzolic soils, Mountain Regsol & Lithosol Soils
WU3-R1-LF	Mahaweli, Kelani, Walawe	Red Yellow Podzolic soils with prominent A1 horizon & Red Yellow Podzolic soils with dard B horizon
WM1a-R0	Mahaweli, Kelani, Kalu, Walawe, Gin ganga, Nilwala	Red Yellow Podzolic soils with semi prominent A1 horizon & Lithosol soills
WM1b-R0	kalu, Walawe, Nilwala	Red Yellow Podzolic soils with semi prominent A1 horizon & Lithosol soills
WM2a-R0	Mahaweli, Maha oya	Red Yellow Podzolic, Reddish Brown latosolic & Low Humic Gley soils
WM2b-R0	Mahaweli, Kelani, Deduru Oya	Reddish Brown Latosolic (RBL), Immature Brown Loam(IBL), Low Humic Gley & Red Yellow Podzolic soils
WM3-R0	Mahaweli, Deduru oya, Maha oya	Reddish Brown Latosolic, Immature Brown Loam, Low Humic Gley(LHG), Lithosol Soils
WL1-R0-r	Kalu, Kelani, Bentota, Gin, Nilwala, Maha oya	Red Yellow Podzolic, Red Yellow Podzolic with semi prominent A1 horizon & Low Humic Gley soils
WL2a-R0	Kalu, Walawe, Nilwala, Gin, Bentota	Red Yellow Podzolic, Reddish Brown Latosolic & Low Humic Gley soils
WL2b-R0-r	Kelani, Deduru Oya, Maha oya	Red Yellow Podzolic, Red Yellow Podzolic soils with strongly mottled sub-soil, RBL & LHG soils
WL3-R0	Kelani, Maha oya	Red Yellow Podzolic soils with soft and hard laterite, LHG & Regosol soils
IU1-R1	Mahaweli	Red Yellow Podzolic, Mountain Regosol & Lithosol soils
IU2-R1	Mahaweli, Menik, Gal oya, Kumbukkan Oya	Red Yellow Podzolic, Mountain Regosol & Lithosol soils
IU3a-R1-T	Mahaweli, Walawe, Kirindi	Red Yellow Podzolic & Mountain Regosol
IU3b-R1	Mahaweli, Walawe, Kirindi	Red Yellow Podzolic, Mountain Regosol & Lithosol soils
IU3c-R1-T	Mahaweli, Menik, Kirindi	Red Yellow Podzolic & Low Humic Gley Soils
IU3d-R1	Mahaweli	Red Yellow Podzolic & Mountain Regosol
IU3e-R1	Mahaweli, Kirindi	Red Yellow Podzolic & Low Humic Gley Soils
IM1a-R1	Mahaweli, Gal oya	RBL, RYP, IBL, LHG, Reddish Brown Earth(RBE), Mountain Regesol & Lithosol soils
IM1b-R1-LF	Mahaweli	RBL, IBL,Mountain Regosol & Lithosol soils
IM2-R1-t2	Kalu, Walawe, Menik, Gal oya, Kumbukkan oya	RBL, RYP, IBL, LHG & Lithosol soils
IM3a-R0	Mahaweli, Deduru oya	IBL, RBL & LHG soils
IM3b-R1	Mahaweli	RBL, RBE &LHG soils
IM3c-R1	Mahaweli	RBL & IBL soils
IL1-R0-t2	Kalu, Walawe, Menik, Gal oya, Kumbukkan oya, Maha oya	RYP, soilswith strongly molted sub-soil & Regosol , RBL, RBE, LHG & Regosol soils
IL2-R1	Mahaweli, Kumbukkan, Gal oya	RBE, LHG & RBL soils
IL3-R3-t1	Mahaweli	Non Calcic Brown(NCB), Reddish Brown Earth & Low Humic Gley Soils
DL1a-R0-t1	Mahaweli, Walawe, Gal oya, Menik, Kirindi oya, Kumbukkan oya	Reddish Brown Earth & Low Humic Gley Soils
DL1b-t1-LF	Mahaweli	Reddish Brown Earth & Low Humic Gley Soils
DL2a-R2-t2-LF	Gal oya	NCB, RBE,LHG & Old Alluvia Solis
DL2b-R2-t2-P	Mahaweli, Gal oya	NCB, RBE,, Old Alluvial, LHG, Regasol & Bolodized-solonetz soils
DL3-t2		Red Yellow Latasols (RYL) & Regosol Soils
DL4-P		Solodized - solonets & Grumusol Soils
DL5-R2-t1	Mahaweli, Walawe, Kumbukkan oya, Kirindi oya	RBE with high ammount od grawel in sub- soil, LHG & Solodized - solonets soils
DL3&DL4		
DL2&DL4-R2-t1-P	Mahaweli	
DL1b1-R1-t2	Mahaweli	Reddish Brown Earth & Low Humic Gley Soils
DL2a1	Kelani	NCB, RBE,LHG & Old Alluvia Solis
WL3_1-R0-LU	Kelani, Maha oya	Red Yellow Podzolic soils with soft and hard laterite, LHG & Regosol soils

4.4 Impact on Livelihoods

4.4.1 Analysis of Survey and Interview Data

A comprehensive questionnaire survey was carried out as part of the third objective of this study to collect insightful opinions, comments, and recommendations regarding two important products, the updated agro-ecological zoning criteria and the recently developed seasonal high-risk zoning map of extreme rainfall events in Sri Lanka. The questionnaire was purposefully created to involve important parties, with a particular emphasis on those who work directly in the disaster relief and agriculture industries (Appendix D – Questionnaire survey on Extreme rainfall and new Agroecological zones).

When selecting participants for the interviews, this study primarily focused on research officers representing different sectors (Table 4-18), as it is essential to first assess the practical applicability of the proposed approaches. Accordingly, research officers from the main agricultural crop institutes in Sri Lanka were selected, covering key crops such as tea, rubber, coconut, paddy, and potato. In addition, research officers affiliated with the Disaster Management Centre were included in the study. Furthermore, some farmers and other individuals engaged in the agricultural sector were interviewed to initiate and provide a foundation for future researchers who may wish to build upon this study. However, the data collected from these informal interviews were not included in the formal analysis and future recommendations.

Considering the above factors, a group of **50 research individuals** was selected for the interviews. This group of professionals was picked because of their extensive knowledge and practical experience with the difficulties caused by extreme weather events and how they affect risk mitigation, livelihoods, and food security. By incorporating their knowledge and viewpoints, the research intends to assure the relevance, practicality, and efficacy of the proposed zoning frameworks, paving the way for informed decision-making and adaptation measures in the face of climate change.

4.4.2 Findings of the Questionnaire Survey

As mentioned above, this questionnaire survey was conducted among different groups of professionals who have been actively engaged in the agriculture and disaster management sectors for years in different parts of Sri Lanka (Figure 4-33 & Figure 4-34). The distribution of the selected research participants is as follows.

Table 4-18: Number of Research Professionals involved in the survey

Main Sector/ Institute	Number of Professionals
Tea Research Institute, Thalawakelle	8
Tea Research Institute, Ratnapura	2
Rubber Research Institute, Agalawatte	10
Coconut Research Institute, Lunuwila	8
Rice Research Institute, Bathalagoda	10
Potato Research Center, Nuwara Eliya	4
Researcher – Disaster management	5
Researcher – Climate change	3

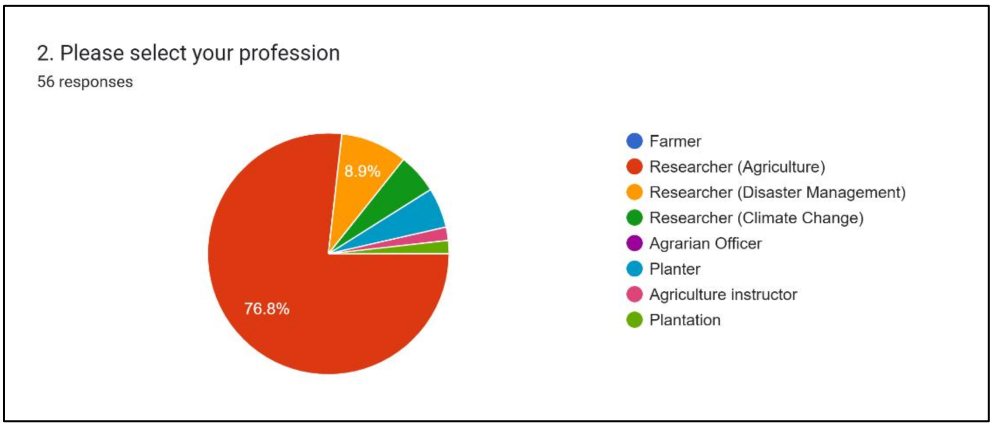


Figure 4-33: Occupation of the interviewee

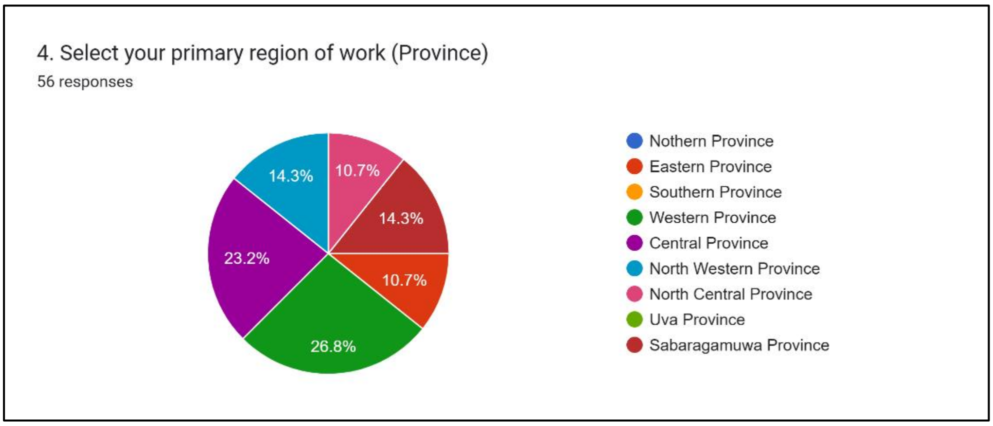


Figure 4-34: Working areas of Interviewee

Extreme rainfall analysis and high-risk zoning map

According to the findings of the questionnaire survey, almost everyone has experienced an increment of extreme rainfall events during the past few years but not in the quantitative measurements.

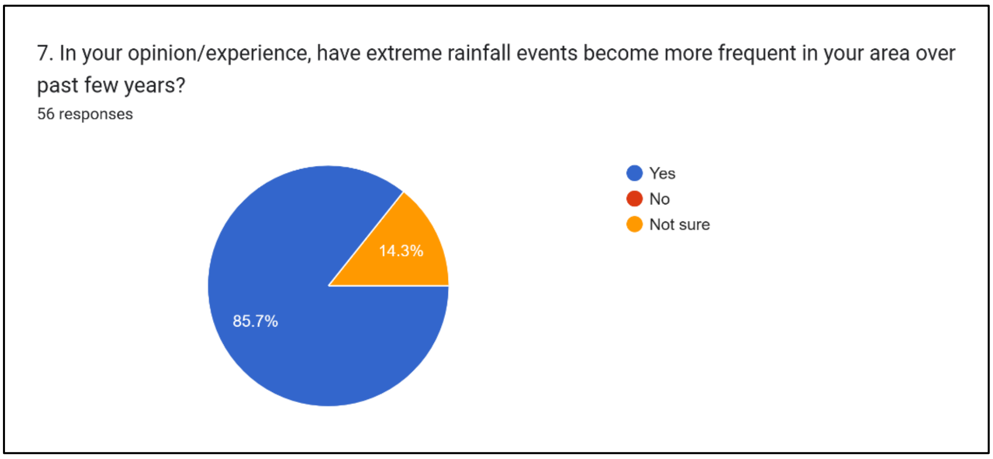


Figure 4-35: Occurrence of Extreme precipitation events over last few decades

Survey respondents made insightful remarks regarding the effects of extreme precipitation occurrences in their work areas. Their professional experience and the unique difficulties they encounter in their fields have influenced these answers. Based on the replies received for the question 8 (Figure 4-36), crop damage, which significantly affects agricultural output and livelihoods, was identified as the most major disaster brought on by extreme rainfall events. Pest infestations and plant disease outbreaks were shown to be common secondary effects that were made worse by extended periods of precipitation in the impacted areas. Furthermore, landslides and floods were identified as a serious concern in particular regions, endangering infrastructure and habitation.

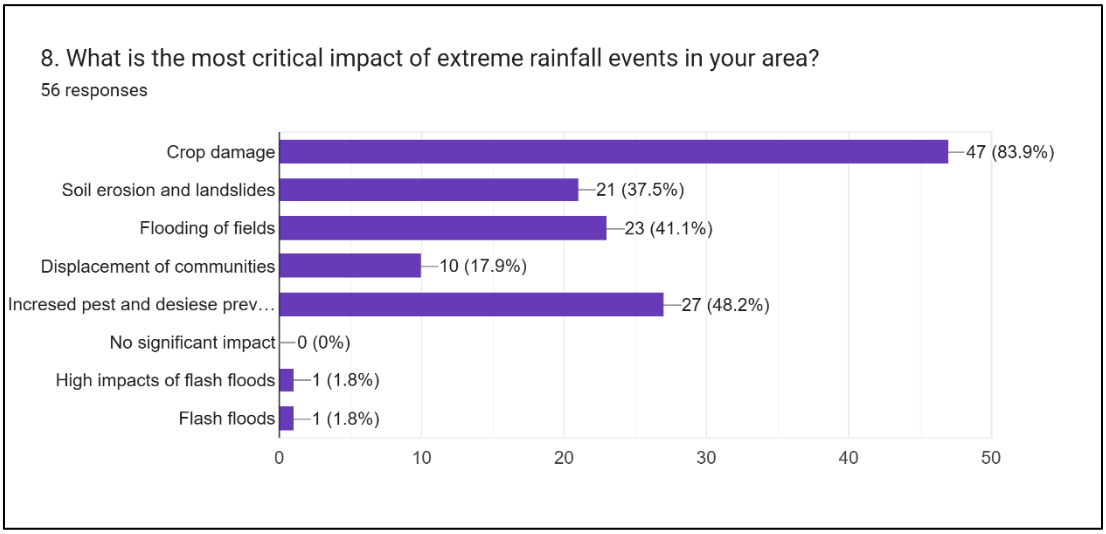


Figure 4-36: Impacts of extreme rainfall events in particular areas

In this study, the seasonal extreme rainfall analysis map was created based on historical precipitation records using the data gathered through this study. This map provides useful information for preparation and planning by highlighting high-risk areas during various climatic seasons. Previous studies have examined the trends of individual extreme precipitation indices across Sri Lanka; however, these analyses do not provide a comprehensive understanding of the overall increase in extreme precipitation events in the country.

The development of real-time extreme precipitation forecasting maps for each zone across various time periods was strongly recommended based on feedback from industry specialists (Figure 4-37). Such a strategy is considered highly desirable, as it would provide valuable, timely information to support decision-making in sectors such as agriculture, disaster management, and water resource planning. However, implementing this approach presents considerable challenges. Specifically, the prediction of extreme precipitation events within defined time frames remains difficult due to the lack of statistically significant trends in these events over the past several decades. The high variability and irregular occurrence of extreme precipitation further complicate the development of reliable forecasting models. As a result, while the concept is ideal from a practical standpoint, its realization requires more advanced research efforts, enhanced data availability, and potentially the integration of emerging technologies such as machine learning and high-resolution climate modeling.

The forecasting models can be improved by including daily updated satellite remote sensing data to overcome this constraint. Better forecasting of extreme precipitation occurrences and dynamic monitoring would be made possible by such improvements. The extreme precipitation analysis's present identification of high-risk zones for each climate season, which ranks as the second most popular option among responders due to its rapid relevance and practicality, is still a useful tool.

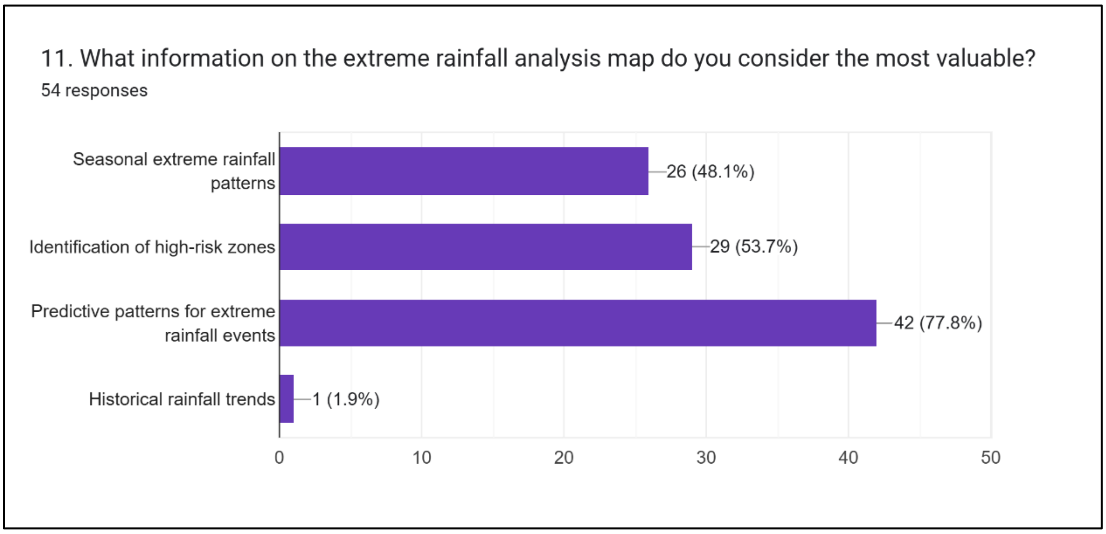


Figure 4-37: Suggestions on Extreme precipitation maps

Among those interviewed, the extreme precipitation-prone area map has received overwhelmingly positive feedback. Almost every participant conveyed gratitude for the analysis and its usefulness. Many expressed how excited they were to incorporate the knowledge gained from this data into their upcoming projects, acknowledging its importance in tackling issues associated with extreme precipitation occurrences. This comment highlights the map's applicability and potential influence as a vital tool for well-informed decision-making in disaster relief, agriculture, and other climate-sensitive industries.

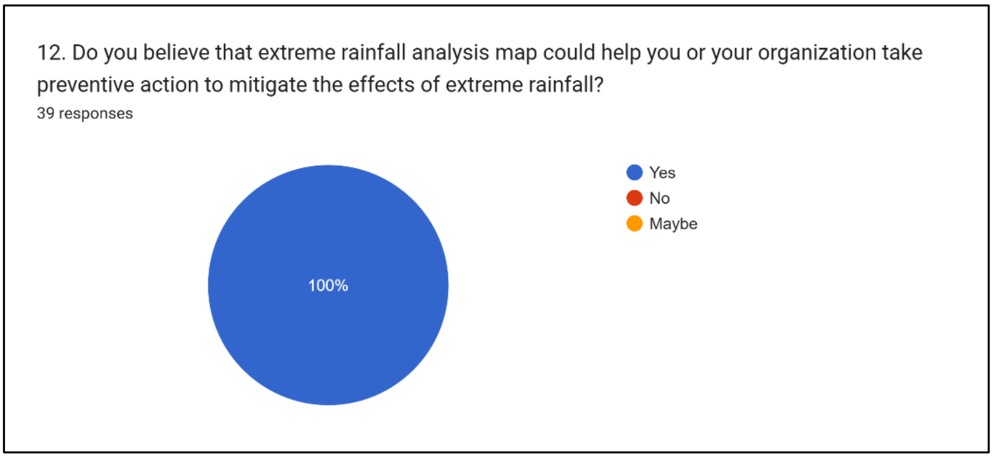


Figure 4-38: Importance of Extreme Rainfall Map

Re-demarcation of Agro-ecological Regions

According to the answers to question 14, all of the people interviewed showed a thorough awareness of Sri Lanka's agroecological zoning system because they are well-educated and actively engaged in the agriculture and disaster management industries. However, because the current zoning system lacks adequate information, they frequently face a variety of difficulties when carrying out their responsibilities. Organizations regularly use these agroecological zones in their decision-making processes, where having detailed and organized information is essential. Because of this, almost everyone was in favor of re-demarcating Sri Lanka's existing agro-ecological zones.

The three main components of Sri Lanka's present agroecological zoning system are elevation, yearly rainfall, and soil category. However, the interviewees emphasized the significance of adding more aspects to the zoning criteria based on their experiences (Figure 4-39). Many respondents recommended adding land use data, and topographical elements including landforms, river basins, and administrative boundaries to the zoning process in addition to the current parameters. Additionally, some respondents emphasized the importance of irrigation systems in their line of work, emphasizing the necessity of taking these systems into account as a key component of the updated zoning framework. Everyone has responded that they would like to work with an updated zoning system in their future works and it would be beneficial for them in decision-making processes.

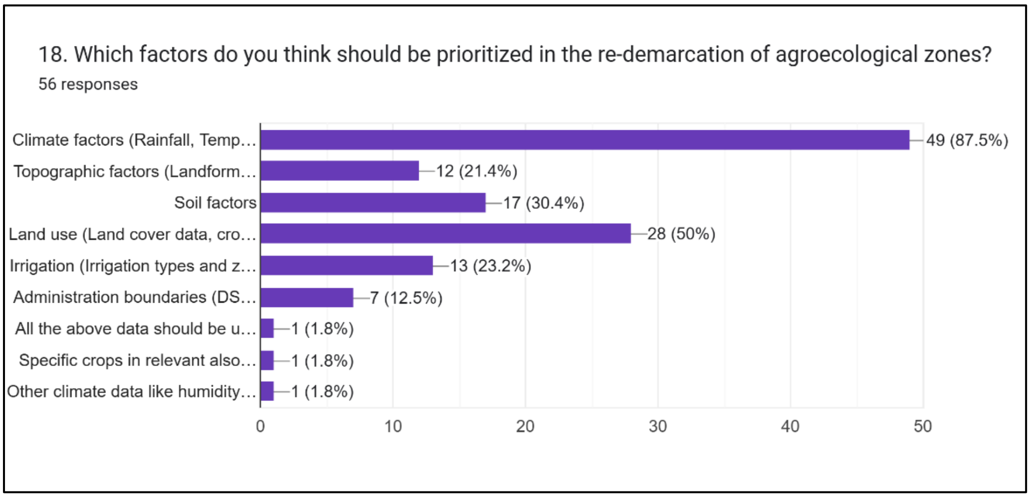


Figure 4-39: Prioritization of factors in demarcating AEZs

While adapting these new zoning criteria and climate realities among the farmers, researchers, and other officials, the facts that the industry experts have highlighted should be considered a lot. The most important thing is knowledge transferring to all levels (Figure 4-40). Not only that, they are requesting to access the data that are used for the analysis. Because there is a huge problem in accessing data owned by different organizations such as climate data, shapefiles of the different land features, etc. If the people who are working in the industry have access to these databases and have a proper understanding of these analysis tools and processes, it would be easy for them to summarise their own data for their working purposes.

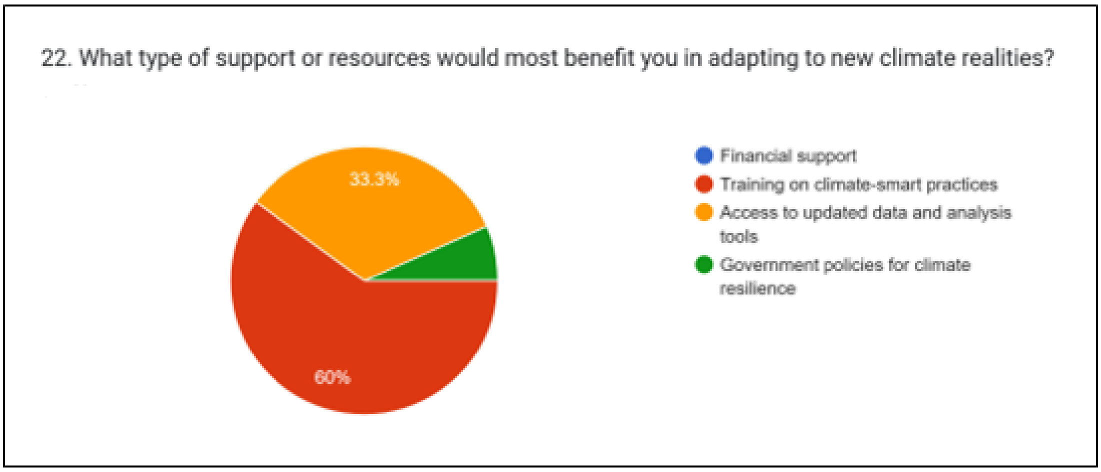


Figure 4-40: Type of support needed in adapting to new climate realities

It was evident from reviewing the survey's overall responses that nearly all respondents supported changing the current agro-ecological regions. They highlighted the necessity of redefining these regions in a way that is more comprehensive, accessible, and representative of the agricultural and climatic realities of today. The government and other pertinent groups must actively address this issue in order to do this. Implementing a well-organized, scientifically based framework that can assist farmers, legislators, and other stakeholders in adjusting to shifting circumstances and guaranteeing sustainable agricultural practices requires their participation.

4.4.3 Summary of the findings of Questionnaire Survey

A comprehensive questionnaire survey was conducted to gather expert insights on two key products developed in this study: the updated agroecological zoning criteria and the seasonal high-risk zoning map for extreme rainfall events in Sri Lanka. The survey primarily targeted research officers from major agricultural crop institutes, including those specializing in tea, rubber, coconut, rice, and potato, as well as officers from the Disaster Management Centre. These professionals were selected for their extensive knowledge and practical experience in addressing the challenges posed by extreme weather events. Although a few farmers and other individuals engaged in the agricultural sector were also consulted informally, their feedback was not included in the formal analysis and future recommendations.

A total of 56 personals participated in the survey including workers and farmers. Their involvement aimed to ensure that the proposed zoning frameworks would be both relevant and practically applicable, supporting informed decision-making and adaptation measures in response to climate change. According to the survey findings, the majority of respondents reported an observed increase in extreme rainfall events over recent years, although these observations were not always backed by quantitative measurements. The impacts of such events were significant across the sectors represented. Crop damage was identified as the most critical impact, severely affecting agricultural output and livelihoods. In addition, respondents noted secondary effects such as an increase in pest infestations and outbreaks of plant diseases, which were often exacerbated by prolonged periods of heavy rainfall. Furthermore, landslides were identified as a major hazard in certain areas, posing serious risks to infrastructure and habitation. These findings emphasize the growing threat of extreme rainfall to Sri Lanka's agricultural and disaster management sectors and highlight the importance of the newly proposed agroecological zoning criteria and seasonal risk maps for enhancing resilience and guiding future planning efforts.

In this study, a detailed survey among industrial workers could not be conducted due to the timeline and the objectives of the research. However, through the few individuals interviewed, it was observed that they had limited knowledge of theoretical concepts and current research findings, despite their strong practical experience. Nevertheless, since the sample size of farmers and other industrial workers was small, no clear conclusions can be drawn from their responses. Therefore, the collected data are included in this document to provide some initial insights, which could be beneficial for anyone willing to continue and expand this study in the future.

5. CONCLUSION

5.1.1 Summary of Findings

The study's conclusions provide important new information about how well Sri Lanka can use the extreme precipitation indexes that the World Meteorological Organization (WMO) proposed. Only a few indices were found to significantly affect the nation's agriculture and other important industries. Although helpful in some situations, these indexes don't offer a comprehensive or in-depth understanding of the differences in significant precipitation events throughout Sri Lanka. The lack of noteworthy trend values over the last few decades is one of the main causes of this constraint, which limits the indices' ability to provide accurate forecasts or an in-depth understanding of the temporal and geographical dynamics of excessive rainfall. This study suggested a multi-criteria analysis as a substitute method to address these issues and more accurately identify high-risk areas during different rainfall seasons. By combining many data sources and variables, this method provides a stronger foundation for comprehending and managing the hazards connected to extreme precipitation events. This methodology offers a clearer, more practical viewpoint for decision-making by going beyond conventional indicators, especially in the areas of agriculture, disaster management, and climate adaptation.

This study highlights the crucial need for a thorough update on Sri Lanka's agroecological zones. The zones that have been in place for a long time no longer accurately represent the current agricultural and meteorological conditions. Updating these zones is vital to fulfill the developing demands of the country, particularly in light of increased climatic variability and its cascading consequences on food security, water resources, and land management. By following World Health Organization (WHO) principles and modifying them to fit Sri Lanka's particular circumstances and customs, this study adopted a proactive stance. In contrast to traditional zoning techniques, this study added important new elements to the zoning framework, including administrative boundaries, land use patterns, irrigation zones, and river basins. Combining these components led to the creation of a thorough, updated zoning system that is both realistic for everyday use and supported by science. In order to provide more sustainable and knowledgeable decision-making throughout Sri Lanka, this updated framework may be used as a fundamental tool for many industries, including agriculture, urban planning, disaster risk reduction, and environmental conservation.

5.1.2 Limitations of the Study

This study was carried out by accepted worldwide frameworks, emphasizing modifying these approaches for the Sri Lankan setting. To guarantee the dependability and applicability of the results, a number of constraints have been carefully taken into account throughout the procedure, including data availability, correctness, and regional variability. With these obstacles, the study recognizes the necessity for ongoing development and enhancement in the future while attempting to produce significant and useful findings suited to Sri Lanka's particular meteorological and socioeconomic circumstances. Some of the points are summarized below.

- There are many obstacles in obtaining historical rainfall and other climate data for Sri Lanka. A significant amount of money is frequently needed to obtain data from relevant institutions, and many stations do not have continuous records. As a result, only 39 rainfall stations were chosen for this study based on their capacity to reflect the diverse climate conditions found throughout Sri Lanka and the availability of data. It is crucial to remember that this data might not be enough for future research to analyze other parameters or validate climate models.
- ETCCDI indices have been used to forecast trend values in the majority of earlier research on extreme rainfall trends. These trend values and their statistical significance, however, show limitations upon closer inspection because they cannot be used directly for precise prediction. Furthermore, some of these indexes are not relevant to local populations, agriculture, or disasters. A comprehensive assessment was carried out to close this gap, combining occurrences of heavy rainfall with ETCCDI indexes and professional guidance. This strategy offers a fresh way to pinpoint areas that are at high risk of experiencing significant precipitation occurrences. The AHP (Analytic Hierarchy Process) pairwise comparison approach was used to compute factor and sub-factor values in a multi-criteria analysis. It is crucial to remember that as more expert input is obtained, these factor values might experience slight modifications.
- In the past, more than 100 rainfall stations and more than 30 years of rainfall data were utilized to define agro-climate zones. However, because of limitations in data availability, only 39 rainfall stations were included in this investigation. As previously stated, this small dataset is not enough to validate data from future climate models. As a result, this study does not alter the current agro-climate zones. Instead, to offer more information, future prediction details were included in the AEZ shapefile's attribute table.
- It is difficult to strictly follow administrative boundaries in Sri Lanka when it comes to the AEZ criterion. Instead, land use data specifically, the main crops in various zones are given more weight in the new zoning criterion. This method makes it possible to make decisions about different crops more effectively and efficiently on an individual basis.

5.1.3 Suggestions for the Future Research

There is a lot of potential for this study to be used in several fields in the future. They made insightful recommendations to improve the use of agroecological zoning criteria and extreme precipitation analysis during conversations with industry experts and through questionnaire surveys. The goal of these enhancements is to guarantee improved utilization in many areas, such as resource planning, agriculture, and catastrophe management.

- Only previously recorded data was utilized to establish the precise zones over various periods in the high-risk areas map for extreme precipitation occurrences. By creating a web application with a regularly updated map that is easily accessible to everyone, this approach can be further improved. Users will be able to more efficiently plan future actions and put suitable mitigation measures in place with the help of such a platform.
- The creation of monthly high-risk zone maps was recommended by a large number of questionnaire survey participants. These monthly zoning maps may be created using the same dataset as this study, offering more timely and comprehensive information for improved planning and decision-making.
- The criteria applied in various industries frequently differ notably. For example, "up country" in agroecological zoning refers to regions above 600 meters above mean sea level (MSL), while "up country" in the tea industry refers to regions above 900 meters. When making decisions, these disparities may present difficulties. In order to ensure more precise and efficient decision-making, sector-specific zoning schemes that are adapted to the particular needs of each sector would be advantageous.

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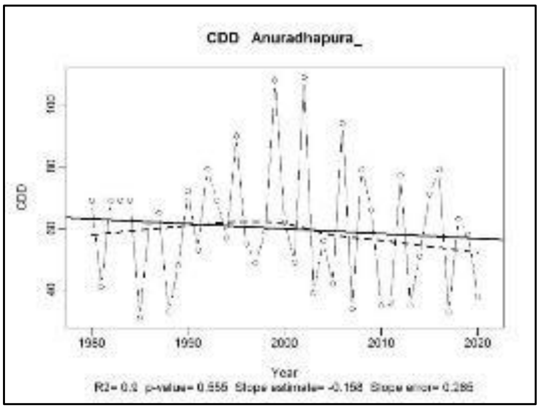
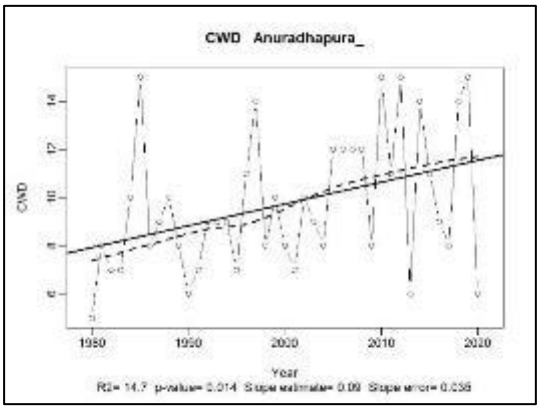
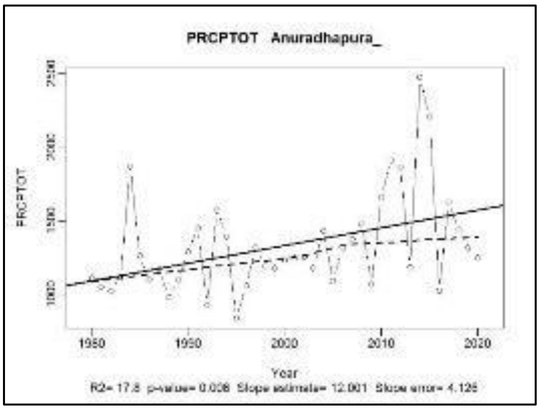
APPENDICES

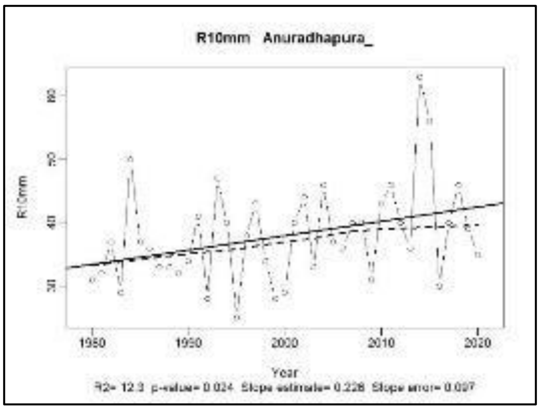
Appendix A: RClimDex Analysis data

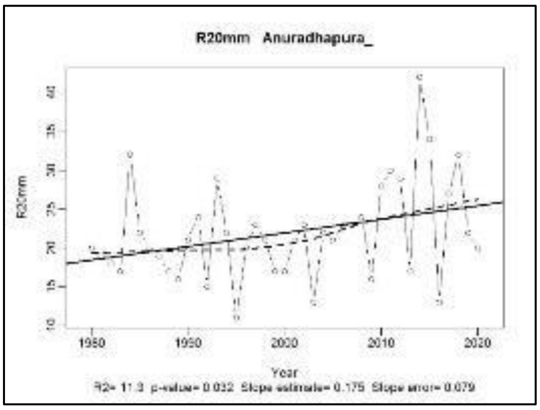
Trend analysis data of "Anuradhapura" rainfall station

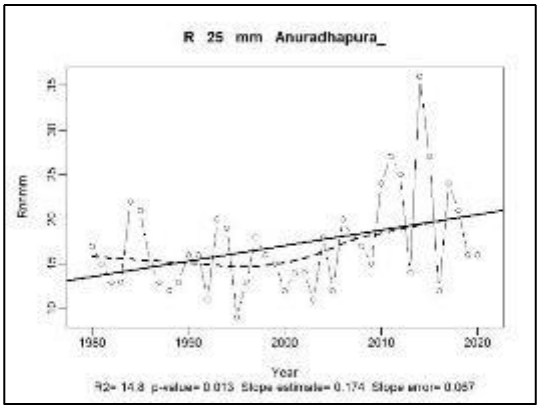


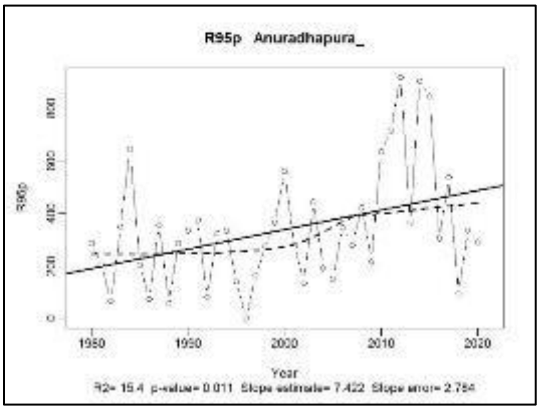


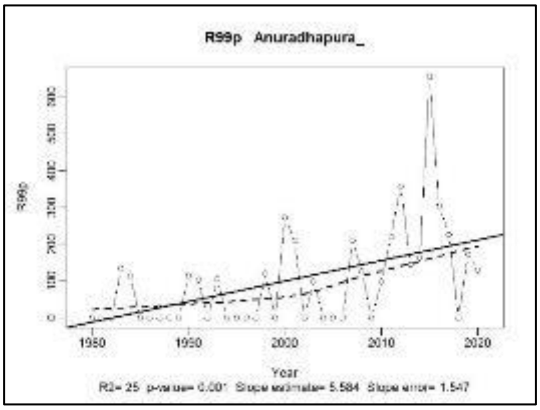


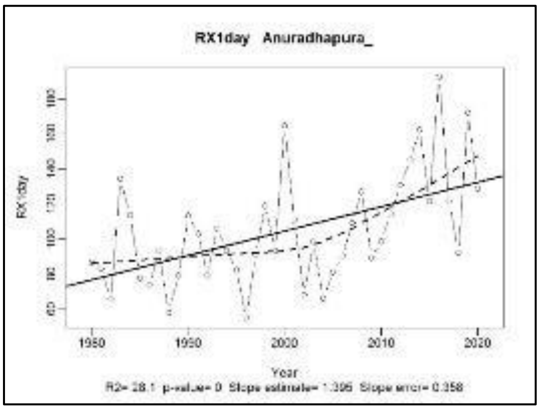


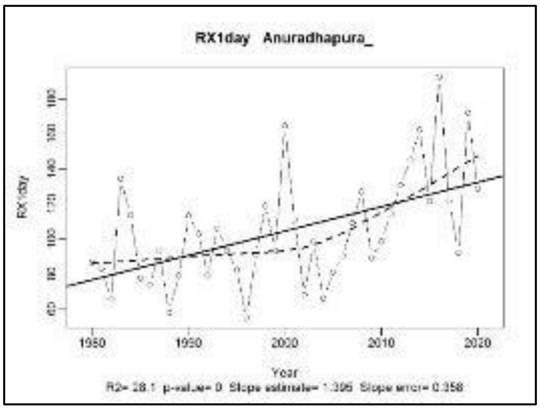


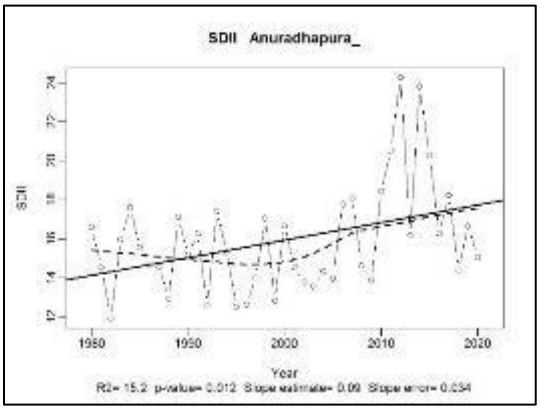




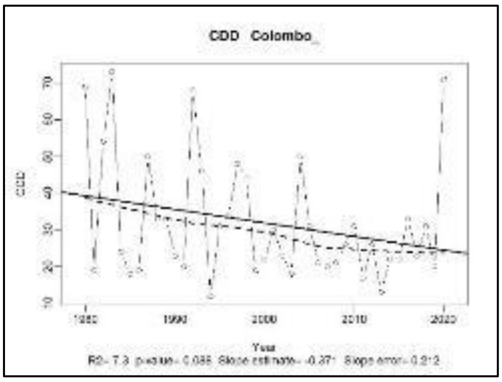


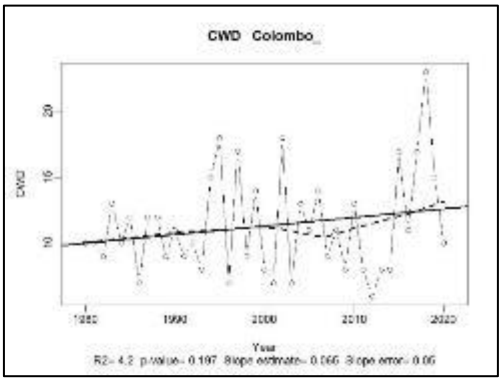


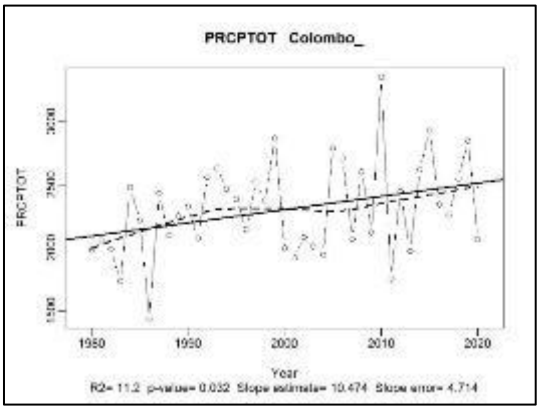


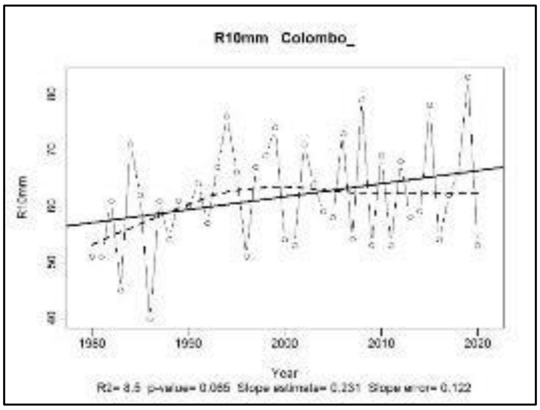


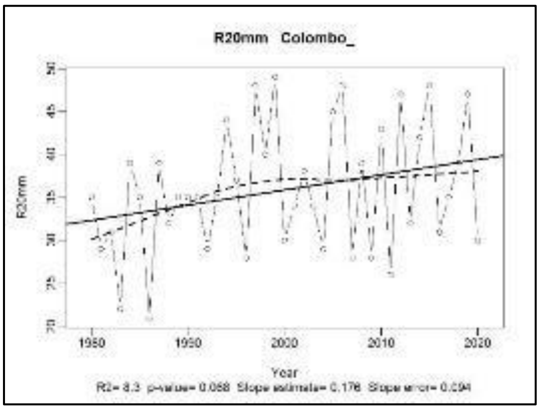
Trend analysis data of "Colombo" rainfall station

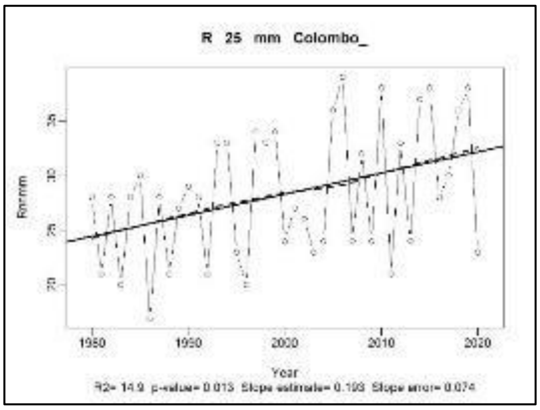


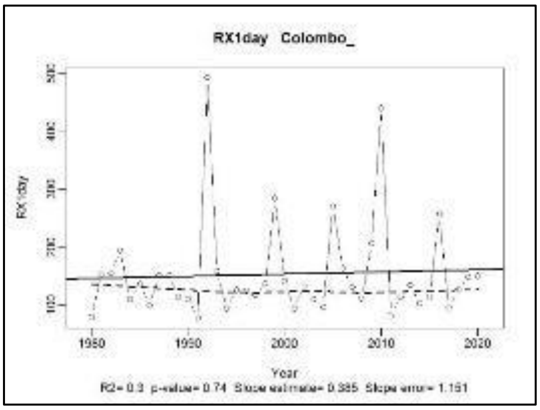


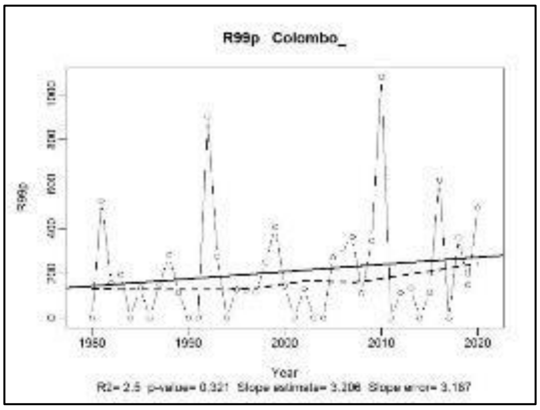

PRCPTOT Colombo_
PRCPTOT
Year
R2= 11.2 p-value= 0.032 Slope estimate= 10.474 Slope error= 4.714

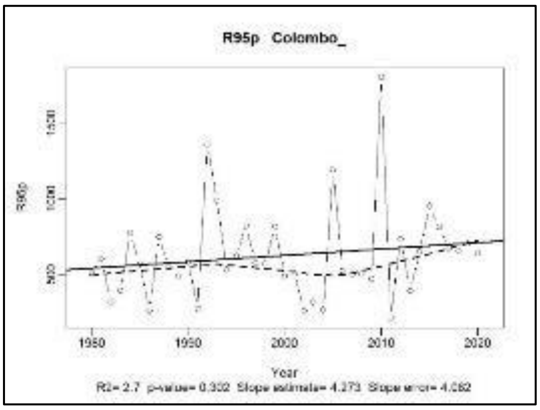

R10mm Colombo_
R10mm
Year
R2= 8.5 p-value= 0.065 Slope estimate= 0.231 Slope error= 0.122

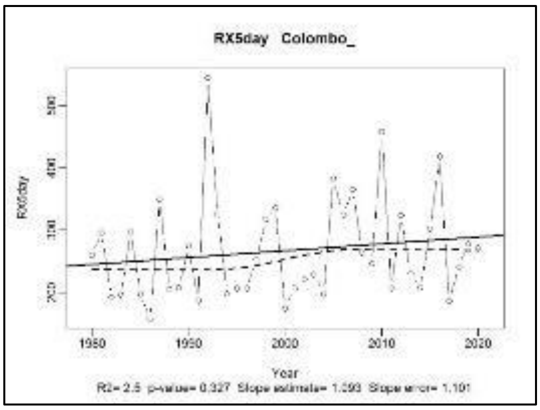

R20mm Colombo_
R20mm
Year
R2= 8.3 p-value= 0.068 Slope estimate= 0.176 Slope error= 0.094

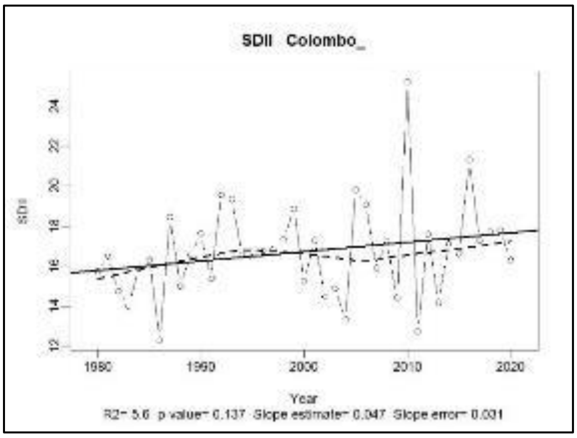

R 25 mm Colombo_
Year
R2= 14.9 p-value= 0.013 Slope estimate= 0.193 Slope error= 0.074


RX1day Colombo_
RX1day
Year
R2= 0.3 p-value= 0.74 Slope estimate= 0.385 Slope error= 1.151


R99p Colombo_
R99p
Year
R2= 2.5 p-value= 0.321 Slope estimate= 3.206 Slope error= 3.187

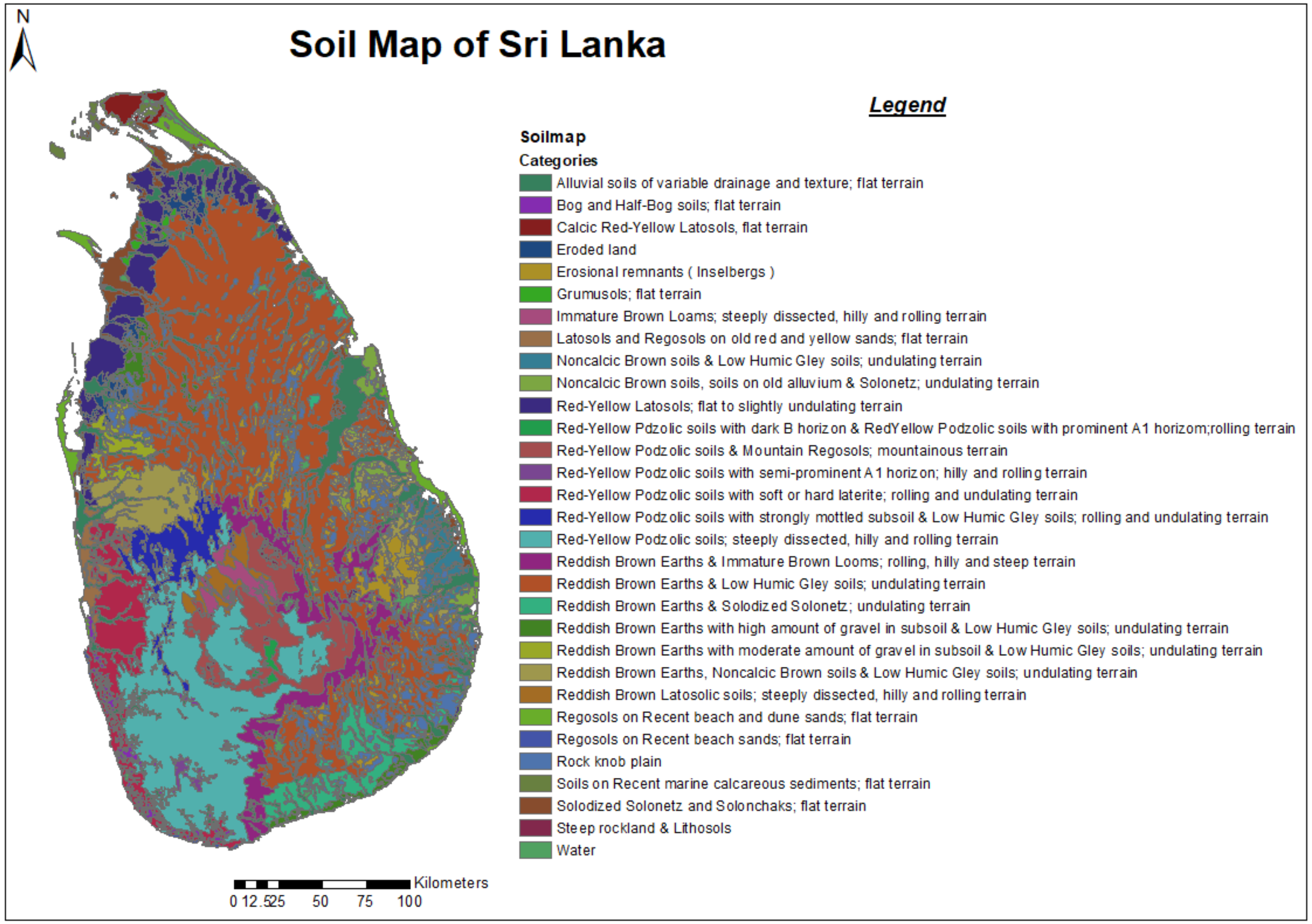

R95p Colombo_
R95p
Year
R2= 2.7 p-value= 0.302 Slope estimate= 4.273 Slope error= 4.082


RX5day Colombo_
RX5day
Year
R2= 2.5 p-value= 0.327 Slope estimate= 1.093 Slope error= 1.101



Similar to these datasets, plots displaying the trend values of each index for each of the 39 rainfall stations were made using RClimDex data. These trend values were then used to create maps that illustrated the patterns at each station.

Appendix B: Soil Map of Sri Lanka



Appendix C – AHP Pairwise comparison

The major factor weightage for each extreme rainfall index has to be determined to do a multi-criteria analysis to determine regions that were severely impacted by extreme precipitation events. This was accomplished via a pairwise AHP (Analytic Hierarchy Process) comparison, as described in the earlier chapters. People engaged in the sectors of agriculture, disaster management, and climate change provided the data utilized in this analysis. The gathered information is shown for reference below.

1. Person: Dr. Jeewan Dhananjaya
   Designation: Senior Research Officer, TRI, Thalawakelle
   Research area: Agriculture

Primary Questionnaire sheet: Effective criteria and pair wise comparison (AHP)										
Factor	More Importance than				Equal	Less importance than				Factor
R99p	5	4	**3**	2	1	2	3	4	5	PRCPTOT
R99p	5	**4**	3	2	1	2	3	4	5	R10mm
R99p	5	**4**	3	2	1	2	3	4	5	R20mm
R99p	5	**4**	3	2	1	2	3	4	5	R25mm
R99p	5	4	3	**2**	1	2	3	4	5	R95p
R99p	5	4	3	2	1	2	**3**	4	5	RX5day
R95p	5	4	3	**2**	1	2	3	4	5	PRCPTOT
R95p	**5**	4	3	2	1	2	3	4	5	R10mm
R95p	5	**4**	3	2	1	2	3	4	5	R20mm
R95p	5	**4**	3	2	1	2	3	4	5	R25mm
R95p	5	4	3	2	1	2	**3**	4	5	RX5day
RX5day	5	4	**3**	2	1	2	3	4	5	PRCPTOT
RX5day	**5**	4	3	2	1	2	3	4	5	R10mm
RX5day	5	**4**	3	2	1	2	3	4	5	R20mm
RX5day	5	**4**	3	2	1	2	3	4	5	R25mm
PRCPTOT	5	**4**	3	2	1	2	3	4	5	R10mm
PRCPTOT	5	4	**3**	2	1	2	3	4	5	R20mm
PRCPTOT	5	4	**3**	2	1	2	3	4	5	R25mm
R25mm	5	4	3	**2**	1	2	3	4	5	R10mm
R25mm	5	4	3	**2**	1	2	3	4	5	R20mm
R20mm	5	4	3	2	**1**	2	3	4	5	R10mm

2. Person: Mr. Saminda Kahawandala
   Designation: Research officer, Department of Agriculture, Seetha Eliya
   Research Area: Agriculture

Factor	More Importance than				Equal	Less importance than				Factor
R99p	5	4	3	2	1	2	3	4	5	PRCPTOT
R99p	5	4	3	2	1	2	3	4	5	R10mm
R99p	5	4	3	2	1	2	3	4	5	R20mm
R99p	5	4	3	2	1	2	3	4	5	R25mm
R99p	5	4	3	2	1	2	3	4	5	R95p
R99p	5	4	3	2	1	2	3	4	5	RX5day
R95p	5	4	3	2	1	2	3	4	5	PRCPTOT
R95p	5	4	3	2	1	2	3	4	5	R10mm
R95p	5	4	3	2	1	2	3	4	5	R20mm
R95p	5	4	3	2	1	2	3	4	5	R25mm
R95p	5	4	3	2	1	2	3	4	5	RX5day
RX5day	5	4	3	2	1	2	3	4	5	PRCPTOT
RX5day	5	4	3	2	1	2	3	4	5	R10mm
RX5day	5	4	3	2	1	2	3	4	5	R20mm
RX5day	5	4	3	2	1	2	3	4	5	R25mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R10mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R20mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R25mm
R25mm	5	4	3	2	1	2	3	4	5	R10mm
R25mm	5	4	3	2	1	2	3	4	5	R20mm
R20mm	5	4	3	2	1	2	3	4	5	R10mm

3. Person: Mr. Chamal Jayaminda
   Designation: PhD candidate, Swansea University, UK
   Research Area: Climate change

Primary Questionnaire sheet: Effective criteria and pair wise comparison (AHP)										
Factor	More Importance than				Equal	Less importance than				Factor
R99p	5	4	3	2	1	2	3	4	5	PRCPTOT
R99p	5	4	3	2	1	2	3	4	5	R10mm
R99p	5	4	3	2	1	2	3	4	5	R20mm
R99p	5	4	3	2	1	2	3	4	5	R25mm
R99p	5	4	3	2	1	2	3	4	5	R95p
R99p	5	4	3	2	1	2	3	4	5	RX5day
R95p	5	4	3	2	1	2	3	4	5	PRCPTOT
R95p	5	4	3	2	1	2	3	4	5	R10mm
R95p	5	4	3	2	1	2	3	4	5	R20mm
R95p	5	4	3	2	1	2	3	4	5	R25mm
R95p	5	4	3	2	1	2	3	4	5	RX5day
RX5day	5	4	3	2	1	2	3	4	5	PRCPTOT
RX5day	5	4	3	2	1	2	3	4	5	R10mm
RX5day	5	4	3	2	1	2	3	4	5	R20mm
RX5day	5	4	3	2	1	2	3	4	5	R25mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R10mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R20mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R25mm
R25mm	5	4	3	2	1	2	3	4	5	R10mm
R25mm	5	4	3	2	1	2	3	4	5	R20mm
R20mm	5	4	3	2	1	2	3	4	5	R10mm

4. Person: Mr. Dilum Rajapakse
   Designation: PhD candidate, RMIT University, Australia

Research Area: Disaster Management

Primary Questionnaire sheet: Effective criteria and pair wise comparison (AHP)										
Factor	More Importance than				Equal	Less importance than				Factor
R99p	5	4	3	2	1	2	3	4	5	PRCPTOT
R99p	5	4	3	2	1	2	3	4	5	R10mm
R99p	5	4	3	2	1	2	3	4	5	R20mm
R99p	5	4	3	2	1	2	3	4	5	R25mm
R99p	5	4	3	2	1	2	3	4	5	R95p
R99p	5	4	3	2	1	2	3	4	5	RX5day
R95p	5	4	3	2	1	2	3	4	5	PRCPTOT
R95p	5	4	3	2	1	2	3	4	5	R10mm
R95p	5	4	3	2	1	2	3	4	5	R20mm
R95p	5	4	3	2	1	2	3	4	5	R25mm
R95p	5	4	3	2	1	2	3	4	5	RX5day
RX5day	5	4	3	2	1	2	3	4	5	PRCPTOT
RX5day	5	4	3	2	1	2	3	4	5	R10mm
RX5day	5	4	3	2	1	2	3	4	5	R20mm
RX5day	5	4	3	2	1	2	3	4	5	R25mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R10mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R20mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R25mm
R25mm	5	4	3	2	1	2	3	4	5	R10mm
R25mm	5	4	3	2	1	2	3	4	5	R20mm
R20mm	5	4	3	2	1	2	3	4	5	R10mm

5. Person: Mr. Chamika Kannangara
   Designation: PhD candidate, RMIT University, Australia
   Research Area: Disaster Management

Primary Questionnaire sheet: Effective criteria and pair wise comparison (AHP)										
Factor	More Importance than				Equal	Less importance than				Factor
R99p	5	4	3	2	1	2	3	4	5	PRCPTOT
R99p	5	4	3	2	1	2	3	4	5	R10mm
R99p	5	4	3	2	1	2	3	4	5	R20mm
R99p	5	4	3	2	1	2	3	4	5	R25mm
R99p	5	4	3	2	1	2	3	4	5	R95p
R99p	5	4	3	2	1	2	3	4	5	RX5day
R95p	5	4	3	2	1	2	3	4	5	PRCPTOT
R95p	5	4	3	2	1	2	3	4	5	R10mm
R95p	5	4	3	2	1	2	3	4	5	R20mm
R95p	5	4	3	2	1	2	3	4	5	R25mm
R95p	5	4	3	2	1	2	3	4	5	RX5day
RX5day	5	4	3	2	1	2	3	4	5	PRCPTOT
RX5day	5	4	3	2	1	2	3	4	5	R10mm
RX5day	5	4	3	2	1	2	3	4	5	R20mm
RX5day	5	4	3	2	1	2	3	4	5	R25mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R10mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R20mm
PRCPTOT	5	4	3	2	1	2	3	4	5	R25mm
R25mm	5	4	3	2	1	2	3	4	5	R10mm
R25mm	5	4	3	2	1	2	3	4	5	R20mm
R20mm	5	4	3	2	1	2	3	4	5	R10mm

Weightage calculation

- Pair-wise comparison matrix

	R99p	R95p	RX5day	PRCPTOT	R25mm	R20mm	R10mm
R99p	1	2	0.611111	2.666667	3.666667	3.666667	4
R95p	0.5	1	0.777778	2.333333	3.333333	3.333333	4.333333
RX5day	1.636364	1.285714	1	3.666667	3.666667	3.666667	4.333333
PRCPTOT	0.375	0.428571	0.272727	1	2.333333	2.666667	3.333333
R25mm	0.272727	0.3	0.272727	0.428571	1	1.666667	2.666667
R20mm	0.272727	0.3	0.272727	0.375	0.6	1	1.666667
R10mm	0.25	0.230769	0.230769	0.3	0.375	0.6	1

- Normalized pair-wise matrix

	R99p	R95p	RX5day	PRCPTOT	R25mm	R20mm	R10mm	**Weight**
R99p	0.23219	0.360682	0.17776	0.247596	0.244853	0.220884	0.1875	**0.238780551**
R95p	0.116095	0.180341	0.22624	0.216646	0.222593	0.200803	0.203125	**0.195120561**
RX5day	0.379947	0.231867	0.29088	0.340444	0.244853	0.220884	0.203125	**0.273142828**
PRCPTOT	0.087071	0.077289	0.079331	0.092848	0.155815	0.160643	0.15625	**0.115606779**
R25mm	0.063325	0.054102	0.079331	0.039792	0.066778	0.100402	0.125	**0.075532794**
R20mm	0.063325	0.054102	0.079331	0.034818	0.040067	0.060241	0.078125	**0.058572673**
R10mm	0.058047	0.041617	0.067126	0.027855	0.025042	0.036145	0.046875	**0.043243814**

- Consistency Ratio (CR)

	R99p	R95p	RX5day	PRCPTOT	R25mm	R20mm	R10mm	Weighted Sum	Weights	
R99p	0.238781	0.390241	0.166921	0.308285	0.276954	0.214766	0.172975	1.768922337	0.24	7.37051
R95p	0.11939	0.195121	0.212444	0.269749	0.251776	0.195242	0.18739	1.431112494	0.2	7.155562
RX5day	0.390732	0.250869	0.273143	0.423892	0.276954	0.214766	0.18739	2.017745362	0.27	7.473131
PRCPTOT	0.089543	0.083623	0.074493	0.115607	0.176243	0.156194	0.144146	0.839849109	0.12	6.998743
R25mm	0.065122	0.058536	0.074493	0.049546	0.075533	0.097621	0.115317	0.53616815	0.08	6.702102
R20mm	0.065122	0.058536	0.074493	0.043353	0.04532	0.058573	0.072073	0.41746955	0.06	6.957826
R10mm	0.059695	0.045028	0.063033	0.034682	0.028325	0.035144	0.043244	0.309150169	0.04	7.728754

- Final weightages

	Weights
R99p	**0.24**
R95p	**0.2**
RX5day	**0.27**
PRCPTOT	**0.12**
R25mm	**0.08**
R20mm	**0.06**
R10mm	**0.04**

Appendix D – Questionnaire survey on Extreme rainfall and new Agroecological zones

Survey on Extreme Rainfall Impacts and Agroecological Zone Re-Demarcation in Sri Lanka

This survey aims to gather insights on the impacts of extreme rainfall events and the potential for re-demarcating agroecological zones in Sri Lanka. This study is part of a research initiative assessing climate change's influence on rainfall variability and its effects on agricultural practices, disaster management, and community livelihoods. By sharing your experiences and opinions, you contribute to a deeper understanding of the challenges posed by changing rainfall patterns and how updated agroecological zones can enhance resilience across the country.

Section A

1. Name
2. Please select your profession
   - Farmer
   - Researcher (Agriculture)
   - Researcher (Disaster Management)
   - Researcher (Climate Change)
   - Agrarian Officer
   - Other (Specify)
3. Occupation and workplace (Optional)
4. Select your primary region of work (Province)
   - Northern Province
   - Eastern Province
   - Southern Province
   - Western Province
   - Central Province
   - North Western Province
   - North Central Province
   - Uva Province
   - Sabaragamuwa Province
5. How many years do you work in the relevant industry?

- <5 years
- 5 – 10 years
- > 10 years

Section B

6. Are you aware of any significant changes in rainfall patterns in your area over recent years?
   - Yes
   - No
7. In your opinion/experience, have extreme rainfall events become more frequent in your area?
   - Yes
   - No
   - Not sure
8. What do you consider the most critical impact of extreme rainfall events in your area?
   - Crop damage
   - Soil erosion and landslides
   - Flooding of fields
   - Displacement of communities
   - Increased pest and disease prevalence
   - No significant impact
   - Other (Specify)
9. How would you rate your current preparedness level for extreme rainfall events?
   - Very Prepared
   - Somewhat Prepared
   - Not Very Prepared
   - Not Prepared at All
10. How useful is it that you find a seasonal-wise extreme rainfall analysis map to help you make decisions related to your area of profession?
    - Extremely Useful
    - Somewhat Useful
    - Not Very Useful
    - Not Useful at All

11. What information on the extreme rainfall analysis map do you consider the most valuable? (Select all that apply)
    - Seasonal extreme rainfall patterns
    - Identification of high-risk zones
    - Predictive patterns for extreme rainfall events
    - Historical rainfall trends
    - Other (Specify)
12. Do you believe this map could help you or your organization take preventive action to mitigate the effects of extreme rainfall?
    - Yes
    - No
    - Maybe
13. Would you recommend any additional data or improvements for the rainfall analysis map? (Open-ended)

Section C

Agroecological regions are zones that have been divided considering different factors that affect agriculture and are helpful for decision-making processes. Currently, Sri Lanka is divided into 46 agroecological zones by considering factors, elevation, annual rainfall, and soil pattern. In this research, it is proposed to re-demarcate the current agroecological zones with more affected factors (Ex: administration boundaries and irrigation pattern, extreme rainfalls), that can be more effectively used for the decision-making process of different officials.

14. Are you aware of the concept of agroecological zones (AEZs) and their relevance to agricultural planning?
    - Yes
    - No
15. Do you believe the current agroecological zones in Sri Lanka are still accurate given the changing climate patterns and all other affecting factors?
    - Yes
    - No
    - Not Sure
16. Do you support the idea of re-demarcating agroecological zones in Sri Lanka based on recent climate data and other important factors?

- Yes
- No
- Not Sure

17. How beneficial would re-demarcated agroecological zones be for your work or livelihood?
    - Extremely Beneficial
    - Somewhat Beneficial
    - Not Very Beneficial
    - Not Beneficial at All
18. Which factors do you think should be prioritized in the re-demarcation of agroecological zones? (Select all that apply)
    - Climate factors (Rainfall, Temperature)
    - Topographic factors (Landforms, Watersheds)
    - Soil factors
    - Land use (Land cover data, crop distribution, crop suitability areas)
    - Irrigation (Irrigation types and zones, seasonal water contribution)
    - Administration boundaries (DSD, District, and provincial boundaries)
    - Other (Specify)
19. Do you believe that re-demarcated agroecological zones will improve agricultural productivity and the decision-making process in Sri Lanka?
    - Yes
    - No
    - Not Sure
20. How likely are you to adapt your farming or work practices based on the re-demarcated agroecological zones?
    - Very Likely
    - Somewhat Likely
    - Not Very Likely
    - Not Likely at All
21. Do you feel adequately supported by local government or relevant agencies in adapting to changing climate impacts on agriculture?
    - Yes
    - No

- Somewhat

22. What type of support or resources would most benefit you in adapting to new climate realities? (Select all that apply)
    - Financial support
    - Training on climate-smart practices
    - Access to updated data and analysis tools
    - Government policies for climate resilience
    - Other (Specify)
23. Any additional comments or recommendations you would like to share? (Open-ended)