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RESEARCH PAPER

Climate Change Impacts on Surface Water Resources of the Northern Region of Sri Lanka

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Abstract

This research assesses the influence of climate change on surface water resources situated in the northern province of Sri Lanka. The investigators analyzed hydro-climatic data using multiple techniques in order to determine the impact of climate change on crucial parameters related to the region's surface water sources. Through Mann-Kendall trend analysis and Sen's slope estimation, it was revealed that the rainfall and temperature within the study area have experienced an increase. Specifically, the yearly total rainfall has a growth rate of 24.6/decade, while the temperature has increased by 0.54°C/decade. The reduction of rainy days causes a noteworthy increase in runoff, while the increase in temperature leads to a higher level of evaporation, inducing water scarcity and drought in the study area due to the low water level or availability in the area. It is worth noting that the water supply inadequacy in the SWMS and FIMS is compounded further by high evaporation rates and temperatures. There is a strongly negative correlation between the decline of rainy days and the increased volume of runoff, with an R-value of -0.70. This is an indication that the reduction of rainy days increases the amount of runoff in the region due to the high intensity of rainfall over a short period. Meanwhile, there is a positive correlation between temperature and evaporation. The rate of evaporation has increased by 48mm/decade. Given these findings, it is suggested that increasing water holding capacity and constructing new reservoirs within the river basins of Aruvi Aru (lower stream), Paranki Aru (upper and lower stream), Pali Aru (lower stream), Per Aru (lower stream), and Mandaikallaru (upper and lower stream), as well as infiltration by maintaining porous surfaces with green coverage may help to reduce the impact of water scarcity and prevent frequent flooding.

Keywords: Climate change impacts; Surface water; Northern region.

1. Introduction

Climate change is a current emerging issue affecting countries all over the world. All countries face challenges and difficulties in managing climate change impacts in all sectors of human survival [1]. Climate change is becoming an important issue taking 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 [2]. Most researchers consider that climate change is the statistical conclusion of weather or climatic data. Many scholars hold the belief that climate, the enduring atmospheric patterns present on a broader temporal scale, constantly accompanies alterations in the surface of the vast oceans. Primarily, it encompasses the collective state of prevailing meteorological elements intertwined with both inherent and anthropogenic modifications. Furthermore, it constitutes the quantitative summation of climatic fluctuations within a designated location, region, nation, or even the global sphere. Typically, the assessment of climate change assumes substantiality after integrating data over a span of thirty years. These statistical contents include averages, variability, and extremes [3].

Water is an essential resource for all living organisms, and water is necessary to factor into the natural process of the earth. Every stage of human development and survival depends on the water. Over the past 04 billion years, life started in the water [4]. The first living things of this world (organisms) were minuscule, made up of only one cell. Many millennia, these organisms became more significant and complex, slowly becoming more like the Animals, Birds, and plants we know today. The world's first animals to leave the waters belong to amphibians. Water is a critical resource for the survival of every living species in the world. The development of the world is not possible without water. Without water, the earth would be lifeless. Water is a crucial resource for the function of the entire planet [5]. Human developmental activities and ecosystem functions depend on water resources. It enables agricultural activities and food production, energy generation activities, drinking and domestic uses, and manufacturing output as a resource. Aquatic ecosystems, conversely, bestow upon humanity and the environment invaluable ecosystem services. These include but are not limited to recreational opportunities, water cleansing, flood prevention, nutrient exchange, wildlife refuge, spiritual significance, and an array of further provisions.

Surface water defines water on this earth's surface, whether in-bounds or limits shaped naturally or artificially, or diffused. Surface waters refer to Reservoirs, Lakes, Open tanks, Streams, and Rivers [6]. When precipitation descends on the terrestrial expanse, it percolates into the subterranean realm and replenishes the groundwater aquifers or perceptibly transforms into runoff. This surface water flows downstream, meandering over and penetrating the soil, merging into streams, rivers, ponds, and lakes. Regardless, surface water sources don't solely subsist on runoff; numerous sources receive inputs of groundwater, intensifying in volume during periods of meager flow [7].

Changing climate significantly impacts water availability and the quality and quantity of water available and accessible. There is no balance between demand and supply due to climate change [8] [9]. Climate change is creating uncertainty in the supply and management of water resources. Increasing temperature directly affects the surface and groundwater. However, compared to groundwater, surface water has much impact due to climate change. However, much is not yet well understood. When the link between increased temperatures and changes in rainfall has been modelled in detail, the same is not valid for river flows and the groundwater system's recharge [10]. Globally, the overall effects of climate change on freshwater resources are expected to be negative. The water resources sector in many countries and islands is severely affected by climate change. Due to the rapid urbanization context, increasing demand for good water quality, sea-level changes might forward to flooding in lowland areas and saltwater intrusion into coastal aquifers [11].

Climate change in water resources impacts human society in many aspects, such as drinking and domestic water usage, agriculture usage, and industrial utilization. However, the water quality affected by climate change directly affects drinking and household water usage [12]. However, the quantity of water affects the extent and amount of water—the impact of climate change on the amount of water affecting the water supply and demand. The agricultural sectors have much threat to the effect of climate change on the world's water resources. In recent decades, water scarcity is becoming a severe problem in dry zone areas of Sri Lanka [13]. Water scarcity creates an unnecessary economic burden on the government of Sri Lanka. Eastern, North Western, Northern, and North Central provinces routinely face critical issues due to the water scarcity caused by climate change. Simultaneously, some areas like Southern Province, Western Province, and Sabragamuwa Provinces frequently face flood occurrences. In recent years, many regions in the study area have experienced water scarcity problems. At the same time, other regions faced water surplus problems (floods), and these problems are increasing year by year due to climate change, but they have not been addressed yet [14].

There will be an increase in a soil moisture deficit in Jaffna, Mannar, Vavuniya, Trincomalee, and

Anuradhapura areas in 2050 under the climate change scenarios. Further, it will affect the surface water, agriculture, and other socio-economic sectors of the Northern region of Sri Lanka. The further author explained that the Northern part of Sri Lanka would be drier in 2050 due to climate change, mainly due to the increasing soil moisture deficit pattern. Climatic parameter changes are directly affecting the water resources of Sri Lanka. Climate change has impacted water resources, especially surface water resources, in water availability and water supply [15].

The Northern region's water resources in Sri Lanka hold an unequivocal significance in the area's sustenance owing to its geolocation within the dry zone category. Ascertaining the impacts of climate change on Sri Lanka's surface water resources has become a pressing necessity [15]. The analysis site experiences four distinct climatic seasons which include the North-East Monsoon Season (NEMS), South West Monsoon Season (SWMS), First Inter Monsoon Season (FIMS), and Second Inter Monsoon Season (SIMS). It is worth noting that rainfall is not uniformly distributed across these four seasons; only the North-East Monsoon Season and the Second Inter Monsoon Season receive the required amount of precipitation. In fact, the rainfall witnessed during the North-East Monsoon Season - predominantly between October and January - satisfactorily caters to various necessities throughout the year, such as drinking, domestic, agricultural, and manufacturing needs [16]. Recent climate fluctuations have instigated substantial oscillations in precipitation patterns, giving rise to periods of drought and subsequent episodes of flooding. Consequently, the water reservoirs in the Northern region are confronted with significant perils posed by climate change. The Southwest Monsoon Season (SWMS) experiences severe water scarcity, leading to a sudden depletion in reservoir water levels as well as the unavailability of water in both river basins and reservoirs. Moreover, the study area is witnessing an escalating demand for water resources. The absence of water in the reservoirs has disrupted the supply, exacerbating the frequency of drought occurrences which are direct consequences of climate change in Northern Sri Lanka [17].

Consequently, there was no kind of research regarding any subjects carried out due to the internal war in the Northern Province of Sri Lanka. 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 comparison, other countries have carried out future development plans with appropriate strategies to adapt to the projected climate change in their respective countries. In Sri Lanka, there are few such plans and procedures due to the civil war. After the civil war had ended 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 effects of climate change on water resources in the Northern Province of Sri Lanka.

2. Study Area

The study area under consideration is the Northern Province, situated in the north most part of the country, proximal to India. It spans administratively over five districts, comprising a total of 34 divisional secretariat divisions within Northern Sri Lanka (Figure 1). The study area's northern borders align with the Palk Strait, its eastern borders with the Bay of Bengal, and its western borders with the Arabic Sea. The North Central Province bounds its southern borders. The Northern Province receives an annual average rainfall of 1240mm, complemented by an annual mean temperature of 29 °C (Figure 2).

The Northern region is bestowed with 24 rivers, all categorized as seasonal rivers, across which 54 Major/Medium Irrigation schemes are located (Figures 3 and 4). The IDNP maintains these schemes, which comprise nine significant tanks, and jointly provide irrigation water to 70,197 acres of farmland, significantly benefitting its 28,459 farming families. Furthermore, the IDNP also supervises the Valukkaiaru drainage scheme, providing drainage facilities to 2,000 acres, 54

Salt Water Exclusion schemes providing saltwater exclusion facilities to 16,508 acres, and the Jaffna Lagoon scheme, encompassing the Elephant Pass Lagoon scheme, Upparu Lagoon scheme, and Vadamarachchi Lagoon scheme.

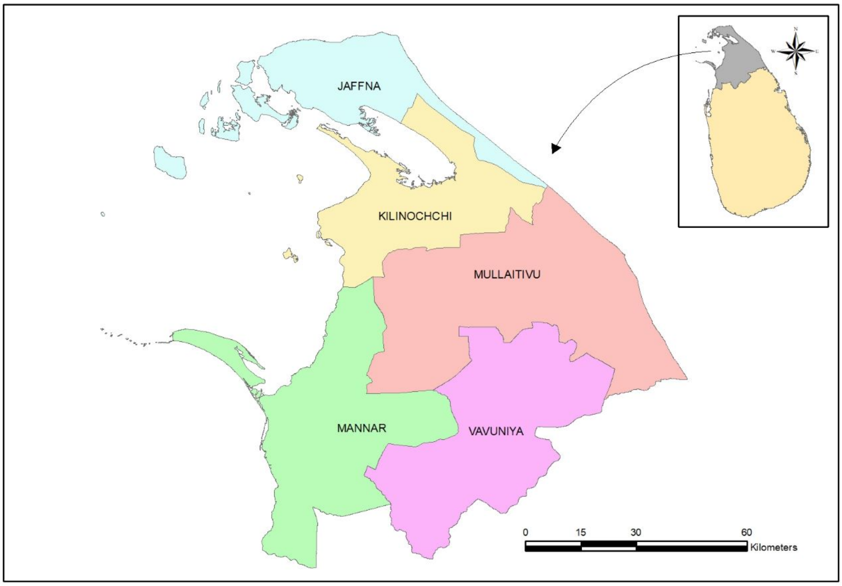

Figure 1: *The Location of the Northern Province of Sri Lanka. There are five districts in the Northern province of Sri Lanka with 34 divisional secretariat divisions.*

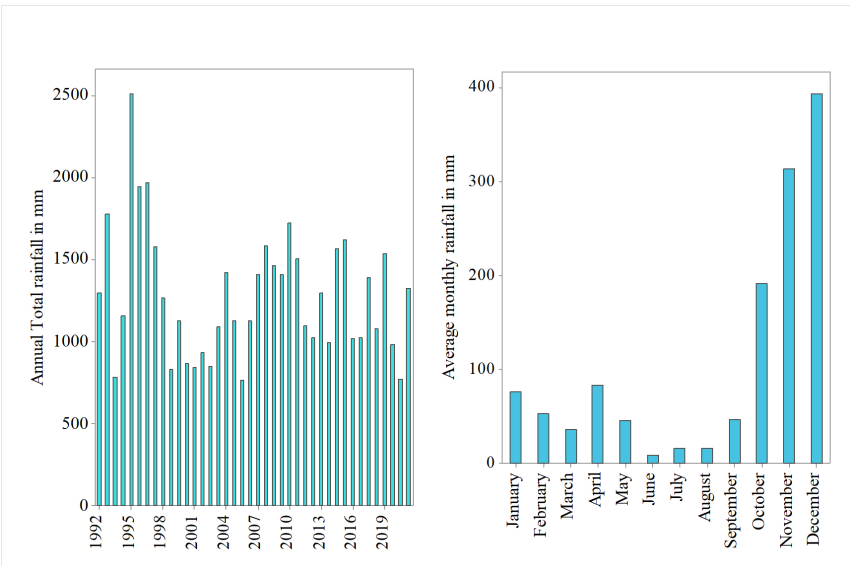

Figure 2: *The annual total rainfall of the years from 1992 to 2022 and the monthly average rainfall of the Northern Province of Sri Lanka. The NEMS months (October, November, and December) have higher rainfall than other months.*

Furthermore, the northern territory boasts nine crucial Major/Medium Irrigation schemes, encompassing five substantial reservoirs upheld by the esteemed Central Irrigation Department. These schemes efficaciously cater to the irrigation water needs of a vast expanse spanning 45,551 acres of farmland. In addition, the esteemed Agrarian Development Department supervises no less than two thousand seven hundred and forty-four minor irrigation schemes, which supply irrigation water to 77,874 acres, significantly ameliorating the lives of over 89,336 agriculture-oriented families in the region. Ultimately, the aquifers strewn across the Jaffna Peninsula's inner limestone layers and a moiety of the Mannar district represent notable water sources fulfilling essential drinking and agricultural water requirements for the province.

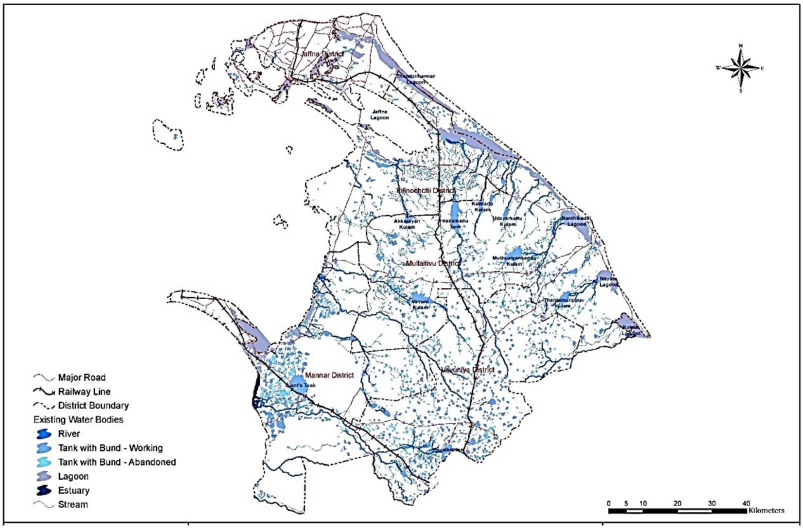

Figure 3: *Surface water network of the Northern region of Sri Lanka. This network includes river basins, reservoirs, ponds, and lagoons (Lagoons are with salt water).*

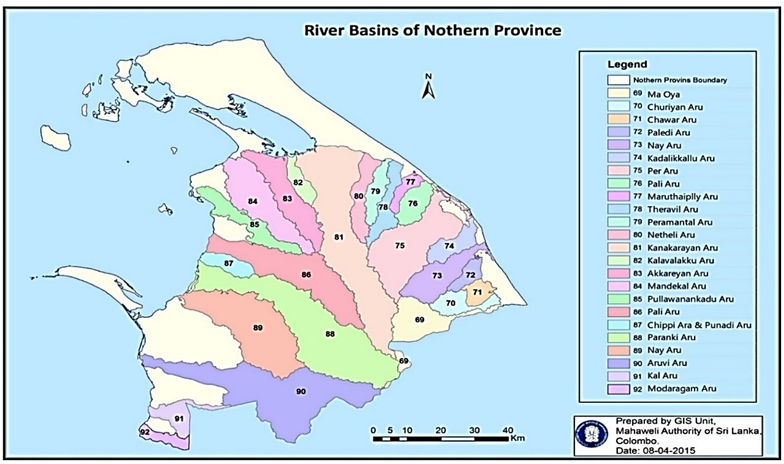

Figure 4: *River Basins Map of the Northern region of Sri Lanka. The numbers before the names of the rivers are retrieved from the national numbering system; Source: Mahaweli Authority, (2015).*

3. Materials and Methods

3.1 Data

The requisite secondary data for the study were procured from the Department of Meteorology (DoM) in Colombo, Sri Lanka. Precipitation and temperature data, alongside related information, were gathered for a total of sixteen stations, which included Akkarayankulam, Ambalapperumalkulam, Vavuniya Iranaimadhu, Thirunelveli, Nainathivu Kanukkerni, Pallavarayankaddu, Thannimurippu, Nedunkerny, Mankulam, Karukkaikkulam, Murungan, Muththaiyankaddu, Pavatkulam, and Vavunikkulam, covering the period from 1992 to 2022. Monthly extremes of temperature (maximum, average, and minimum), annual and monthly precipitation totals, number of days with precipitation, as well as evaporation from soil and non-soil surfaces were obtained from DoM. (Figure 5).

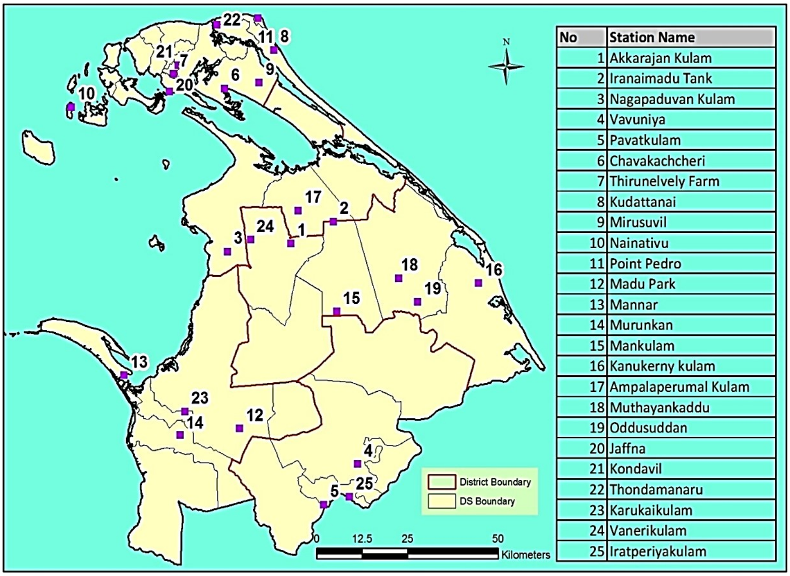

Figure 5: *The rain gauge stations of the Northern Province, Sri Lanka.*

The primary source for obtaining rainfall data in the Northern Province of Sri Lanka is the reports and data from the Irrigation Department of Northern Province (IDNP) in each district. Pertinent data, encompassing information on Runoff, Surface flow, Evaporation, Soil Evaporation, Catchment Inflow and Outflow, water levels, water availability, water supply, and water demand, regarding the six major tanks, namely Iranaimadu, Vavunikkulam, Muththaiyankaddu, Akkarayankulam, Pavatkulam, and Kanukkerny, of the study area were obtained from the IDNP. Moreover, this department also measures the rainfall over the tanks under their maintenance in some districts such as Mullaitivu and Kilinochchi of the study area. This department possesses the authority and responsibility to monitor and decide on the tank's water levels and the evacuation of excess water during floods from the surface resources.

The Economic Development Department (Tamil Eelam Porunmiya Mempaaddu Niruvanam) of the Liberation Tigers of Tamil Eelam (LTTE), which ruled the study area for an extended period and was fighting with the Sri Lankan government, published materials concerning the measurement of the Hydro climatic variables of the surface water resources. These reports were considered for analysis to identify the impact of climate change on the surface water resources of the Northern Province of Sri Lanka. Moreover, the LTTE governed numerous areas, particularly Mullaitivu, Kilinochchi, many parts of Mannar, and Vavuniya, where they operated surface water bodies.

3.2 Methods of Data Analysis

The primary aim of this investigation is to scrutinize the ramifications of climate change on the surface water resources of Sri Lanka's Northern region. To this end, hydroclimatic data procured were scrutinized via the Pearson correlation analysis method. Collected hydroclimatic data, namely, Evaporation from Soil (EFS), Direct Rainfall Recharge (DRR), Catchment Inflow (CI), Return Flow (RF), Evaporation Losses (EL), See Page (SP), Water for Irrigation (WI), Dead Storage (DS), Runoff to Sea (RTS), Water Availability (WA), Water Supply (WS), and Water Demand (WD) were analyzed utilizing XLSTAT and Minitab version 17. In brief, the temporal pattern of hydrological data was determined for chosen rivers and reservoirs, whereas the spatial variations and patterns were studied utilizing ArcGIS 10.4.

The dependable variable in this investigation was the hydrological parameter. It is imperative to highlight that the hydrological parameters of this region are subject to climatic parameters. Henceforth, selected climatic parameters continuously determine some chosen hydrological parameters. If any changes in the independent variables would undoubtedly influence the dependent variables (Table 1). Therefore, the following table illustrates the independent variables that determine the dependent variables. Consequently, each independent variable was correlated with each dependent variable utilizing the Pearson correlation analysis method.

Table 1: *Relationship between climatic and hydrological parameters.*

Independent Variables (Climatic Parameters)	Dependent variables (Hydrological Parameters)
Temperature (Annual, Seasonal, and Monthly)	Evaporation, Water Availability, Water Supply, Water Demand, Effective Yield, Capacity Gross/ Capacity Net, Fully Saturated Level.
Rainfall (Annual total, Seasonal total, and Monthly total) and Rainy days	Water Availability, Water Demand, Water Supply, Runoff, Catchment Detention, Effective Yield, Capacity Gross/ Capacity Net, Fully Saturated Level, catchment Inflow, and Return Flow.
Evaporation	Water availability, water level, water demand, and supply.
Extreme weather events	Water availability, Runoff, Evaporation, Water demand (Irrigation, drinking, and domestic), and Water supply.

3.2.1 Mann-Kendal Analysis and Sen's slope estimation for historical climate change

The aim of this investigation is to examine the influence of climate change on the surface water resources located in the Northern region of Sri Lanka. In order to accomplish this objective, the researchers have utilized two prevalent statistical approaches, namely the Mann-Kendall trend analysis test and Sen's slope analysis technique. The Mann-Kendall trend analysis method has become increasingly prevalent among researchers in recent times on account of its proficiency in scrutinizing temperature and precipitation data over extended periods of time [19]. In this examination, data values are assessed comparatively, rather than on an absolute scale. Precisely, each value in the time sequence is contrasted with following values, where Mann-Kendall statistics (S) are initially presumed to be zero. If a data value in a subsequent period is superior to the previous value, S is augmented by 1, and conversely. The ultimate value of S is the net consequence of these augmentations and reductions. The calculation of Mann-Kendall statistics (S) is performed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{Sign}\,(x_i - x_k) \tag{1}$$

where, *xi* and *xk* are sequential data in the series and

$$\text{Sign}\,(X_i - X_k) = \begin{cases} +1 \text{ when} & (X_i - X_k) > 0 \\ & 0 \text{ when } (X_i - X_k) = 0 \\ -1 \text{ when} & (X_i - X_k) < 0 \end{cases} \tag{2}$$

A positive value of "*S*" denotes an ascending progression, and a negative value specifies a declining progression. Yet, statistical analysis is imperative to determine the significance of the progression. Kendall (1975) elucidates the standard approximation test utilized in the testing process. Notably, this test presupposes that there is a minimum number of tied values within the dataset. The equation below calculates the variance (S).

$$\text{Var}(S) = \frac{S(n-1)(2n+5) - \sum_{p-1}^{q} +p\left(t_p - 1\right)\left(2_p^t + 5\right)}{18} \tag{3}$$

where n is the number of data points, g is the number of tied groups and t_p is the number of data points in the p^{th} group.

$$Z = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(S)}}; & \text{if } S > 0 \\ 0; & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}; & \text{if } S < 0 \end{cases} \tag{4}$$

The directional trend will decline when Z takes a negative value, and the evaluated Z-statistics surpass the Z-value aligned with the significance level of 5%. Conversely, a positive value of Z and computed Z-statistics exceeding the Z-value linked to the 5% level of significance, indicate a rising trend. However, if the computed Z-statistics are below the Z-value, which corresponds to the 5% level of significance, it implies the absence of any trend.

Sen's slope is a non-parametric statistical technique utilized globally in the domain of climatology research, mainly to recognize variations in the size of hydro climatic factors. Sen accomplished the discovery of this slope in 1968 and utilized it to approximate the magnitude of trends present in time series data. The slope value of "n" data pairs can be calculated using the following equation:

$$\beta_i = \text{Median}\left\{\frac{x_j - x_k}{j - k}\right\} \quad \forall (k < j) \tag{5}$$

The βi values' average 'n' serves as Sen's slope estimator test. A downward trend is indicated by a negative βi value, whereas an upward trend is denoted by a positive βi value. In the case of an even '*n*', the Sen estimator's slope is determined using the following equation: Here, *xj* and *xk* signify values of data during periods *j* and *k*, respectively, such that period j follows period *k* (k j).

$$\beta_{\text{med}} = \frac{1}{2}(\beta[n/2] + \beta[(n+2)/2] \tag{6}$$

If '*n*' is an unknown number, then the estimated slope by using Sen's method can be computed as follows:

$$\beta_{\text{med}} = \beta[(n+1)/2] \tag{7}$$

Finally, the βmed is subjected to a two-tailed test at a confidence level of 100 (1 – α)%, while the non-parametric test allows us to project the genuine slope of the monotonic trend.

3.2.2 Correlation Analysis between climate change and surface water components

The Pearson correlation analysis was carried out to ascertain the association between each of the above-water parameters and climatic variations. The identification of water surplus and deficit periods across different locations over the course of months, years, and seasons has been facilitated by this association. Guided by these objective analyses, recommendations for effective management of water resources have been proffered. The coefficient of correlation "*r*" can be calculated using the following formula.

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\left(n\sum x^2 - (\sum x)^2\right)\left(n\sum y^2 - (\sum y)^2\right)}} \tag{8}$$

The method of correlation analysis has been employed to ascertain the interconnection between climatic variability and water parameters. Correlation, a statistical technique, can indicate the presence and strength of an association between pairs of variables. This analytical tool investigates the relationship between the two variables. Several methodologies and tactics are employed in correlation analysis to examine and ascertain the degree of relationship between two variables. The correlation analysis tests the link between two variables with respect to the following aspects: (1) the strength of the relationship, and (2) the direction of the relationship. Several correlation techniques are available in statistical analysis, including the coefficient correlation method, which has been employed in this study. The coefficient of correlation "*r*" is a widely used statistical measure that determines the degree of association between two variables presented in the data set. The value of "r" ranges from +1 to -1, where $r = +1$ indicates the presence of perfect positive correlation between two data sets. Conversely, $r = -1$ suggests the existence of perfect negative correlation, and r = 0 signifies lack of correlation between the two variables.

4. Result

Climate change poses a critically significant danger to Sri Lanka, particularly to its Northern region. The many manifestations of climate change have a pervasive effect on the physical, economic, and social aspects of the study area. Thus, the present inquiry endeavours to discern the repercussions of climate change on the study area's surface water resources.

4.1 Increasing Trend of Rainfall and Temperature of the Northern Province of Sri Lanka

The results of the Mann-Kendall (MK) trend analysis show that the rainfall trend across each station in the study area is mixed. Most of the station's MK results suggest p values (Alba) of less than 0.05, which leads to the rejection of H0 for twelve stations mentioned in Table 2. However, H0 acceptance was found at only four stations, namely Kanukkerny, Muththaiyankaddu, Pavatkulam, and Thirunelvely. H0 rejection indicates a trend in the series; hence, the study area has a trend in the rainfall of twelve stations, including Akkarayankulam, Ambalapperumalkulam, Mankulam, Iranaimadu, Karukkaikulam, Thannimurippu, Murungan, Nainatheevu, Nedunkerny, Pallavarayankaddu, Vavunikkulam, and Vavuniya. Conversely, H0 acceptance indicates the lack of a trend that applies to rainfall data from Kanukkerny, Muththaiyankaddu, Pallavarayankaddu, and Thirunelvely stations, although most stations demonstrate a movement in rainfall across the study area. Figure 4 graphically represents the trend pattern of precipitation across all stations in the Northern region of Sri Lanka. Therefore, the study area's rainfall reveals a trend from the perspective of observed climate change. This rainfall trend shows an increasing pattern in some stations and a decreasing pattern across others. Specifically, the Iranaimadu and Kanukkerny stations show a decreasing annual trend, while all the other fourteen stations demonstrate an increasing yearly trend.

Table 2: *Mann Kendal trend analysis details of rainfall stations of the Northern region of Sri Lanka*

Series\Test	p-value	Alpha	Kendall's tau	Test interpretation
Ambalapperumal	0.018	0.05	0.273	Reject H0
Akkarayankulam	0.040	0.05	0.237	Reject H0
Iranaimadu	0.024	0.05	-0.256	Reject H0
Kanukkerny	0.497	0.05	-0.068	Accept H0
Karukkaikulam	0.009	0.05	0.264	Reject H0
Vavuniya	0.027	0.05	0.262	Reject H0
Thannimurippu	0.019	0.05	0.236	Reject H0
Murungan	0.023	0.05	0.245	Reject H0
Muththaiyankaddu	0.757	0.05	-0.032	Accept H0
Nainatheevu	<0.0001	0.05	0.415	Reject H0
Nedunkerny	0.045	0.05	0.208	Reject H0
Mankulam	0.044	0.05	0.229	Reject H0
Pallavarayankaddu	0.021	0.05	0.323	Reject H0
Pavatkulam	0.182	0.05	0.136	Accept H0
Thirunelvely	0.985	0.05	-0.003	Accept H0
Vavunikkulam	0.042	0.05	0.236	Reject H0

The historical yearly precipitation in Northern Sri Lanka has observed a significant increase from 18.76mm/decade to 37.68 mm/decade between 1992 and 2022 (Figure 6). The Sen's slope values of the study area illustrate variations across stations and the alterations in rainfall patterns. However, the ascending values are distinct in each season. Based on the Sen's slope analysis, rainfall during the Northeast Monsoon season has declined, while the Southwest Monsoon season has observed decreased rainfall in the study area. Nevertheless, annual levels at each station reveal a consistent upward trend in the region. Table 3 outlines Sen's values for each station on the rainfall pattern in Northern Sri Lanka from 1992 to 2022. The Ambalapperumalkulam stations report annual precipitation Sen's slope values that are notably greater than other stations. Regarding the Sen's slope values for the Northeast Monsoon season, only the Nedunkerny station displays a positive value of 0.76. Nevertheless, the Northeast Monsoon Sen's slope values present negative values, implying that seasonal rainfall in the northeast monsoon area has declined in the study area over the last three decades. Finally, concerning the Southwest Monsoon season, the Ambalapperumalkulam station's Sen's slope value is higher than other stations. Sen's slope values for the Southwest Monsoon season demonstrate an overall increasing trend across all stations except for the Nedunkerny station, which shows decreasing values of -0.98 in the study area (Figure 7 - 9).

The Mann-Kendall trend analysis of temperature data discloses the configuration of its direction. The p-values of temperature stations- Thirunelvely, Vavuniya, Iranaimadu, Murungan and Kanukkerny, divulge a statistical significance level surpassing that of the alpha level (Table 5). Additionally, the results from the Mann-Kendall analysis declaim the null hypothesis. Table 5 manifests the p-values of all corresponding temperature stations. As disclosed by the Mann-Kendall trend analysis, all areas of research demonstrate an evident inclination.

Temperature is a fundamental factor that plays a pivotal role in determining the climatic conditions of the Northern region. Being situated in a tropical zone, the Jaffna peninsula receives direct solar radiation throughout the year, leading to elevated temperatures. However, these temperatures experience fluctuations, exhibiting variability across different months of the year.

Table 3: *Sen's slope values of rainfall in the different stations for the different climatic seasons of the Northern region of Sri Lanka*

Station	Seasons	Sen's Slope Values/decade	Trend
Akkarayankulam	NEM	-0.98	Falling
	SWM	1.23	Rising
	Annual	2.234	Rising
Ambalapperumalkulam	NEM	0.12	Rising
	SWM	2.197	Rising
	Annual	3.768	Rising
Iranaimadu	NEM	-0.89	Falling
	SWM	1.08	Rising
	Annual	2.987	Rising
Mankulam	NEM	-0.01	Falling
	SWM	1.342	Rising
	Annual	2.876	Rising
Kanukkerny	NEM	0.54	Rising
	SWM	1.62	Rising
	Annual	2.876	Rising
Karukkaikulam	NEM	-0.43	Falling
	SWM	1.98	Rising
	Annual	3.164	Rising
Murungan	NEM	0.067	Rising
	SWM	0.978	Rising
	Annual	1.89	Rising
Muththaiyankaddu	NEM	-0.987	Falling
	SWM	0.795	Rising
	Annual	2.134	Rising
Pallavarayankaddu	NEM	-0.0634	Falling
	SWM	1.349	Rising
	Annual	2.876	Rising
Pavatkulam	NEM	0	No trend
	SWM	1.816	Rising
	Annual	2.917	Rising
Thirunelvely	NEM	0.005	Rising
	SWM	1.0678	Rising
	Annual	2.676	Rising
Nainatheevu	NEM	-0.87	Falling
	SWM	1.872	Rising
	Annual	3.012	Rising
Nedunkerny	NEM	0.76	Rising
	SWM	-0.98	Falling
	Annual	1.876	Rising
Vavunikkulam	NEM	-1.005	Falling
	SWM	0.956	Rising
	Annual	1.89	Rising

Table 4: *table 3 Continued*

Station	Seasons	Sen's Slope Values/decade	Trend
Vavuniya	NEM	-0.98	Falling
	SWM	1.056	Rising
	Annual	2.89	Rising
Thannimurippu	NEM	0.033	Rising
	SWM	1.734	Rising
	Annual	2.183	Rising

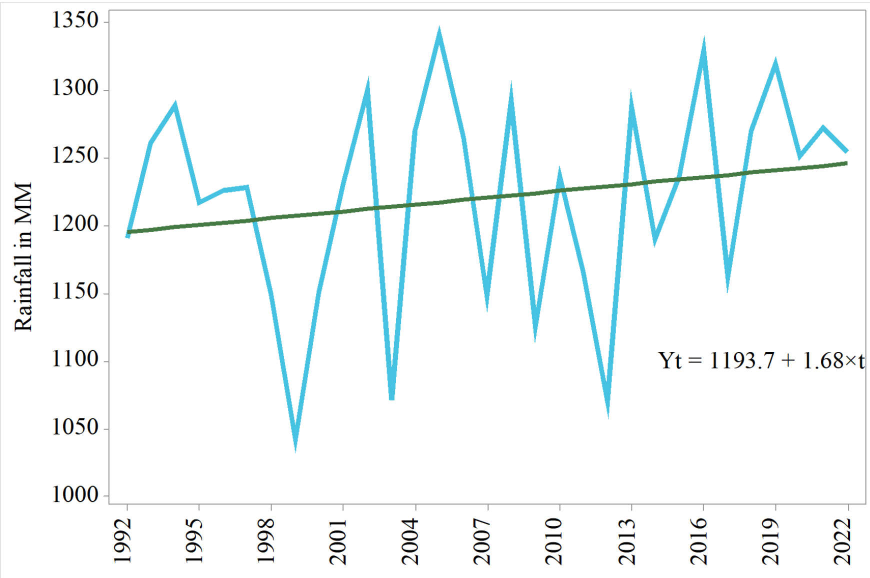

Figure 6: *Trend of annual total rainfall of the Northern Province of Sri Lanka. There are fluctuations in the annual total rainfall, but the trend is increasing from 1992.*

According to Sen's slope analysis, there has been a discernible rise in temperatures in the Northern region of Sri Lanka, registering an increase of 0.44 °C per decade from 1992 to 2022 (Table 6 and Figure 10). Nonetheless, the temperature trend exhibits marked spatial and temporal variations. The table below illustrates the diverse slope values traced by Sen's method concerning the temperature upsurge observed across multiple stations within the study area.

A rising pattern has been discerned in the mean, minimum, and maximum average monthly temperatures of Sri Lanka's Northern region spanning from 1992 to 2022.

4.2 Reduced number of rainy days and increased Runoff to sea

The impacts of climate change have been identified in several components of the surface water resources across the Northern region of Sri Lanka. Analyses of rainfall trends reveal a decrease in the number of rainy days in this region, with the current climactic period witnessing a significantly lower number (64) compared to the previous two periods (84 and 73 respectively). However, the annual total rainfall in this region has remained consistent at an average of 1240 since 1930, despite variations each year. This decrease in rainy days potentially affects the intensity of precipitation, producing short periods of rainfall that can impact the surface water's storage and sea runoff.

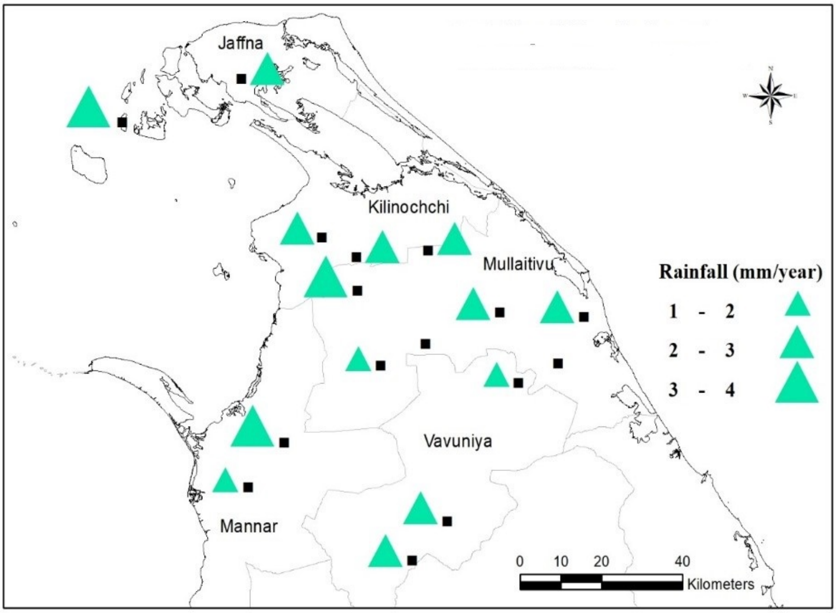

Figure 7: *Sen's Slope values for the annual rainfall pattern of Northern Sri Lanka.*

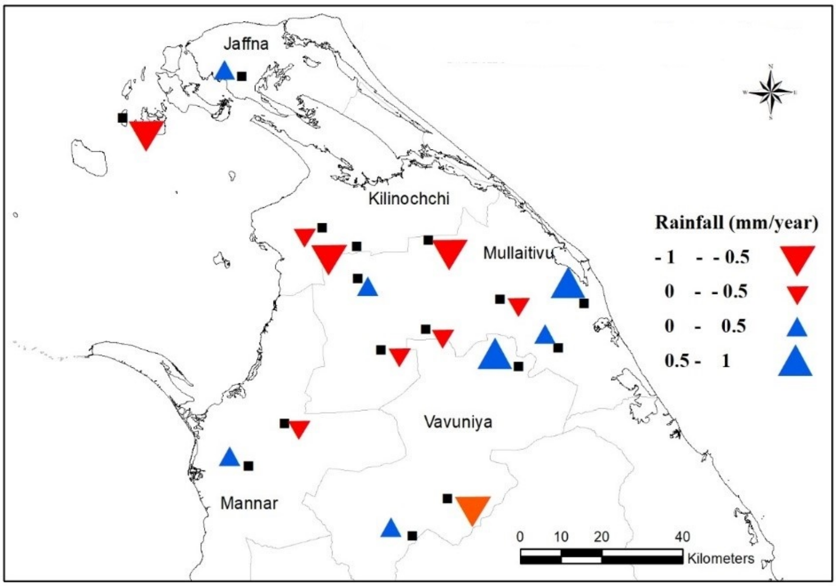

Figure 8: *The Sen's Slope value for the NEMS in different stations of the Northern Province of Sri Lanka.*

The Northern region has experienced a significant increase in runoff to the sea across every climatic period, reducing the number of rainy days impacting runoff. Unfortunately, this excessive runoff not only results in enormous amounts of unutilized water, but also depletes the available surface water in waterbodies like reservoirs and rivers. The accompanying figure and table depict

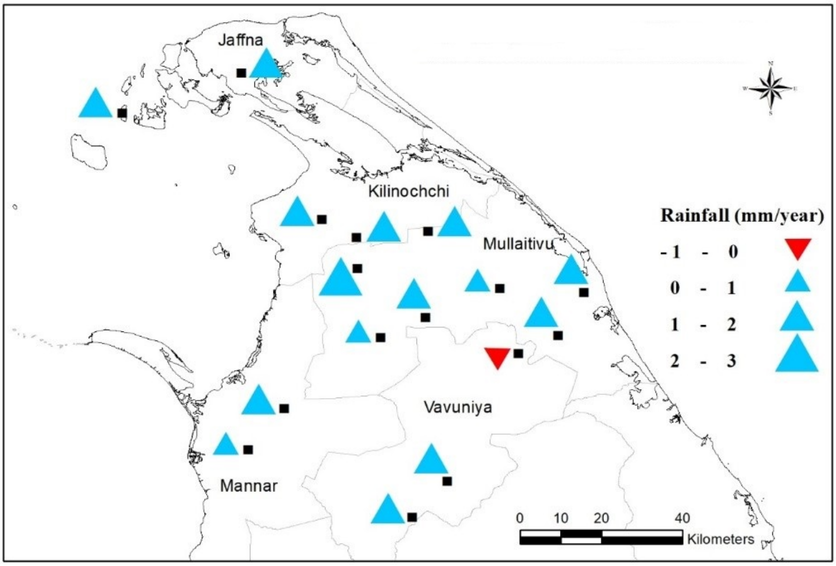

Figure 9: *Sen's Slope values of rainfall trend for SWMS in the Northern Region of Sri Lanka.*

Table 5: *The Mann Kendal trend analysis of temperature of the Northern region of Sri Lanka*

Series\Test	p-value	alba	Kendall's tau	Test Interpretation
Iranaimadu	<0.0001	0.05	0.467	Reject H0
Vavuniya	<0.0001	0.05	0.443	Reject H0
Murungan	<0.0001	0.05	0.460	Reject H0
Kanukkerny	<0.0001	0.05	0.403	Reject H0
Thirunelvely	0.005	0.05	0.275	Reject H0

the pattern of increasing runoff to the sea in Million Cubic Meters (MCM) for several river basins like Kanagrayan River (13.6), Aruvi Aru River (30.8 MCM), Paranki Aru River basin (13.3 MCM), Per aru river basin (8.4MCM) and Pali Aru river basins (9.3MCM), which discharge vast amounts of water to the sea as runoff. Figure 12 illustrates the correlation between the runoff to the sea in the Northern region of Sri Lanka and the number of rainy days.

Through the utilization of a correlation analysis method, the relationship between identified climatic change parameters and surface water components within the study area was identified. A negative correlation was uncovered between runoff and the number of rainy days, with a decreasing pattern observed in the latter and an increasing runoff pattern identified as per the analysis. This negative correlation is statistically expected since one variable increases while the other decreases (Figure 12). However, a strong relationship is exhibited between the two variables since changes in the annual total rainfall, alongside a decrease in rainy days, result in further impacts on surface water storage and groundwater recharge. This is evident in the statistically negative correlation value of -0.6976, indicating a robust relationship between the number of rainy days and sea runoff (Figure 13). The SWMS in the study area is vulnerable to drought due to minimal rainfall, with a large volume of the water mixing with the sea unnecessarily. Any increase in runoff will have detrimental effects on water storage in reservoirs.

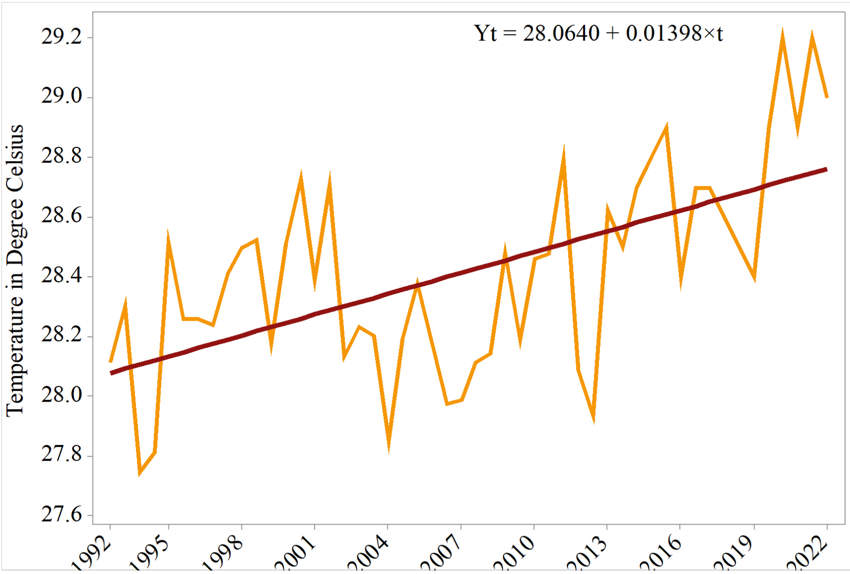

Figure 10: *Annual mean Temperature trend of the Northern Province of Sri Lanka.*

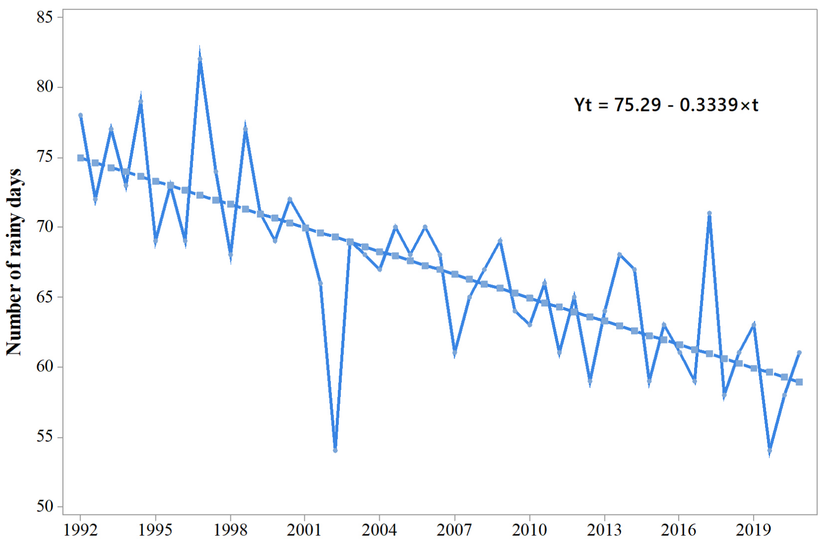

Figure 11: *The decreasing pattern of number of rainy days in the Northern Province of Sri Lanka which is the main cause for the increasing frequency of the flood hazards and the runoff to sea.*

4.3 Increasing temperature and evaporation rate

According to the analysis of Sri Lanka's northern region's annual evaporation data from 1992, the evaporation rate increased by 17% in the last sixty years from the previous climatic period. However spatially there are variations in the evaporation and soil evaporation pattern (Figure 14 and 15). The temperature during the study period has concurrently increased by 0.84 °C, while evaporation has risen by 17 %. This situation will severely impact surface water storage in the research area if the

Table 6: *Sen's slope values of temperature for Annual, North East Monsoon Season and South West Monsoon Season in different stations of the Northern region of Sri Lanka*

Station	Seasons	Sen's Slope Values/decade	Trend
Iranaimadu	NEM	0.37	Rising
	SWM	0.32	Rising
	Annual	0.43	Rising
Vavuniya	NEM	0.33	Rising
	SWM	0.44	Rising
	Annual	0.49	Rising
Kanukkerny	NEM	0.35	Rising
	SWM	0.38	Rising
	Annual	0.41	Rising
Murungan	NEM	0.31	Rising
	SWM	0.39	Rising
	Annual	0.44	Rising
Thirunelvely	NEM	0.36	Rising
	SWM	0.39	Rising
	Annual	0.45	Rising

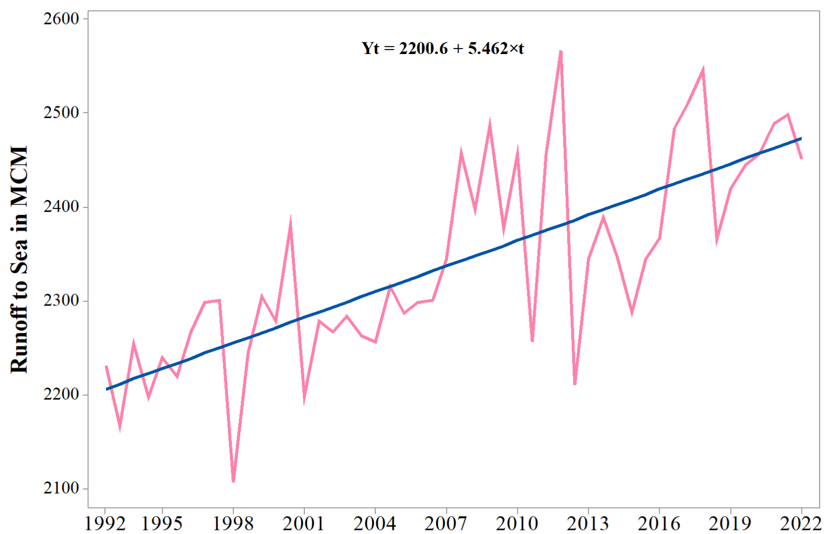

Figure 12: *Trend of runoff to sea in the Northern region of Sri Lanka from 1972 to 2022. There is an increasing trend of runoff to the sea which is the main cause for the unexpected flood during the FIMS and SIMS drought of water scarcity in the SWMS of the study area.*

evaporation rate rises (Figure 16 and 17). Due to the increased evaporation rate, most surface water bodies lost their water in the next three to four months from NEMS. The farmers of the study area faced difficulties getting water at the end of the FIMS because there was no water in their sources.

In the study area, a favourable correlation has been established between temperature and evaporation, with an impressive correlation coefficient of 0.429. It is noteworthy that temperature is

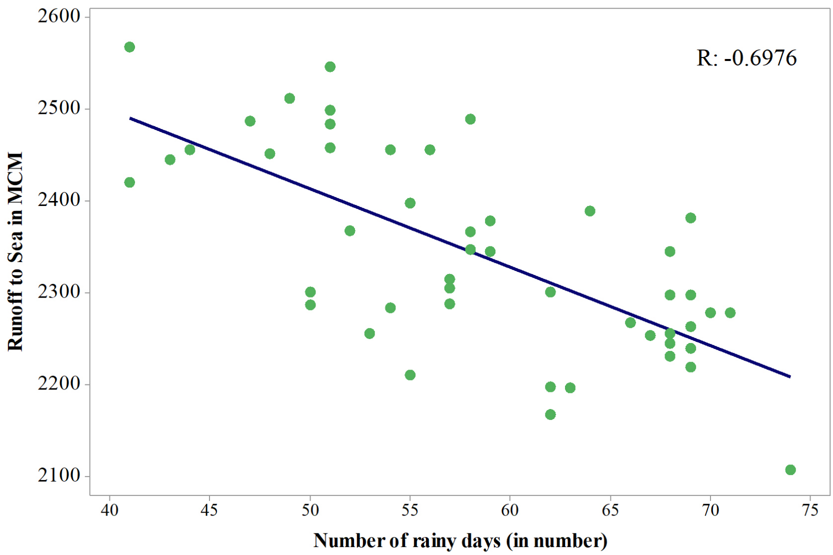

Figure 13: *This figure illustrates a negative relationship between the runoff to sea and the number of rainy days in the study area. The R-value is -0.69 which means that there is a negative correlation between these two variables. In another way can understand that decreasing number of rainy days influences the increasing runoff to sea and indicates that the intensity of the rainfall for the rainy day influences the runoff.*

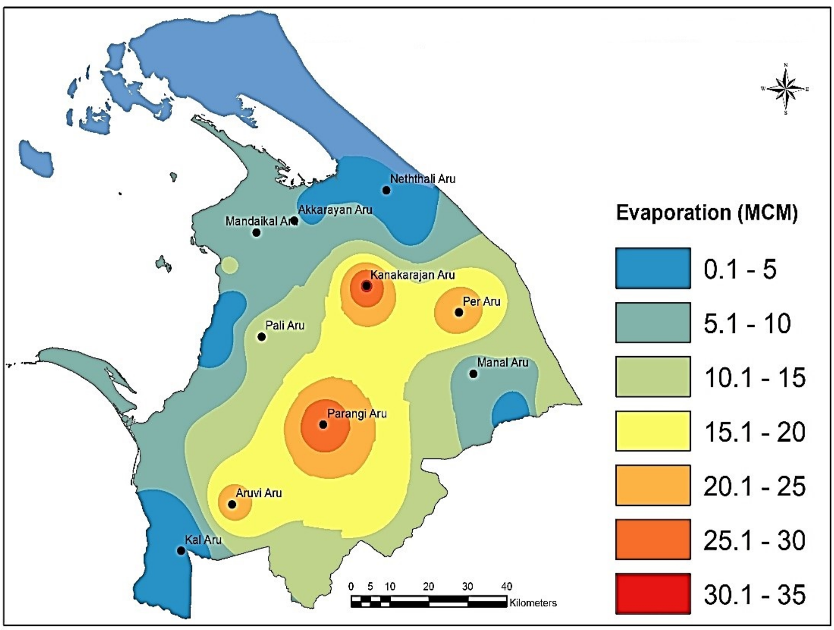

Figure 14: *Spatial pattern of Evaporation in the Northern Sri Lanka.*

undoubtedly the most pivotal climatic determinant dictating the evaporation rate of a place, and as this study affirms, there is indeed a positive correlation between temperature and evaporation,

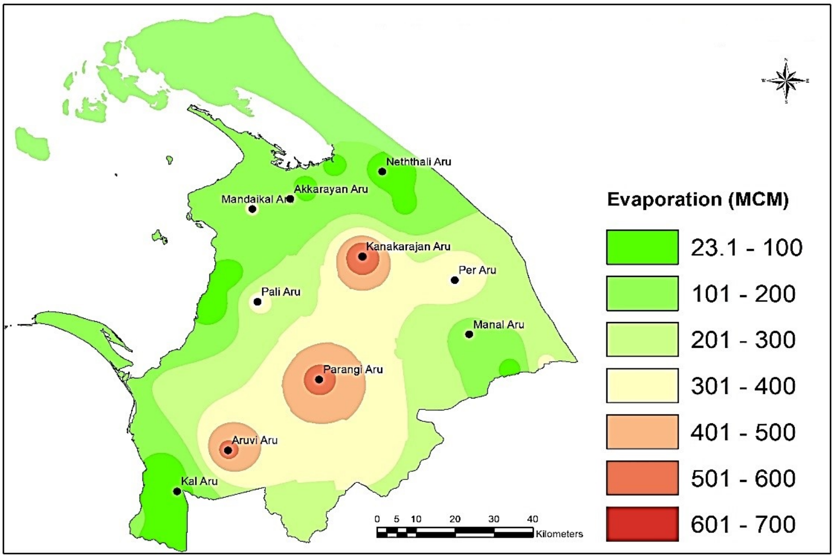

Figure 15: *Spatial pattern of soil evaporation.*

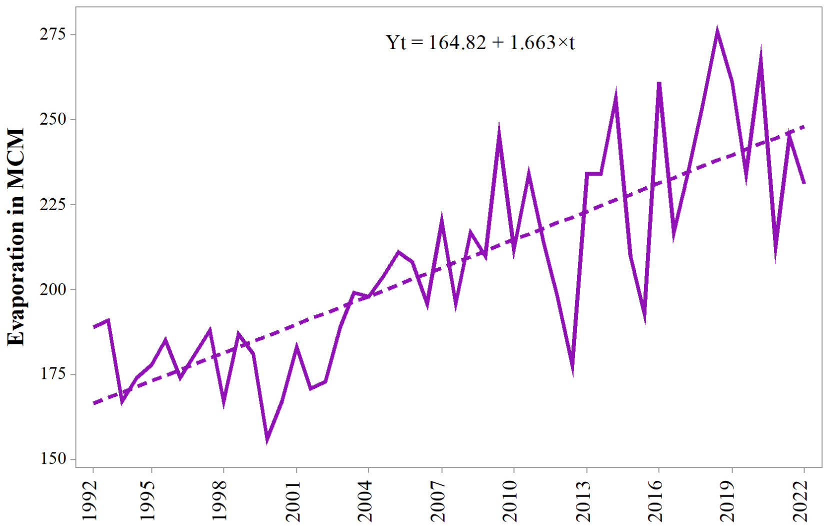

Figure 16: *Increasing trend of evaporation in the study area.*

as depicted in Figure 18. Furthermore, it's worth noting that similar to the effects of evaporation on temperature, soil evaporation equally influences temperature changes. Consequently, this study has established a positive correlation between soil evaporation and the temperature of the Northern region of Sri Lanka, with an R-value of 0.429.

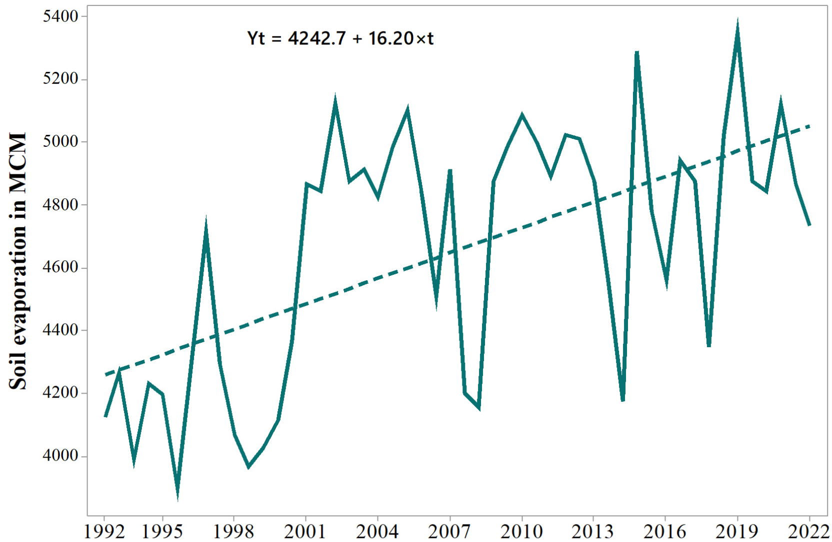

Figure 17: *Trend analysis of soil evaporation of the Northern region of Sri Lanka.*

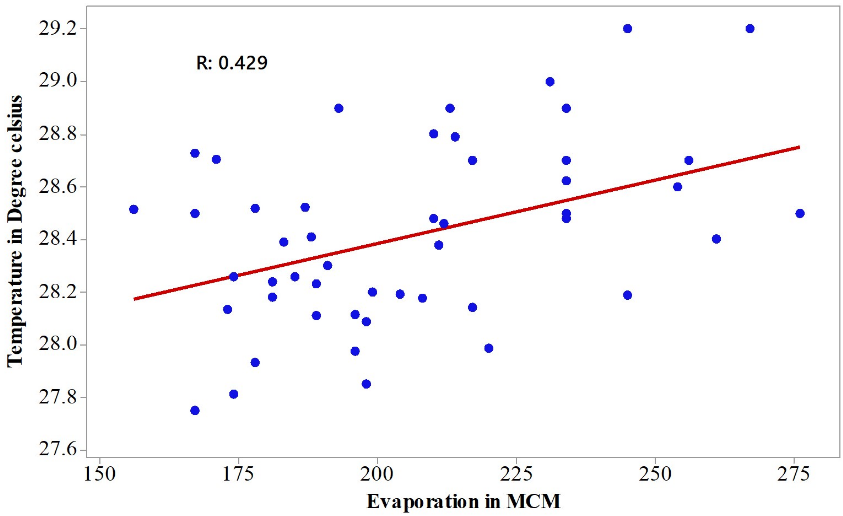

Figure 18: *Trend analysis of soil evaporation of the Northern region of Sri Lanka.*

4.4 Climate change and water demand

In accord with the geographical location of the study area, one hundred percent of paddy cultivation, sixty-five percent of subsidiary crop cultivation, forty-five percent of vegetable crop cultivation, and twenty-three percent of cash crop cultivation hinge on surface water resources. Moreover, a striking nineteen percent of the population relies on surface water for their domestic and potable water needs. As per the water governing bodies, namely the Department of Irrigation, National Water Supply, and Drainage Board, climate change has adversely affected water demand in the area. A considerable eighty-nine percent of water reservoir administrators cite that the demand for surface water has been on the rise. The irrigation water requirement was a mere 280 MCM from 1970 to 1980, which surged to 310 MCM from 1980 to 1990. Additionally, it increased to 350 MCM from 1990 to 2000, 405 MCM from 2000 to 2010, and an alarming 480 MCM from 2010 to 2019. Nonetheless, the population growth has not exhibited a concurrent increase; in fact, it decreased owing to the internal conflict, leading to displacement. The research indicates that there has been no alteration in agriculture, particularly in paddy cultivation, nor in the availability of land or other farming activities. Despite these observations, water demand is escalating due to the study area's high evaporation rate, water scarcity issues during the SWMS, frequent drought occurrences, and the escalating need for potable water. The district-based water demand in the study area is delineated in Table 7.

Table 7: *The water requirement and water availability of the Northern region.*

District	Agriculture water requirement (MCM)		Domestic water supply requirement in MCMC	Industrial water requirement in MCMC	Total water requirement of the province in MCM	The volume of the water available in MCM
	Rained	Irrigation				
Jaffna	156	147.3	35.65	4.00		
Kilinochchi	266.6	255.4	3.5	1.00		
Mullaitivu	70.1	243.9	10.95	1.00	2137.65	3328.88
Vavuniya	399.56	81.44	10.2	1.00		
Mannar	334.96	105.04	9.05	1.00		
Total	1227.22	833.08	69.35	8.00		

As per the irrigation department, farmers have made a request for canal water supply to aid in the cultivation of the Yala season. However, only a certain percentage of land will be granted permission to undertake paddy cultivation in the study area, based on the percentage of water available in the reservoirs during February, March, April, May, June, and July. The allocation of total land extent will be proportionate to the quantity of water available in the reservoirs. In the past, all land was authorized to carry out Yala season paddy cultivation, prior to the year 2000. Unfortunately, owing to a changing climate, water availability has been disrupted, causing an escalation in the evaporation rate, resulting in an amplified demand for water in the study area. The water scarcity issue of the FIMS and SWMS in the study area presents challenges for farmers managing irrigation facilities to support their cultivating activities. Consequently, the crops of the farmers are being destroyed due to inadequate water supply (refer to Figures 19 and 20).

4.5 Climate Change and Water Supply in the Northern Region of Sri Lanka

The phenomenon of climate change has significantly altered the water supply scenario of the examined region. The water supply pattern has undergone a considerable modification and now experiences frequent disruption due to the recurring incidence of both droughts and floods. The drought spells have gravely impaired the availability of water to such an extent that the concerned authorities, namely the Department of Irrigation and the National Water Supply and Drainage Board, have been rendered incapable of catering to the requirements of irrigation and drinking purposes. Similarly, the water supply system collapses during the flood, leading to further interruptions in supply. Over half of the population, 50.9% to be precise, have complained of the reduced quantity of water supply, with 20.3% indicating their dissatisfaction with reductions in water supply duration, while 16.8% voiced concerns over the change in supply timings. Approximately 67%, the vast majority, declared being influenced by the discontinuation of water supply, particularly during the Yala season, which has been increasingly beset by issues related to water distribution. In contrast, water managers in the Northern region, suffering from an absence or low level of rainfall in the months of February, March, and April, found it problematic to provide farmers with an adequate supply of water from

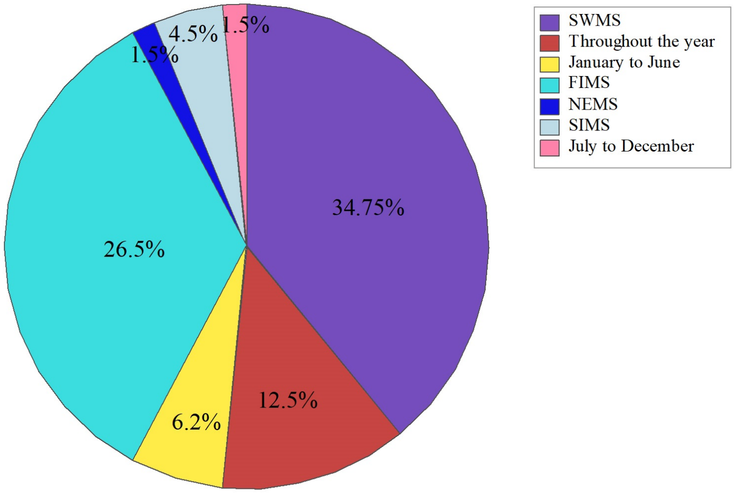

Figure 19: *Severe water scarcity period in the Northern region of Sri Lanka. The FIMS and SWMS have higher water scarcity problems in the study area.*

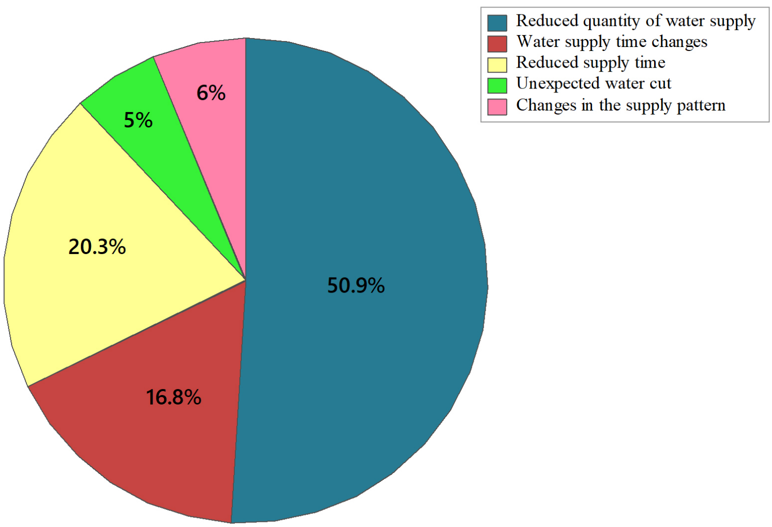

Figure 20: *Water demand and the water required extent in the Northern Region of Sri Lanka.*

the reservoirs. Managing the demand for water, particularly during times of scarcity, continues to pose difficulties for the responsible water governance authorities. In this regard, they have sought water supply to overcome the deficiencies, particularly in the SWMS and FIMS (Figure 21). Despite these appeals, the reservoirs' water levels remain inadequate, rendering the priority-setting duty arduous on account of political pressures.

Consumers of drinking and domestic water from the supply line reported being severely impacted

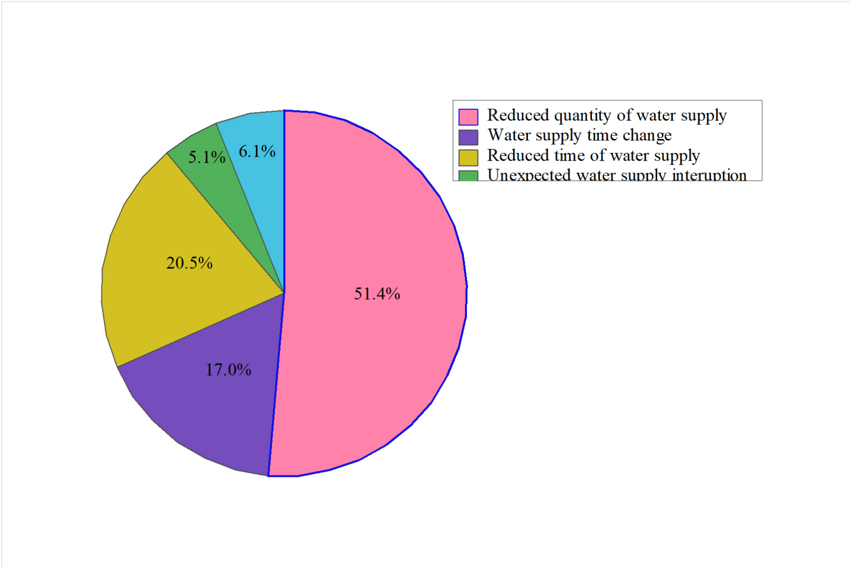

Figure 21: *Climate change impact on the water supply of the Northern region of Sri Lanka.*

during the FIMS and SWMS as a result of the water shortage and reduced supply. Moreover, the National Water Supply and Drainage Board (NWSDB), the entity tasked with providing drinking and domestic water to the public in Sri Lanka, expressed difficulties in obtaining sufficient water from their existing source to meet demand, because the water level of the surface water bodies are less during the SWMS months such as May, June, July, August and September and FIMS months such as March and April (Figure 22)

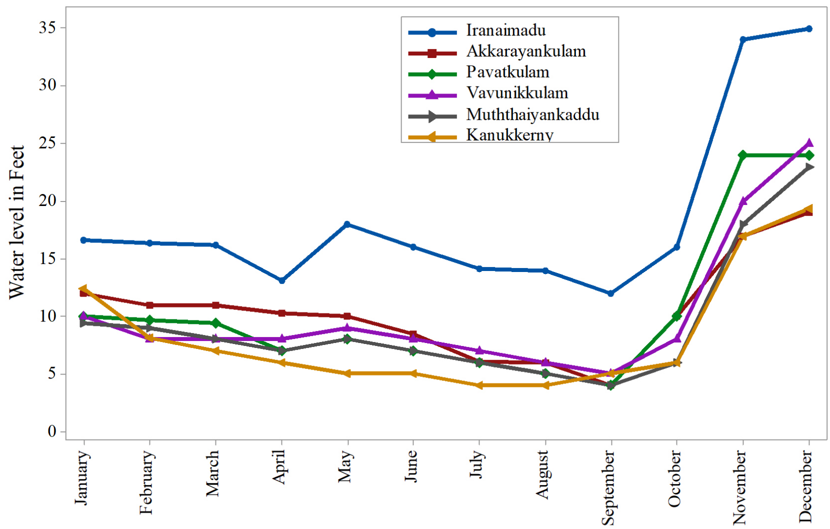

Figure 22: *Monthly pattern of water level in the selected reservoirs in the Northern Province of Sri Lanka.*

Initially, prior to 2000, water scarcity did not pose a significant problem in the study area.

However, it has rapidly developed into an acute issue. During periods of water scarcity, the populace receives little or no supply. They are also forced to move to alternate locations to obtain water for their everyday needs. The local residents had previously travelled 3km to obtain water. Presently, 35% report obtaining their water within a 02km distance, whilst 41% acquire water within 01 km distance. The community attributes the growing severity of water scarcity to the intensifying drought in the area. They also point to extreme temperatures and high evaporation rates as the primary causal factors of water scarcity. A diagram outlining the various facets of the growing water scarcity problem in the study area is provided below.

5. Discussion

The examination of climate change has produced substantial findings in this study, unveiling noteworthy alterations in the study region. However, diverse investigations have unveiled a comparable trend of climate change in numerous geographical locations [10][6][11][12]. Reports on climate change from national-level agencies reveal a rise in temperature by 0.81°C from 1901 to 2019 across Sri Lanka, serving as a benchmark for acceptable variation in climate fluctuation within the country [13]. Nonetheless, this investigation reveals that the Northern region of Sri Lanka has encountered a temperature shift of 0.84°C, which is commensurate with nationwide analyses. Moreover, the seasonal variations in temperature are similar to those reported in other areas. The present inquiry elucidates a surge in temperature in the South-West Monsoon Season (SWMS) by 0.96°C, and analogous investigations corroborate this extent of augmentation for this period. [14][15][16][17].

The monthly pattern of studies in the observed temperature changes in the study area do not align with those found in other studies, as the latter indicate varying values for the changes in the monthly temperature increase pattern [18][19]. Nevertheless, notable disparities have been discerned pertaining to the months of June, July, August, and September. Although numerous investigations similarly suggest a surge in monthly fluctuations of temperature, the augmented magnitude observed in our present study distinguishes itself from preceding research [13]. The dwindling frequency of wet days has adversely affected both surface and subterranean water resources. Despite a steady rise in the overall annual precipitation in the area under examination, an irregular distribution of rainfall can trigger an unwelcome decline in the recharge of groundwater and the storage of surface water. Consequently, the SWMS has been plagued by a scarcity of water in numerous locations throughout the area including but not limited to, Island Areas, Manthai West and East, Thunukkai, Nanaddan, Musali, Mannar, and Kandavalai.

The increasing evaporation rate has impacted water level and availability. Higher runoff rates have affected the water level, water availability, flood vulnerability, and drought have also increased in the study area due to climate change. Studies related to climate change's impact on surface water resources in Sri Lanka indicate similar results [20][21]. Additionally, the studies [22][23] revealed that the evaporation rate directly impacts the authors' water sources studied future climate change affects the water resources of Sri Lanka.

The availability of water in the reservoir will be impacted by the high evaporation rate, and higher runoff will affect the water availability and the reservoir. Water demand has increased due to unexpected dry conditions in the SWMS, and the authorities faced difficulties in supplying the water for the demand. Water usage has also increased in the study area due to awareness programs about water. Many people have used their homeland for cultivation due to the awareness of organic farming. The high water demand usage has also increased, and there is no water in the supply reservoir. Few authors also indicated the same results in their studies [8][15]. Due to water scarcity or shortage, farmers in the study area face difficulties harvesting paddy during the Yala season. Again, water authorities also indicate that they face problems managing the water supply based on the high demand for water due to climate change [24].

The elevated mean temperature shall affect the water bodies and soil evaporation and thereby precipitate aridity in the researched locality. The months of July, August, and September have observed the majority of drought occurrences. A substantial number of stations indicated increased drought severity above a drought intensity level of -1.00. Drying was persistent from the Southwest Monsoon season to the mid-phase of the second inter-Monsoon season and adversely affected agriculture. Certain observations elucidated the monsoon process fluctuations and a decline in rainfall during the Southwest Monsoon season. Furthermore, frequency and severity of droughts amplified towards the Northwestern region of Sri Lanka [25][26].

Water scarcity is an increasingly pressing matter in the area under investigation. The principal reasons for the intensification of this problem in the northern region of Sri Lanka are the climb in temperature, evaporation, reduction in the number of rainy days, and alterations in the seasonal rainfall pattern. It is worth noting that this issue is not isolated to the northern region of the country, but is a burning concern in various other parts of Sri Lanka, due to the worldwide climate alterations. A few studies have discovered that the long-lasting absence of rainfall primarily contributes to the scarcity of water in many regions of the country. The specific reason for this challenge in the area under examination has yet to be ascertained. However, upon examining the total rainfall in the study area, the shortage of water or drought in the SWMS is attributable to inadequate management practices by the water administration. Following the 1970s, there was no construction of new reservoirs in the research area.

Evapotranspiration is a crucial hydro-climatic determinant for the investigation of water resources in a particular location. It represents the summation of water losses from both the land surface and vegetative cover. As a result, this parameter is a vital element in the study of water balance and the overall water cycle. The rate of evapotranspiration in a specific location is primarily influenced by precipitation, temperature, and wind speed. It is widely used to assess a location's water deficit or surplus. According to Manjula Ranagalage and team [20], the Northern region of Sri Lanka has experienced a 4% increase in forest cover over the past two decades. In light of this development, the study of evapotranspiration in the Northern region of Sri Lanka is crucial for assessing its water resources. Nevertheless, due to the internal conflict and inadequate resources in the weather observation center, no data exists on evapotranspiration in this region. This parameter has only been recorded at one station (Thirunelvely) since 2015. Therefore, the lack of reliable data is a significant constraint in the present study. Despite this, the study aims to investigate the impact of climate change on surface water resources in the Northern region of Sri Lanka using available hydro-climatic variables.Some neighbouring countries have also conducted studies that revealed that climate change has a significant impact on water resources [6]. The rising temperatures and changes in rainfall patterns have caused variations in the surface water components [21]. In Tamil Nadu, India, the rising temperatures have led to an increase in the rate of evaporation, further exacerbating the impact of climate change on the storage of groundwater resources [22]. Drought and flooding have become increasingly common in several states of India as a result of climate change. The changing patterns of rainfall also affect the water level in the water resources in Kerala, India [23].

Several results of this study significantly differ from previous studies. However, many current study findings are singular and unique in many ways, showing their individuality. The internal war heavily affected the study area for thirty years, from 1980 to 2009. This study will be the first and primary literature source describing the hydro-climatic characteristics of the Northern region of Sri Lanka, elaborating on observed climate change, projecting future climate change, and analyzing the impact of climate change on surface water resources in this region.

6. Conclusions

The economic prosperity of the Northern region of Sri Lanka hinges entirely on surface water resources such as rivers, lakes, reservoirs, and ponds. An overwhelming seventy percent of the area's farmers engage in paddy cultivation during the 'Maha' and 'Yala' seasons, relying solely on the aforementioned surface water resources to irrigate their fields during the latter part of the maha season and the entire yala season. This sustains the food demand of the people of the area, while more than thirty-four percent of the workforce of the study area is directly or indirectly involved in surface water-related economic activities.

In some places, particularly on the mainland, surface water resources provide drinking and domestic water facilities to the people who reside there. As such, any impact on surface water resources would significantly affect the economic sector of the study area. The increasingly dire effects of climate change now threaten the surface water resources of this area. As temperatures rise, water levels directly decline, the availability of surface water resources is greatly affected, and drought or water scarcity impact the study area during the first inter-monsoon and south-west inter-monsoon seasons. An accelerated rate of evaporation causes water scarcity in the western part of the study area.

While the overall amount of rainfall has remained relatively unchanged, climate change has altered its intensity pattern. Previously, the study area would receive rainfall gradually, allowing a great extent of water to flow to surface water bodies, thus reducing flood vulnerability in the upper and middle catchment areas of the perennial rivers of the study area. Climate change has altered this, resulting in much greater rainfall within a short period, causing water to flow into the sea as runoff and, in turn, creating flood vulnerability in the catchment areas. If this situation persists, the study area's water supply will become critically scarce, and its people will need to expend much time and money seeking water for drinking, domestic, and other activities. In this context, the water governors of the study area would do well to consider the impact of climate change on surface water resources and take steps to protect them. Incorporating both structural and non-structural mitigation measures into the area's surface water resources would ensure sustainable water consumption. Otherwise, the study area will face an unmanageable water problem shortly.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A: Not Applicable.

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