SPATIO-TEMPORAL TREND ANALYSIS OF HYDRO-CLIMATIC VARIABLES OF THE NORTHERN REGION IN SRI LANKA

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by

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LIST OF SYMBOLS

° - Degree

C Celsius

LIST OF ABBREVIATIONS

A.M	Ante Meridiem
Aru	Rivers
C	Celsius
CAOGCM	Coupled Atmosphere-Ocean General Circulation Models
CC	Capacity cross
CCKP	Climate change Knowledge Portal
CD	Catchment detention
CI	Catchment inflow
CMIP	Climate Model Intercomparison Project
CN	Capacity net
ENSO	El Nino Southern oscillation
ES	Evaporation from soil
EY	Effective Yield
FIMS	First Inter Monsoon Season
FSD	Full supply depth
FSL	Fully saturated level
Ft	Feet
Hec.	Hectare
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
Km	Kilometer
M	Meter
Mb	Millie Bar
MCM	Million Cubic Meter
MM	Millie Meter

NEMS	North East Monsoon Season
Oya	Rivers
P.M	Post Meridiem
RCP	Representative Concentration Pathway
RF	Return flow
RR	Runoff of Rainfall
RS	Runoff to the sea
SIMS	Second Inter Monsoon Season
SLRs	Sri Lankan Rupees
SqKm	Square kilometer
SPSS	Statistical Package for Social Sciences
SST	Sea Surface Temperature
SWMS	South West Monsoon Season

ANALISIS TREND RUANG MASA PEMBOLEH UBAH HIDRO-IKLIM DI WILAYAH UTARA SRI LANKA

ABSTRAK

Sri Lanka telah mengalami banjir dan kemarau yang teruk dalam beberapa dekad kebelakangan ini, menyebabkan isu kesihatan dan kerugian pertanian dan pendapatan. Kajian ini menilai trend Spatio-temporal pembolehubah hidro-iklim sejarah dan masa depan di wilayah utara Sri Lanka. Secara keseluruhannya, utara Sri Lanka menghadapi peningkatan keparahan kemarau semasa musim monsun barat daya tetapi meningkatkan keterukan banjir semasa timur laut. Analisis arah aliran menunjukkan bahawa suhu, kerpasan dan sejatan dari 1970 hingga 2019 telah meningkat sebanyak 0.44 °C /dekad, 18.76mm/dekad kepada 37.68 mm/dekad, dan sejatan meningkat sebanyak 17%, masing-masing. Lebih 50% daripada jumlah hujan direkodkan dalam tempoh dua minggu, terutamanya dari 20 November hingga 05 Disember setiap tahun. Dalam tempoh 2020-2100, kerpasan dan suhu diunjurkan meningkat sebanyak 1.13°C (1.81°C) dan 106.19 mm (186mm) di bawah senario RCP4.5 (8.5), masing-masing, berbanding garis dasar dari 1970 hingga 2019 Terdapat korelasi negatif yang kuat antara bilangan hari hujan yang berkurangan dan volum larian, dengan nilai R - 0.70; ini menunjukkan bahawa mengesahkan bahawa mengurangkan hari hujan meningkatkan air larian di wilayah ini disebabkan oleh intensiti hujan yang tinggi dalam tempoh yang singkat. Ketersediaan air takungan tiba-tiba berkurangan pada bahagian akhir musim antara monsun pertama dan yang membawa kepada kesan ke atas bekalan dan permintaan air di kawasan kajian. Secara spatial dibandingkan dengan bahagian lain, kawasan barat suhu kawasan kajian telah meningkat dengan pesat sebanyak 0.04°C bahagian tengah kawasan kajian mengalami

pola peningkatan hujan 9mm berbanding kawasan lain. Mengikut corak spatial kemarau, wilayah barat mempunyai bilangan kejadian kemarau yang lebih tinggi daripada kawasan lain di wilayah Utara Sri Lanka. Oleh itu, adalah dicadangkan untuk meningkatkan kapasiti penampungan air dengan membina takungan baharu di lembangan sungai Aruvi Aru (arus bawah), Paranki Aru (alur atas dan bawah), Pali Aru (arus bawah), Mandaikallaru (alur atas dan bawah).), Akarayan Aru (aliran bawah), Theravil Aru, Per Aru (aliran bawah) dan Maa Oya (aliran bawah) serta meningkatkan penyusupan dengan mengekalkan permukaan berliang dengan penutup hijau. Analisis perubahan iklim yang diperhatikan serta perubahan iklim masa depan bagi wilayah Utara Sri Lanka mendedahkan bahawa perubahan signifikan dalam magnitud dan frekuensi kemarau akan membawa impak teruk kepada sumber air sedia ada di wilayah Utara Sri Lanka.

SPATIO-TEMPORAL TREND ANALYSIS OF HYDRO-CLIMATIC VARIABLES OF THE NORTHERN REGION IN SRI LANKA

ABSTRACT

In recent decades, Sri Lanka has experienced severe floods and droughts, causing health issues and agricultural and income losses. This study evaluated the Spatio-temporal trend of historical and future hydro-climatic variables in the northern region of Sri Lanka. Overall, northern Sri Lanka faced an increase in drought severity during the southwest monsoon season but increased flood severity during the northeast. The trend analysis shows that temperature, precipitation, and evaporation from 1970 to 2019 have increased by 0.44 °C /decade, 18.76mm/decade to 37.68 mm/decade, and evaporation increased by 17%, respectively. More than 50% of the total rainfall is recorded within two weeks, especially from the 20th of November to the 05th of December every year. In the 2020-2100 period, precipitation and temperature are projected to increase by 1.13°C (1.81°C) and 106.19 mm (186mm) under the RCP4.5 (8.5) scenario, respectively as compared to the baseline from 1970 to 2019. There is a strong negative correlation between the reduced number of rainy days and the runoff volume, with an R-value of - 0.70; this indicates and confirms that reduction of rainy days increased the runoff in this region due to the high intensity of the rainfall within a short period. The water availability of the reservoirs significantly dropped during the latter part of the first inter monsoon season, leading to the impact on water supply and demand in the study area. Spatially compared to other parts, the temperature of the western region of the study area has been increasing rapidly by 0.04°C and the middle part of the study area is experiencing an increasing pattern of 9mm rainfall more than other areas. According to the spatial pattern of drought, the

western region has a higher number of drought occurrences than other areas of the Northern region of Sri Lanka. As such, it is proposed to increase the water holding capacity by constructing new reservoirs in the river basins of Aruvi Aru (lower stream), Paranki Aru (upper and lower stream), Pali Aru (lower stream), Mandaikallaru (upper and lower stream), Akarayan Aru (lower stream), Theravil Aru, Per Aru (lower stream) and Maa Oya (lower stream) as well as increasing infiltration by keeping porous surfaces with green cover. The observed and future climate change analysis of the Northern region of Sri Lanka revealed that a significant change in drought magnitude and frequency would lead to a severe impact on surface water resources availability of the Northern region of Sri Lanka.

CHAPTER 1

INTRODUCTION TO THE RESEARCH

1.1 Background of the Research

Climate change has become a serious threat to the global economy (Mihailovic et al., 2020). Its impacts are felt pervasively across all primary and sub-sectors of the development economy (Chan, 2016). Climate change is accompanied by an increase in frequency and intensity of extreme weather occurrences, including droughts, cyclones, floods, heatwaves, intense rainfalls, cold and heat waves, all of which are projected in several parts of Asia. For example, the Asian countries will encounter a temperature increase by 2-4 ° C of sea surface temperature and a 10-20% increase in tropical cyclone intensity from 2020 to 2050 (Calow et al., 2011). In recent decades, many countries have focused primarily on mitigating the climate change impacts. They have extended their valuable support to other countries to adapt to or minimize the hazards of climate change in their respective countries (Forootan, 2019).

Water resources are defined as the sources of water that are useful or potentially useful to humans (Loukas et al., 2021). Meanwhile, water balance indicates the relation between the water integrated into the body and the amount lost from the body (Silva, 2006). Water balance is the analysis and quantification of the water cycle components, accounting for flow (inflows and outflow) and storage changes in natural systems containing water (Somasundaram et al., 2020).

Water is the first resource that has been severely threatened by climate change. Therefore, many countries have concentrated extensively on managing water resources, which are categorized as a critical sector in the natural resources (Kusangaya et al., 2014). Some countries formulated new policies or rearranged their

existing system to preserve water from adverse effects of climate change, and they have created public awareness about climate change (IPCC, 2017). Projected future climate change variations globally and within the South Asian countries represents an intensification of present climatic variability rather than the mean climate state (Raswan, 2017).

Many developing countries worldwide face severe water-related problems due to climate change (Chan, 2020). Sri Lanka is a developing country located in the tropical zone within the Indian Ocean. After thirty years of internal civil war, the government has suffered much socially and economically. Furthermore, its geographical location is prone to climate variabilities spatially and temporally (Piratheeparajah, 2016). After thirty years of the internal conflict, various development activities were carried out by multiple sources in Sri Lanka, and displaced people resettled in their lands. The government and non-government organizations initiated many rehabilitation programmes with the aid of foreign agencies. However, climate change is a crucial obstacle to the sustainable development of Sri Lanka, especially in the war-affected regions (Rajendram, 2005). The increasing unpredictable extreme weather due to climate change has become the biggest challenge to Sri Lanka's government. For instance, flood and drought hazards occur in different parts of Sri Lanka simultaneously in same seasons (Ogou, 2021).

According to the ranking list for climate risk, the highest being the worse, Paparizou and Dirk Schindler (2017) ranked Sri Lanka in second place under the climate risk index in 2019 after Puerto Rico. Climate change has turned a burning issue in Sri Lanka, causing a serious threat to the safety of water resources. Hence, the government of Sri Lanka faces various challenges in mitigating the hazarduous effects of climate change on the water resources of Sri Lanka (Manawadu & Fernando, 2008).

Climate change's effect on surface water resources creates uncertainty on the activities intended for the progress of socio-economic sectors of Sri Lanka (Weerasooriya, 2009). Climate is the most essential natural phenomenon responsible for all the activities that make human survival possible in Sri Lanka. Some climatic parameters, such as rainfall, temperature, etc., determine all the stages of agriculture in Sri Lanka. For example, irrigation and water supply (for the domestic and industrial sectors) depend on rainfall in Sri Lanka. Thus, it is obvious that climate change inflences the most significant and primary livelihood of Sri Lanka. Sri Lanka National Report on Disaster Risk Poverty and Human Development Relationship (SRRPHD) listed the disaster profile of Sri Lanka. This list records 7023 attacks of animals (due to lack of food and water), 2704 events of urban or wildfire, 1397 floods (including river floods, urban floods, flash floods, and rain floods), 1263 extreme wind events (cyclone, strong surge, storm, and gale), 285 droughts, and 1156 landslides during the period 1974-2008 (Disaster Management Center, 2012).

The water resources of Sri Lanka are facing threats caused by climatic change. Quality and quantity of surface and groundwater resource are severely affected by climate change. The potential impacts of climate change on water resources have become increasingly common and severe, as shown in scientific conferences and expressed by water managers (Brekke et al., 2009). Changes in regional precipitation and temperature variation have important implications for all aspects of the hydrological cycle (Barnabas et al., 2015). Fluctuations caused by climate change are so unpredictable that in the same year and same days, some areas may face water scarcity problems (droughts), while other regions may face water surplus problems (floods)

Due to many places being affected by such disasters simultaneously, the government

finds it difficult to provide relief for all victims of drought and flood in a month (Figure 1.1). As a result, the government struggles to provide solutions to people because people in one area face drought, while those in another area face floods in the same month. Of greater severity is the water scarcity problem, which is increasing in many areas and is fast becoming a severe issue in many parts of the dry zone of Sri Lanka (Maiththiribala, 2017).

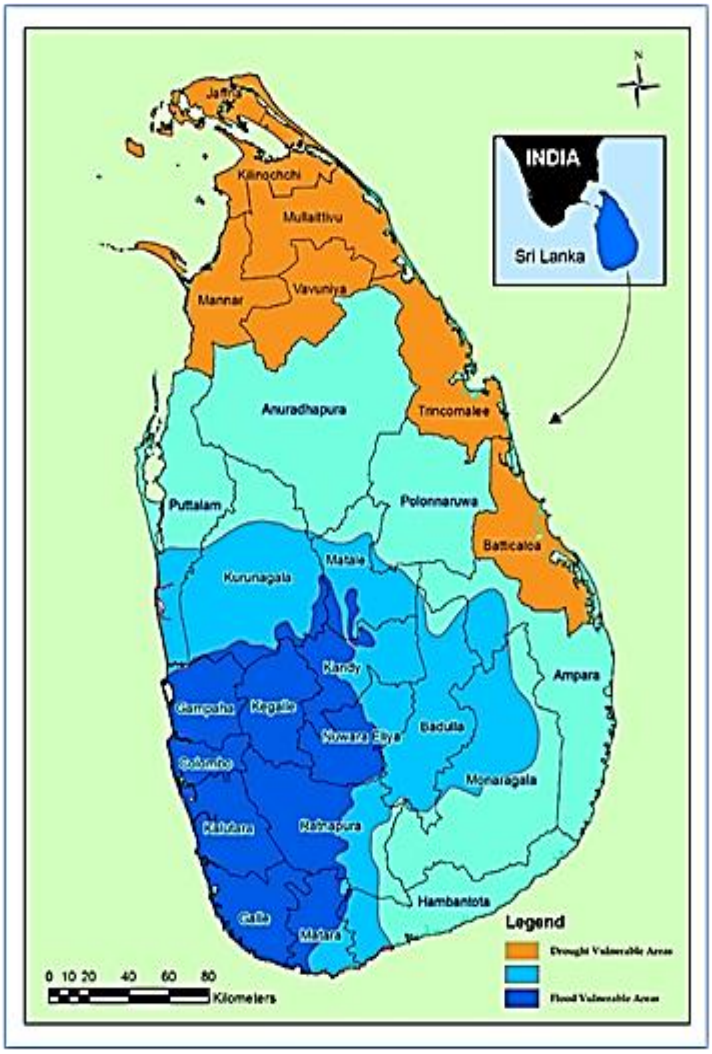

Figure 1.1 Drought and Flood occurrences in a different part of Sri Lanka on the same day

In Sri Lanka, the geographical features of the Northern Region are different compared to other districts. Given that the climatic conditions of the Northern region are entirely determined by the locating factors of the Northern region of Sri Lanka, the area is exposed to a particular type of climatic pattern. The Northern region of Sri Lanka is located near the vast landmass of the Indian peninsula, which influences the wind pattern of the Northern region of Sri Lanka. In addition, the Eastern boundary of the Northern area is the Bay of Bengal and the Western Boundary of the Northern region is the Arabic Sea. The Northern Direction Boundary of the Northern part is the Palk Strait. Changes in these sea surfaces, influence the local climate pattern of the Northern Region of Sri Lanka. In addition to these, the study area contains influence of southwest Monsoon and North-East Monsoon. Due to these geographical influences, the study area is exposed to only two types of monsoon winds, while short winter and long summer seasons prevail in the study area. Furthermore, climate change has impacted all parts of the Northern Region of Sri Lanka. The Northern Region of Sri Lanka's economy faces considerable challenges from climate change (Balsundarampillai, 2010).

Nearly 1,050,000 people are living in the Northern Province (Northern Provincial Council, 2019). It has been found that the Northern region's economic sectors fulfill 81% of their daily needs. Any threat to its economy from whatever source will undoubtedly pose a significant challenge to the already marginalized livelihood of the people of the Northern Province. Once a climate change disaster strikes, it will affect people's lives severely, and it may take more than six months for them to recover and return to normalcy. After thirty years of the internal civil war in the Northern part of Sri Lanka, the Sri Lankan government has initiated many developmental activities to boost economic development in Sri Lanka. However,

climate change severely threatens both the present and future economic development efforts in the study area. The civil war has devastated the economy in Northern Sri Lanka, and in its place, climate change now poses significant challenges to the economic development of the north region. All economic activities in the north area depend on surface and groundwater resources. Mainland (Vanni) depends on surface water resources such as primary, medium, and minor tanks, rivers, lakes, and springs. People in the Jaffna peninsula, islands, and coastal areas depend on groundwater resources. However, climate change hinders all economic activities depriving them of fulfilling their water resources needs.

Furthermore, the uncertainty created by climate change is a significant barrier to effective water resource management. Consequently, the water scarcity problem's spatial pattern spreads rapidly in Sri Lanka in Manthai West, Thunukkai, Manthai East, Canadian, Musali, Mannar, Velanai, Karainagar, Kyts, and Delft. Therefore, people in the Northern Province face numerous water management challenges (Piratheeparajah, 2016).

Based on the above background, studies to identify the spatio temporal trend of hydro climatic variables in the Northern Region of Sri Lanka appear to be urgently needed. However, only few previous studies have focused on climate change impacts on water resources, simultaneously looking at the physical, climatic data, and human aspects in northern Sri Lanka. This study will fill the research gaps mentioned. Results of the study are anticipated to help adapt the current activities to climate change, especially in terms of adapting current and future water resources development to various climate change scenarios in the Northern Province. This study is vitally important in ensuring that water resources development in the northern region are carried out in line with climate change. The water resources system is more resilient

in the face of climate change. Results of this study could contribute to the future planning of developments of the Northern Region.

1.2 Problem Statement

Global climate change has rapidly changed the world's hydro-climatic conditions. Identifying the changes in the region's hydro climatic variable is crucial to determine the impact of the changes on the physical socio-economic setting of that place. Many researchers have found recent trends in the observed (and simulated) hydro climatic variables across the world. Mudelsee (2019) compared temperature trends in observations and three model simulations at the scale in many parts of the world. They found that the temperature variations from 1950 to 2019 were not solely due to natural climate variation, whereas most of the observed warming from 1900 to 1949 were naturally driven. Rainfall is a vital aspect of the tropical region and is highly uncertain in space and time. Many of these changes are triggered by anthropogenic activities such as greenhouse gas emissions and land use changes in the past century. The contribution of anthropogenic and natural causes to regional temperature and rainfall changes is significant in this context (Kumar Guntu & Agarwal, 2020). Kuttippurath et al. (2021) reported a substantial increase in annual and pre-monsoon rainfall and heavy precipitation days. A decrease in consecutive dry days in Bangladesh created many challenges in the development activities (1958–2007). Boko et al. (2011) found a sharp difference in rainfall between the periods 1931–1960 (increasing at 0.6 mm yr−1) and 1961–1990 (rapidly decreasing at 3.0 mm yr−1) in Nigeria, influencing much on the agricultural activities of the country.

Climate change is an emerging threat to all sectors of Sri Lanka. However, according to Sri Lanka's location, the country has much potential for some aspects of climate change, such as sea level rises, rainfall variability, and the increasing number of extreme weather events(Weerakone, 2009). Several studies have been conducted in various parts of Sri Lanka to identify the trend and changes in the hydro climatic variables. The climatic variability analysis shows the critical findings in Sri Lanka. Several policy planning and development implementation activities have been carried out based on the results of trend or changes of climatic variability analysis.

The governing authorities of Sri Lanka face issues in managing the after-effects of flood and drought due to the two entirely different climatic phenomenal changes, such as heavy rainfall and severe temperature increases (Praveen et al., 2020). The rapid changes of hydro climatic variables negatively impact many parts of Sri Lanka. They thus will lead to lasting devastative results in many aspects of human survival all over Sri Lanka. The studies of hydro climatic trend analysis considered the key way to identify climate change in many perspectives by the researcher, administrators, and planners in Sri Lanka. Moreover, the government of Sri Lanka encourages the studies of trend analysis in Sri Lanka, because when one part of the country faces severe flood risk another part of Sri Lanka faces the opposite—drought catastrophe—at the same time.

Rainfall and temperature are the critical aspects of the hydrological cycle, and any changes in these two impact the regularity in the cyclic climatic pattern of a place. Climate change functions as the driving force to the changes in rainfall and temperature, leading to changes in the hydro climatic aspect of the particular region and causing severe damage to agricultural activities. Srivastava & Misra (2016) reported that the modifications of rainfall quantities and frequencies directly change

the stream flow pattern and its demand, spatiotemporal allocation of run-off, ground water reserves, and soil moisture in Sri Lanka.

Nowadays, water resources have been considered the crucial requirements for any development programme and planning, including effective water resource management, food production sector, and food control. The unequal distribution of water throughout the country, because of the natural pattern of rainfall, temperature, evaporation, and runoff pattern that varies significantly in space and time, is the main hindrance for effective water resource management in Sri Lanka. Climate change further accelerates this rainfall variability in many parts of Sri Lanka. Consequently, many regions of the country receive vast amounts of rainfall during the monsoon. In contrast, others receive less rainfall and frequently experience the worst reality of water scarcity. Furthermore, the worst consequence of climate change, especially precipitation and temperature changes, has been experienced by this country's agricultural sector.

After several years of internal war, the Northern Region of Sri Lanka reawakened all the sectors with international agencies' help (Balsundarampillai, 2010). However, despite such assistance, climate change impacts the Northern region and has severely suppressed improving livelihood in sectors such as agriculture, fishing, and services. More than 12 seasonal river basins and more than 52 major and medium reservoirs functioned as the primary water source for the Northern region of Sri Lanka. These water sources mainly depend on the rainfall and the temperature of the study area, and the rivers originated in their catchment area based on the received rainfall.

In recent decades, water scarcity has become a severe problem in the Northern region of Sri Lanka (Ghajarnia et al., 2022). Water scarcity creates an unnecessary economic burden to the governing authorities of the Northern region of Sri Lanka. The Western part of the Northern region and the Island areas face frequent water scarcity problems. The people of the area face challenges due to the uneven pattern of the hydro climatic variables in the Northern region of Sri Lanka during the SWMS. The study area faced flood or water surplus problems during the SIMS and NEMS. The spatial and temporal variability of the hydro climatic variables influences the water availability and the water level of the water resources in the study area. Recently, due to climatic change, the study area has been facing frequent flood or drought impacts due to the unpredictable variation in the hydro climatic components. These problems are increasing with time due to climate change. However, they have not been addressed yet (Maiththiribala, 2017).

Although there are some preliminary studies about the future climate change of the Northern region of Sri Lanka, these are primarily related to temperature and rainfall changes and not specifically related to water resources. In contrast, other countries have carried out future development plans with appropriate strategies to adapt to the projected climate change in their respective countries ((Xia et al., 2017). In Sri Lanka, there are few such plans and procedures due to the civil war and its consequences. After the end of civil war, in recent years, research into these areas has started. Hence, there is an urgent need to study the future climate change pattern to formulate or design future development plans in the Northern region of Sri Lanka. Therefore, this study will fulfill the research gaps on the spatio temporal trend analysis of hydro climatic variables in the Northern part of Sri Lanka.

The study fulfills the research gaps on the spatio temporal trend analysis of hydro climatic variables in the Northern Province of Sri Lanka. Moreover, it provides crucial support to the government's post-war reawakening development plans of the Northern region of Sri Lanka, that are expected to bring the province on par with the rest of the country in terms of sustainable development and achievement of Sustainable Development Goals (SDGs) in the province.

1.3 Rationale for the Research

The following factors justify the purpose of conducting a research in the particular topic

1. Inadequate documental resources about the hydro-climatic details of the Northern region of Sri Lanka is one of the obstacles to the Planning activities in Northern Sri Lanka
2. Availability of only few studies about the changing pattern of hydro climatic variables in the Northern region of Sri Lanka is a challenge to human-oriented activities and the environment has to be studied detailly to formulate sustainable development of the region.
3. Inappropriate climate change adaptive water resources management aggravates this phenomenon, creating a flood in the wet season and drought in the study area's summer period.
4. There is currently no framework to mitigate impacts of climate change in the Northern region of Sri Lanka.

1.4 Research Questions

This research aims to provide answer to the following questions

1. What are the hydro-climatic characteristics prevailing in the Northern region of Sri Lanka?

2. What are the historical changes in the rainfall, rainy days, temperature, and evaporation in the Northern region of Sri Lanka, and what future changes in temperature and rainfall can be projected for the Northern region of Sri Lanka?

3. What are the changes in the hydrological parameters in the Northern region of Sri Lanka

4. What strategies can be proposed to mitigate the impact of rapid variations of hydro climatic variables in the Northern region of Sri Lanka?

1.5 Objectives of the Research

The study focuses primarily on the following aspects

1. To evaluate the hydro-climatic characteristics of the Northern region of Sri Lanka

2. To analyze the spatial and temporal trend of the historical and future climatic variables in the Northern region of Sri Lanka

3. To examine the hydrological variables in the Northern region of Sri Lanka spatially and temporally

4. To develop strategies that can be proposed to mitigate the impact of variations of hydro climatic variables in the Northern region of Sri Lanka

1.6 The Hypothesis of the Research

1. The hydro climatic characteristics of the Northern region of Sri Lanka are unique and specific.
2. Spatially and temporally, there are variations and trends in the observed climatic variability of the Northern region of Sri Lanka, and there will be changes in the future temperature and rainfall patterns in different RCP scenarios.
3. There are variations spatially and temporally in the hydrological parameters of the Northern region of Sri Lanka.

1.7 Chapter Organization

The study comprises of six chapters. Chapter one includes the background of the research, research problems, research questions, research objectives, the research hypothesis, Justification/rationale of the study, and chapter organizations.

Chapter two reviews the past literature on current study. This chapter elaborates on Climate Change and Hydro climatic variabilities, The trend of temperature variations, The trend of Precipitation Variation, Impacts of Extreme variations of Hydro climatic variables, Hydro Climatic hazards, The trend of Hydro climatic variables in South Asia, Water Resources, Surface water, Types of Surface water, Importance of Surface water, Impacts of Climate change on Hydrological parameters, Climate change and Water Management, The trend of Hydro climatic variables in Sri Lanka, and The Hydro-climatic hazards in Sri Lanka

Chapter three is about the study area, including geology, geomorphology, rainfall, temperature, land uses, water resources, administration structure, Population and demography, the economy of the northern province of Sri Lanka, data, and methodology. This chapter covers primary data, secondary data, data collection methods, and data analysis.

Chapter four consists of four significant subdivisions. The first subdivision describes the hydro-climatic characteristics of the surface water resources of Northern Sri Lanka, which contains geographical locations of surface water resources, temperature, rainfall, evaporation, hydrological details of the rivers, length of the river, and the extent of the water catchment area, runoff, irrigation details, seepages, dead storage water supplies, and water demands. Subdivision two of chapter four elaborates on the observed climate changes such as climatic period variations of rainfall, annual total changes, annual trend patterns, seasonal changes of precipitation, monthly rainfall changes, and rainy days. Further, it describes the temperature variations in climatic periods, average yearly temperature, seasonal and monthly temperature variations, evaporation changes, and humidity variations in the Northern region of Sri Lanka. The third subdivision expresses the projected monthly temperature and rainfall changes under RCP 4.5 & RCP 8.5 from 2020 to 2100 under multi models and ensemble patterns. The final subdivision analyses the impact of the climate change on the Northern region of Sri Lanka's surface water resources, water availability, water level, runoff, water demand, water supply, and occurrences of drought and flood hazards. Chapter five discusses the results of the current studies comparing it to previous studies in the same or related titles. Chapter six concludes the study results and proposes feasible strategies to mitigate climate change's impact on the Northern region of Sri Lanka's surface water resources.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review on climate change and water resources, especially in Sri Lanka, is crucial in guiding the direction of this study. The literature review helps identify the need for additional research (research gaps in this research), identify other research relationships, and contribute to the research field and research topic (Maggio et al., 2016). The review also helps place this research within the existing literature, especially in making a case for why this current study is needed. Various investigations in various places by multiple individuals and organizations contributed to the development of this literature review. The most recent and relevant research on influence of climate change on surface water is critically reviewed in this chapter. The study also examines various methodologies and approaches employed in local and international research related to climate change and water resources management. Thus, the literature review identifies the research gaps and guides this research in several ways. For convenience, this chapter is bifurcated into several sub-sections. Each subsection deals with a specific literature review on climate change, water resources, surface water, climate change, and water resources in the global context and Sri Lanka.

2.2 Climate Change and Hydro climatic variabilities

Climate change is a current emerging issue affecting countries all over the world. All countries face challenges and difficulties in managing the impact of climate change in all the sectors of human survival (Mihailovic et al., 2020). Climate change

is emerging as an important issue occupying an important place in every talking stage about nature and even in political talks. There are several definitions of climate change introduced by various scholars worldwide. Most researchers consider that climate change is the statistical conclusion of weather or climatic data. Many scientists believe climate, the prevailing weather system, in long term, is always associated with oceanic surface changes. Mainly, it describes the average weather conditions combined with natural and man-made changes and is the quantitative conclusion of the climate variability in a particular place, region or country, or sphere (Australian Academy of Science, 2015). Usually, climate change is averaged for thirty years to be considered significant. These statistical contents include averages, variability, and extremes.

Furthermore, climate change can be caused by natural or anthropogenic processes or a combination of both. However, some other definitions are different. The climate structure is mostly complex with other natural phenomena of the land, sea, and atmospheric spaces. The design, function, and changes over a place for an extended period are considered climate, and the period is thirty years as standard (Le Treut et al., 2005).

The institution responsible for addressing climate change issues in the UN is the body known as the United Nations Framework Convention on Climate Change (UNFCCC). It is the first international agency dealing with climate change working together with all the countries in the world. It defines climate change as the changing of climate patterns. Dumurul, Kilicarslan (2017) elaborates that global climate change is induced rapidly by human activities directly or indirectly for an extended period, especially after the industrial revolution. This definition elaborates on the influence of humans on climate change. The socio-economic activities alter the global atmosphere's composition and biological variation itself. Therefore, the definition

provided by the Intergovernmental Panel on Climate Change (IPCC) in 2007 is widely accepted as the broader definition of climate change (Pachauri & Meyer, 2014). It states that climate change is a climate system in which variability of climatic elements is an unacceptable way of life. Thus,climate change means any changes in the climate system through time, either due to natural variability or human-made activity. Evidence suggests a clear definition of climate change in the world. The warming of the planet is unambiguous. Over the past decades, global average atmospheric temperatures have risen (Dumurul & Kilicarslan, 2017).

Climate change is the long-term changes in climate elements such as the wind velocity, heat, precipitation, evaporation, and humidity of a place, region, or country. Climate change is presently happening worldwide due to global temperature rise, also known as global warming. Global warming increases the world's overall temperature due to burning of fossil fuel such as petroleum, natural gas, and coal, amongst other causes. Burning these materials releases certain greenhouse gases into the earth's atmosphere. National Geographic Journal illustrated that climate change is a change in the usual weather in a particular region. This should be a change in the amount of rain a place receives annually. Alternatively, it can change a place's usual temperature for a particular period. Alternatively, it could change where rain and snow usually fall on Earth (NASA, 2014). The definition adopted by the United Nations Framework Convention on Climate Change (UNFCCC) focuses on the man-made activities that warm the earth's atmosphere and exclude other effects of man-made activities such as variations in the earth's land surface. Sometimes climate change is used as an umbrella term to include all-climate variabilities and changes, leading to significant misperception. Climate has variability on all period and space scales and will always vary (Hay et al., 2016).

Earlier in the 1970s, most scientists believed that climate change is a myth that some people deliberately popularize. However, in recent decades, due to occurrences of abnormal and highly unpredictable weather all over the world, most people, including scientists, politicians, and the frequent public, accept that climate change is real, causing many impacts in all parts of the world, and is happening now (Singh & Singh, 2012). During the Cop26 summit, Sir David Attenborough, the famous environmentalist, has also warned of the "crippling problems" the world faces now and in the future because of climate change (Hennessey, 2021). Most climatic scientists now agree that climate change is the leading cause of greenhouse gasses (Nachiyunde et al., 2018). Several studies, including various methodologies, models, disparate data, and different analysis models, have concluded that climate change is a real-world problem and a severe issue. Most significantly, 97% of climate scientists agree that climate change is now caused mainly by man-made activities and that humans can do something to reduce its impacts and progression (Rodriquez et al., 2008; Public Health Institute, 2019). Most people facing climate change can change their lifestyles and behaviour to minimize the hazards of climate change. Weather changes are the day-to-day weather pattern; its time is short; climate change, however, is long-term. The following discussion distinguishes between weather and climate variations and climate changes:

1. Weather is the precipitation, cloudiness, evaporation temperature, humidity, and wind velocity, the direction that we experience in the atmosphere at a given time in a particular location.
2. Climate is the standard weather condition over an extended period (30 – 50 years) in a particular area.

3. Climatic erraticism refers to natural disparities in a climate over months to periods. El Niño, which changes temperature, rain, and wind patterns in numerous regions over about 2 – 7 years, is an excellent example of natural climate variability.

Climate change is defined as 'Long-term changes of the weather parameters for an extended period worldwide'. Scientists use numerical examinations to regulate the likelihood that changes in the climate are within the variety of natural inconsistencies — related to the statistical tests used in clinical trials to determine whether the positive response of treatment is probable to have occurred by chance (Public Health Institute, 2019).

The contemporary world has adequate literature on reasons for climate change everywhere in every language. Several studies have explained the causes of climate change with adequate evidence. Several researchers studied climate change, emphasizing the roots of climate change. Natural and anthropogenic factors contribute to climate change—however, man-made factors have induced climate change more than the natural process. According to the earth's history, the natural process took more than 100 million years to increase the global average temperature by 01 degree Celsius. However, it takes human activities only 85 years to increase the global average temperature by 01 degree Celsius. Greenhouse gases are the leading and primary causes of global climate change. The author further explained that greenhouse gases are the main driving factors for global climate change, which are always associated with the variations in the concentration of primary greenhouse gases. They are very functional to absorb the heat and emit them into the atmosphere, ocean, and land (Jameel, 2016).

However, greenhouse gases are not the only factors contributing to climate change. Some other elements also cause climate change worldwide. They are:

1. Dissimilarities in the earth's orbital physiognomies
2. Atmospheric carbon dioxide differentiations.
3. Volcanic eruptions.
4. Variation in solar output.
5. Plate Tectonics
6. Thermohaline Circulation (Nwankwoala, 2015).

Human activities also lead to greenhouse gas emissions and other contaminants that create tiny particles in the lower atmosphere. The maximum influence of human activities on current climate change is apparent from understanding the greenhouse effect's fundamental physics and likening the detailed patterns of past climate change with these expected from different human and natural influences (Royal Society, 2008). Increasing greenhouse gases are found to affect cliimate change. Luichehan (2013) explained that the imbalance of greenhouse gases leads to climate change globally and regionally, causing air pollution, diseases, drought, and extreme flood weather. The authors further recommended remedies to mitigate the adversities of climate change. They include climate-adapted infrastructure design, sustainable energy consumption, appropriate and effective waste treatment, reforestation, and the best solution to reduce climate change.

Climate change is being considered a crucial matter worldwide due to its impact. Several studies pointed out that climate change is the long-term changes of climatic variables in a particular region or place; these studies indicate that climate change is the main threat to the world's physical, social, and economic sectors. Thus,

several theories introduced the causes and effects of climate change in accordance with researcher's research area. However, all these theories putforth a common cause—increasing greenhouse gases—as the leading cause of climate change. However, the IPCC has recognized some more appropriate approaches and they are accepted by many individuals and organizations.

2.2.1 The trend of temperature variations

After several studies about climate change, some scientific shreds of evidence were published by various scholars to identify the trend of climate change. However, climate change is not in a regular pattern generalized to all the regions of the earth. Some are at low levels. Hence, this section describes the kinds of literature on the trend of climate change on various scales.

James Hansen et al. (2019) studied the global temperature trend and indicated that the world's annual temperature has increased by 0.2°C per decade in the last thirty years. Compared to the Eastern Equatorial Pacific region, the Western Equatorial Pacific region has higher warming conditions. Patrick Pringle (2018) studied global temperature changes. The study has revealed that the temperature has increased by 1.8°C from 1950, and the polar region has shown a significant rising than the tropical region.

Atany Bhatachcharya (2019) studied the temperature changes in the Deccan Plateau of India from 1980 to 2019. The study revealed that the annual temperature has increased by 0.92°C during the last forty years. Spatially, however, there are variations in the increase of temperature in the study area. The Pune region has a much-increasing temperature, and the value is 1.03°C.

Pakistan has a slightly less increasing temperature in the South Asian region; the value was 0.57°C in the 20th Century. However, an accelerated increase has been identified in the 21st century by 0.75°C, and especially from 1961 to 2007, 0.47°C increase has been recorded. Within the Nation, there is variation in the increase of temperature—Punjab, Sind, and Balochistan regions have experienced higher warming than other regions (Lacombe et al. 2019).

Boychenko (2016) studied the climate change features of Ukraine and explained that the annual temperature of the country has increased by 0.6±0.2°C per 100 years. In addition, it is expected that the temperature will increase by 2.0°C in 2050 under the RCP 4.5 scenario. Katzenberger et al. (2021) studied the air temperature variation of Poland from 1961 to 2018. The study illustrated that the country's average increase of temperature is 0.33°C/10 years. But spatially, there are variations in the increase of air temperature. The Western part of the country and the Baltic region have a higher increase in air temperature by 0.4°C/10 years. The study indicates that there is a positive correlation between solar radiation and air temperature in Poland. Kusangaya et al. (2014) studied the extreme temperature events of the Sevilla region of Spain. They illustrated that the recent decade (2010 to 2020) has severe air temperature variability compared to previous decades. The current decade has a 0.31°C increase than the last decade from 2000 to 2010 (Praveen et al., 2020).

Hill (2019)explained that there is an excellent sureness that the rise in Global Mean Surface Temperature (GMST) has grasped 0.87-degree Celsius (±0.10°C possible range) above pre-industrial values in the 2006–2015 decade. As per the assessed AR5 scenarios, the earth's average atmospheric temperature increased warming by about 0.85°C from 1880 to 2012, with an essential fraction of the identified global warming attributed to human forces. The Rajasthan and Panjab area

have had a 0.87°C increase for the last forty years from 1980 to 2020. However, this contradicts with other areas of the Indian subcontinent. The study further elaborates on the rainfall trend in Rajasthan and Punjab, indicating a decreasing pattern in the annual and monthly rainfall in the study area. Within the study area, there are variations among the places. Papalaskaris et al. (2016) investigated the trend of the temperature of Western Australia from 1960 to 2020 and concluded that temperature has been increased by 0.34°C; the author further elaborated that the recent two decades show the accelerated increase compared to the previous decades. However, the greenhouse gas emission rate has increased rapidly.

Table 2.1 Trend of temperature increase in different areas

Countries	**Significant Trends**
World	0.5 °C during the 100 years
World	0.3 °C in last10 years
Pakistan	0.5 °C to 1°C raised for the last 120 years
Pakistan	0.11 °C /decade (1976-2005)
Pakistan	0.5 to 4 °C rise from 1901-2007
Himalayan hill region	Increased maximum temperature and average temperature
Eastern Himalayas	0.02 °C
North-East India	+1.0 °C during winter and 1.1 °C during autumn over the last 100 years
Turkey	1.01 °C during the last55 years
Bangladesh	0.6°C from 1961-1990.
India	0.5 °C during the last 100 years