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SPATIAL VARIATION OF CLIMATIC HAZARDS IN THE NORTHERN REGION OF SRI LANKA

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ABSTRACT

There are no discernible patterns concerning drought and flood hazards in Sri Lanka; some areas have experienced more disasters than others. The objective of this study is to identify the spatial patterns of drought and flood hazards that exist in this region. Monthly, seasonal, and annual climatic data were gathered from thirteen stations, covering the period from 1972 to 2022. The Standardized Precipitation Index (SPI) was employed to examine each station's drought and flood hazards from 1972 to 2022. The Arc GIS 10.4 Krigging method was utilized to identify the spatial variations of the drought and flood hazards. During the South West Monsoon Season, severe droughts were detected in Vavunikkulam, Akkarayankulam, Murunkan, and Pavatkulam. Extreme floods were common during the First Inter Monsoon Season; three occurrences were noted at Iranaimadu, Thirunelveli, Pallavarayankaddu, and Nainathivu stations in the Northern region, identified through the SPI method. During the Second Inter Monsoon Season, two extreme floods in Thirunelveli, two in Vavuniya, and three in Murungan and Akkarayankulam stations were identified alongside seven severe droughts at Nainathivu and five at Vavuniya. During the North East Monsoon Season, three severe floods were identified in Akkarayankulam, three in Ambalapperumalkulam, three extreme floods in Pallavaraykaddu, three severe floods in Muththaiyankaddu, four severe floods in Vavunikkulam station, and three severe floods in Vavuniya in the Northern region of Sri Lanka. Some areas in the Northern Region of Sri Lanka have been affected several times spatially by both floods and droughts. The eastern parts of the study area have more flood hazards, while the western parts have more droughts, according to 70% of the people surveyed. Furthermore, the frequency of flood occurrences decreases gradually in the direction from east to west, while that of droughts decreases gradually from west to east.

Key Words: *Drought, Flood, Seasons, Spatial Variations, Northern Region*

INTRODUCTION

The spatial pattern of climatic hazards plays a crucial role in understanding the distribution and occurrence of various weather and climate-related risks across different regions(De Alwis & Noy, 2019). These hazards, which encompass a wide range of phenomena, including hurricanes, droughts, floods, heatwaves, and wildfires, are not randomly distributed but instead follow distinct spatial patterns. By examining these patterns, we can gain valuable insights into the factors that contribute to the occurrence and severity of climatic hazards, which in turn can inform educational initiatives and disaster management strategies(Fung et al., 2020).

One of the primary natural factors that influence the spatial pattern of climatic hazards is topography. The physical features of a region, such as mountains, hills, and valleys, affect the local climate and can create unique microclimates(Kaklauskas et al., 2018). For example, mountainous areas often experience intense rainfall due to orographic lifting, leading to an increased risk of flash floods and landslides. Conversely, valleys and low-lying areas are more prone to the accumulation of cold air, increasing the likelihood of frost and freezing temperatures.(Li et al., 2021) Understanding these topographical influences is vital for developing targeted educational programs that inform residents of specific hazards they may face in their local area(Nagamuthu & Rajendram, 2015).

Latitude also plays a significant role in determining the spatial pattern of climatic hazards(Liao et al., 2021). Near the equator, regions experience more consistent solar radiation throughout the year, leading to higher temperatures and increased risk of heatwaves. Additionally, tropical areas are prone to cyclones and hurricanes due to the warm ocean currents that provide the necessary energy for these storms(Yan et al., 2021). Conversely, high latitudes tend to experience more extreme variations in climate and are susceptible to cold-related hazards like blizzards and extreme cold snaps. Recognizing these latitudinal patterns allows for tailoring education and preparedness efforts specific to the risks faced by communities in different parts of the world(Eckstein et al., 2021).

Proximity to water bodies, such as oceans, seas, and large lakes, is another crucial factor in the spatial pattern of climatic hazards(Knoesen, 2012). Coastal areas are particularly susceptible to tropical storms and storm surges, while regions near large lakes can experience lake-effect snowfall and increased flood risks. Moreover, the influence of water bodies on the local climate can result in variations in temperature, humidity, and precipitation patterns within a relatively small geographic area(Ha et al., 2022). Awareness of these patterns is necessary to promote effective disaster preparedness and response strategies among communities in vulnerable coastal and lakeside regions.

Besides natural factors, human activities also contribute to the spatial pattern of climatic hazards. Land use changes, such as deforestation, urbanization, and conversion of natural habitats, can alter the local climate by modifying the surface characteristics of an area(Meinshausen et al., 2020). For example, deforestation can lead to increased soil erosion and flash flooding, while urbanization can exacerbate the urban heat island effect, intensifying heat waves in densely populated areas. Educating individuals and communities about the consequences of their actions on the local climate can encourage sustainable practices and help mitigate the risks associated with climatic hazards(Kuttippurath et al., 2021).

Understanding the spatial pattern of climatic hazards is crucial in order to effectively manage and mitigate their impacts on human populations and the environment. Climatic hazards, such as hurricanes, droughts, floods, heatwaves, and wildfires, occur in diverse regions across the globe, and their spatial distribution can vary significantly. By analyzing and studying the spatial patterns of these hazards, we can gain valuable insights into their frequency, intensity, duration, and geographic distribution(Fung et al., 2020).

Identifying and mapping the spatial patterns of climatic hazards allow us to identify regions that are more susceptible to certain hazards. This knowledge enables us to assess the vulnerability of populations and infrastructure in these areas and develop targeted strategies to enhance resilience. For example, areas prone to hurricanes can implement stronger building codes and evacuation plans, while regions vulnerable to droughts can focus on water conservation and agricultural practices that are more sustainable in arid conditions(ADB, 2022). Furthermore, studying the spatial patterns of climatic hazards contributes to our understanding of climate change and its implications(Ahmad et al., 2021). As our planet undergoes significant environmental changes, including rising temperatures and altered precipitation patterns, it is crucial to analyze how these changes influence the occurrence and distribution of climatic hazards. This information aids in developing effective adaptation strategies and policies to address the impacts of climate change on vulnerable regions(Eberenz et al., 2021).

Various development activities are underway in the Northern Region of Sri Lanka following a thirty-year internal conflict, but unfortunately, they are facing threats from natural hazards, particularly from drought and flood hazards. This concern has prompted many to focus on natural disaster research to promote sustainable development within the Northern Region of Sri Lanka. In light of this, this study has analyzed the spatial variations in drought and flood hazards within the Northern Region of Sri Lanka over the past forty-two years, from 1972 to 2022.

STUDY AREA

The geographic area being analyzed pertains to the Northern Province, nestled in the northernmost part of the country, adjacent to India. This region is under administrative jurisdiction of five districts, encompassing 34 divisional secretariat divisions in Northern Sri Lanka (Figure 1). Bordered by the Palk Strait on the north, the Bay of Bengal on the east, and the Arabic Sea on the west, the North Central Province demarcates its southern borders. The Northern Province is subject to an average annual rainfall of 1240mm and an annual mean temperature of 29 °C.

The North region has been bestowed with 24 glorious rivers, classified as seasonal rivers, with 54 Major/Medium Irrigation schemes set up alongside them. The management of these schemes, which comprise nine significant tanks serving 70,197 acres of farmland, catering to the needs of over 28,459 agriculture-oriented families, has been undertaken by the IDNP. Additionally, the esteemed Valukkaiaru drainage scheme overseen by Irrigation Department of Northern Province (IDNP) services 2,000 acres and 54 Salt Water Exclusion schemes with saltwater exclusion facilities that benefit 16,508 acres, while the Jaffna Lagoon scheme comprises the Elephant Pass Lagoon scheme, Upparu Lagoon scheme, and Vadamarachchi Lagoon scheme administered by the same department.

The northern territory also features nine pivotal Major/Medium Irrigation schemes, housing five large reservoirs managed by the esteemed Central Irrigation Department, efficiently addressing irrigation water requisites for a vast stretch of land spanning 45,551 acres. Further, the Agrarian Development Department supervises no less than 2,744 minor irrigation schemes, providing irrigation water for 77,874 acres, greatly enhancing the lives of about 89,336 farming families in the region. Ultimately, the aquifers dispersed over the inner limestone layers of the Jaffna

Peninsula and a segment of the Mannar district represent significant water resources catering to the province's crucial drinking and agricultural water needs.

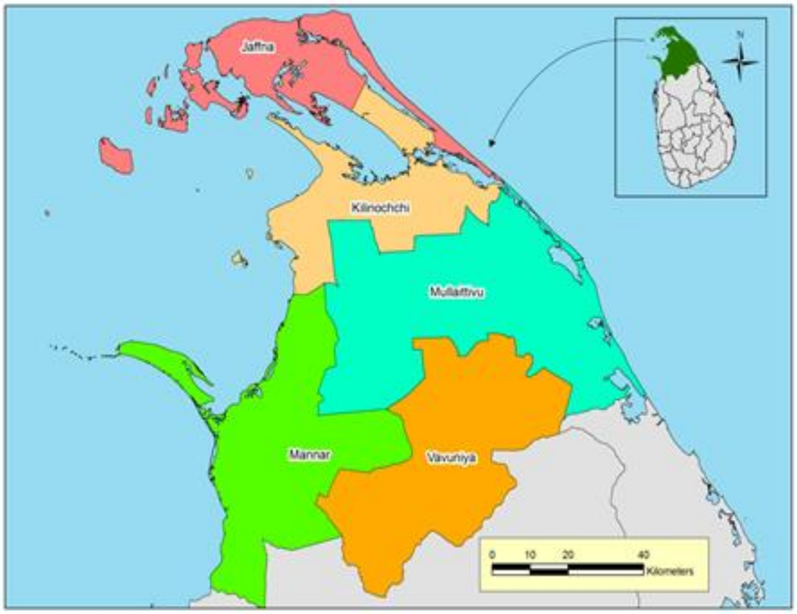
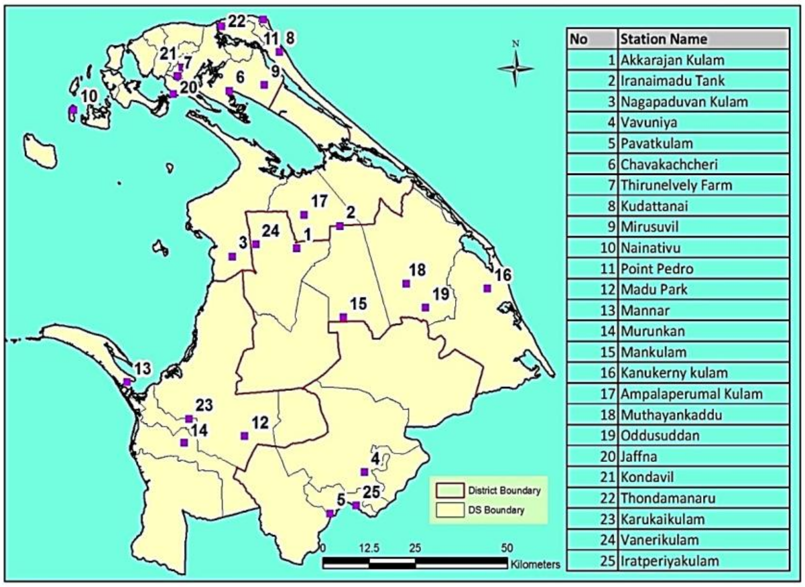


Figure 1: The Location of the Northern Province of Sri Lanka. Five districts in the Northern Province of Sri Lanka have 34 divisional secretariat divisions.



No	Station Name
1	Akkarajan Kulam
2	Iranaimadu Tank
3	Nagapaduvan Kulam
4	Vavuniya
5	Pavatkulam
6	Chavakachcheri
7	Thirunelvely Farm
8	Kudattanai
9	Mirusuvil
10	Nainativu
11	Point Pedro
12	Madu Park
13	Mannar
14	Murunkan
15	Mankulam
16	Kanukerny kulam
17	Ampalaperumal Kulam
18	Muthayankaddu
19	Oddusuddan
20	Jaffna
21	Kondavil
22	Thondamanaru
23	Karukaikulam
24	Vanerikulam
25	Iratperiyakulam

Figure 2: The rain gauge stations of the Northern Province, Sri Lanka

METHODOLOGY

Various data types ranging from primary to secondary have been used immensely in this research. Climatic data played a crucial role in identifying the spatial pattern of the climatic hazards in Northern Sri Lanka.

Sources from the Departments mentioned in the following paragraph were used to obtain the necessary climatic data. Basic secondary data required for this study were collected from the Department of Meteorology, Sri Lanka in Colombo. Data was collected for thirteen stations including Akkarayankulam, Ambalapperumal Kulam, Iranaimadhu, Thirunelveli, Kanukkerni, Karukkaikkulam, Murunkan, MuththaiyanKaddu, Nainathivu, Pavatkulam, Kariyalai Nagapaduvan, Thandikkulam, Vavuniya, and Vavunikkulam from 1972 to 2022 . Data related to Temperature (Monthly Average, Monthly Maximum, and Monthly minimum), Rainfall (Monthly Total, and Annual Total), Relative Humidity, Atmospheric Pressure, and Wind velocity, Wind Direction, and Evaporation were obtained from the Meteorological Department.

Statistical Abstracts of the National Statistical and Information Department. Statistical Abstracts of this department for the period from 1972 to 2022 also served as secondary data. Information and statistics from the statistical abstracts related to the weather and climate of the five districts,
According to the main objective of the study, the meteorological data were analyzed using Standartized Precipitation Index (SPI) in different scales. Meteorologists and climatologists have developed an array of drought indices to investigate past droughts and floods. There are diverse categories of indices, ranging from simple to complex. Nonetheless, American scholars have devised easy-to-calculate, uncomplicated indices that are more sensible and suitable. In keeping with this notion, in 1993, the Standardized Precipitation Index (SPI) was established by American scholars McKee, Doesken, and Kleist(Mehta & Yadav, 2021).

The Standardized Precipitation Index (SPI) is a widely utilized mechanism for evaluating and supervising drought occurrences(Fung et al., 2020). It offers a uniform and quantitative method of quantifying anomalies in precipitation over a specific time frame and may be employed in several spatial and temporal scales. The utility of SPI is particularly evident in areas where water supply is chiefly dependent on precipitation, and it has been adopted in various fields such as agriculture, hydrology, and water resource management(Abeysingha & Rajapaksha, 2020). Compared to other drought indices, SPI holds several advantages, the primary one being that precipitation data alone, which is abundant in many regions, may be used to calculate it. This renders SPI an efficient and cost-effective tool for monitoring and assessing drought incidents, particularly in regions with a dearth of meteorological data, such as temperature and evapotranspiration data. Additionally, SPI provides a standardized and adaptable approach that enables its calculation over different time scales (e.g., monthly, seasonal, and yearly), making it capable of detecting a range of drought events, from short-term to long-term droughts. This feature also allows for contrast and comparison of drought severity and frequency across distinct regions and timeframes(Mehta & Yadav, 2021). However, the statistical properties of SPI make it particularly suitable for recognizing and characterizing drought episodes since it is based on a probability distribution function of precipitation, facilitating identification of drought occurrences and their degrees of severity based on deviations from long-term mean rainfall. Compared to other drought indices such as the Palmer Drought Severity Index (PDSI), Factual

Drought Index (FDI), and Reconnaissance Drought Index (RDI), SPI demands less additional meteorological data, such as temperature and evapotranspiration, which may not be obtainable or dependable in some areas. Hence, SPI is often preferred over these other indices for its simplicity, flexibility, and accuracy in detecting drought events.

SPI is a valuable tool for tracking dry and wet seasons across multiple periods, enabling the identification of drought type, whether meteorological or hydrological, and facilitating comparison of climatic patterns in regions with varied hydrological regimes(Jiang et al., 2021). It is employed extensively in areas with distinct dry seasons, and due to its extensive testing and adoption, it is a potent and well-established tool for characterizing drought patterns and severity. SPI employs a probabilistic approach to rainfall to monitor dry and wet episodes. A drought occurrence persists when the index indicates consistently negative values, equal to or less than one, and ends when it returns to the positive range. The duration of a drought episode is contingent on the interval between the start and end of that period, while the intensity of a drought spell is obtained through a summation of the indicator values throughout the drought. Extremely wet periods are indicated by an index greater than 2.00, whereas extremely dry periods are indicated by an index below -2.00, with values between 0.99 and -0.99 indicating near-normal conditions.

According to Edwards and Mckee (1997), a gamma probability density function to a given frequency distribution of precipitation totals for the station of interest is fitted as

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \text{ for } x > 0 \qquad (1)$$

Where α is a shape parameter $(\alpha > 0), \beta$ is a scale value for calculation $(\beta > 0), x$ is the precipitation amount $(x > 0)$ and

$$\Gamma(\alpha) = \int_{0}^{\infty} y^{\alpha-1} e^{-y} dy \qquad (2)$$

Where gamma function is $\Gamma(\alpha)$ (Luxin Zhai, 2009)

Then the shape parameter α and the scale parameter β are estimated for each time scale of interest (either weeks or months) and for each week or month of the year, depending on whether the weekly or monthly SPI is calculated:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (3)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad (4)$$

“Where $A = \ln(\bar{x}) - \left[\sum \ln(x)\right] / n, n$ is number of precipitation observations, and $\bar{x}$ is mean precipitation over the time scale of interest. The cumulative probability of each observed precipitation event for the given time scale for the station of interest is then computed using the estimated shape and scale parameters. An equiprobability transformation is made from the cumulative probability to the standard normal random variable Z with mean zero and variance of one, where the SPI takes on the value of Z"(Hong Wu, 2005). Lower than median precipitation denoted by values in negative SPI and higher than the median precipitation is denoted by positive values in SPI(Abeysingha & Rajapaksha, 2020).

Table 1: Values of SPI

SPI Values	**Category**
Over 2.0	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.50 to -1.99	Very Dry
Below -2	Extremely Dry

Source: WMO,2022

For SPI analysis in this study, monthly rainfall data of the selected thirteen stations such Akkarayankulam, Ambalappermalkulam, Iranaimadu, Muththiayankaddu, Murungan, Kanukkerny, Thirunelvely, Nainathivu, Pallavarayankaddu, Karukkaikulam, Vavunikulam, Pavatkulam and Vavuniya have been computed using the SPI method. To obtain the SPI-12, SPI-6, and SPI-3 have been analyzed by adopting the Standardized Precipitation Index (SPI). The data of the missing months of some stations have been added from very nearest stations of the study area. The SPI results have been mapped using the Kriging method of the ARC GIS, 10.4 versions.

RESULTS

Spatial Variations of Flood and Drought Years

The analysis of the annual SPI for the rainfall data of the thirteen stations has revealed several spatial variations during drought and flood years. Some stations have experienced a greater number of drought and flood hazards than others. Akkarayankulam station witnessed five droughts and four floods during a period of 42 years from 1972 to 2022. Extreme floods occurred in 1984 and 2001 while severe floods took place in 1993. The drought situation reached an extreme level in 2009 with severe droughts happening in 1974 and 1980, and normal droughts occurring in 2007 and 2011.

The Ambalapperumal Kulam station recorded five floods, including one extreme flood year in 1984, while 1992 witnessed severe drought conditions. The remaining drought years were normal, identified during the years of 1989,1991,1993,1994, 1995, 2008, 2009, 2013, 2017, and 2020. Iranaimadu recorded three floods and four droughts, with extreme flood years identified in 1984 and 2010. Severe droughts were noticed in 1974, 1987, 2008 and 2009.

In Kanukkerny station, eight floods and three droughts occurred, with extreme floods happening in 1984 and severe floods in 1993 and 2011. Extreme drought year was identified in 2009 and normal droughts occurred in 1980 and 1998. Karukkaikulam station had one extreme flood year in 1979, followed by one severe flood in 1984 and one normal flood in 2008. Severe droughts occurred in 1992 and 2010, and normal droughts were witnessed in 1974, 1991 and 1999.

Four flood years and four drought years have been identified in the Murunkan station, including extreme flood years in 1984 and 2008, and extreme drought years in 1990 and 1991. Normal drought years were identified in 1974 and 2009. Muththaiyankaddu station identified severe floods in 1973 and 1984, while normal floods were observed in 1993, 2004, 2011 and 2022. Extreme drought occurred in 2009, while severe droughts were identified in 1991 and 1992 and normal droughts in 1974 and 1989. Five flood years and eight drought years have been identified in the Nainathivu station, with one extreme flood year situated in 1984 and four normal flood years identified during 1996, 1998, 2003, 2010, 2014, 2019, and 20121. There was no presence of extreme or severe droughts in the Nainathivu station. All droughts identified during this period were normal, happening during the years of 1975, 1978, 1981, 1982, 1985, 1987, 1988 and 2002. The Pallavarayankaddu station identified two extreme flood years in 1984 and 2001, while severe floods were observed in 2004 and normal floods in 1998. An extreme drought year was identified in 2008, and severe droughts occurred in 1995 with normal droughts in 1994 and 2005.

There were extreme flood years in 1972 and 2010 in the Pavatkulam station, with severe floods identified in 2022 and normal floods identified in 1973, 1981, 1984, 2008 and 2011. Extreme drought year was identified in 1990 and a severe drought occurred in 2005, while normal droughts were identified in 1988, 1995, 1997, 2003, 2006, 2011, 2015, 2019 and 2021. Seven floods were identified in the Thirunelvely stations from 1972 to 2022. Severe floods occurred in 1984, 1993 and 2001, while the other four flood years were normal, identified during the years of 1975, 1985, 2003 and 2008. Seven severe droughts were identified in this station within forty-two years; these droughts occurred in 1982, 1987, 1989, 1992, 1996, 1997 and 2005. The Vavunikkulam station witnessed two extreme floods in 1984 and 1993, normal floods in 1979, 2011, and 2018, severe drought in 1974 and a drought in 2010. Six flood years were identified in the Vavuniya station, with severe floods occurring in 1999, 1984, 2000 and 2007, and normal flood years during 1972, 1980, 2008 and 2011. Droughts were identified in 1974, 1986 and 1988.

Kanukkerny station had the highest number of flood years at eight, while the maximum number of two extreme flood years were identified within Vavunikkulam, Pallavarayankaddu, Akkarayankulam, and Ambalapperumalkulam. Vavuniya had the highest number of severe floods and normal floods identified. Thirunelvely and Muththaiyankattu both recorded a maximum number of normal floods. Murungan and Nainathivu recorded the highest number of drought years with eight each. Ambalapperumalkulam had the maximum number of extreme drought years. Muththaiyankaddu had the highest number of severe droughts and Nainathivu the maximum number of normal droughts. The flood year of 1984 was the most critical year recorded by almost all stations. The subsequent year, 1993, witnessed floods in several stations in the Northern Region, like Vavunikkulam, Thirunelvely, Muththaiyankaddu, Murungan, Kanukkerny and Akkarayankulam. All stations recorded the worst drought of the period in 1974. Following figure explained the spatial variations of the SPI-3 for selected years.

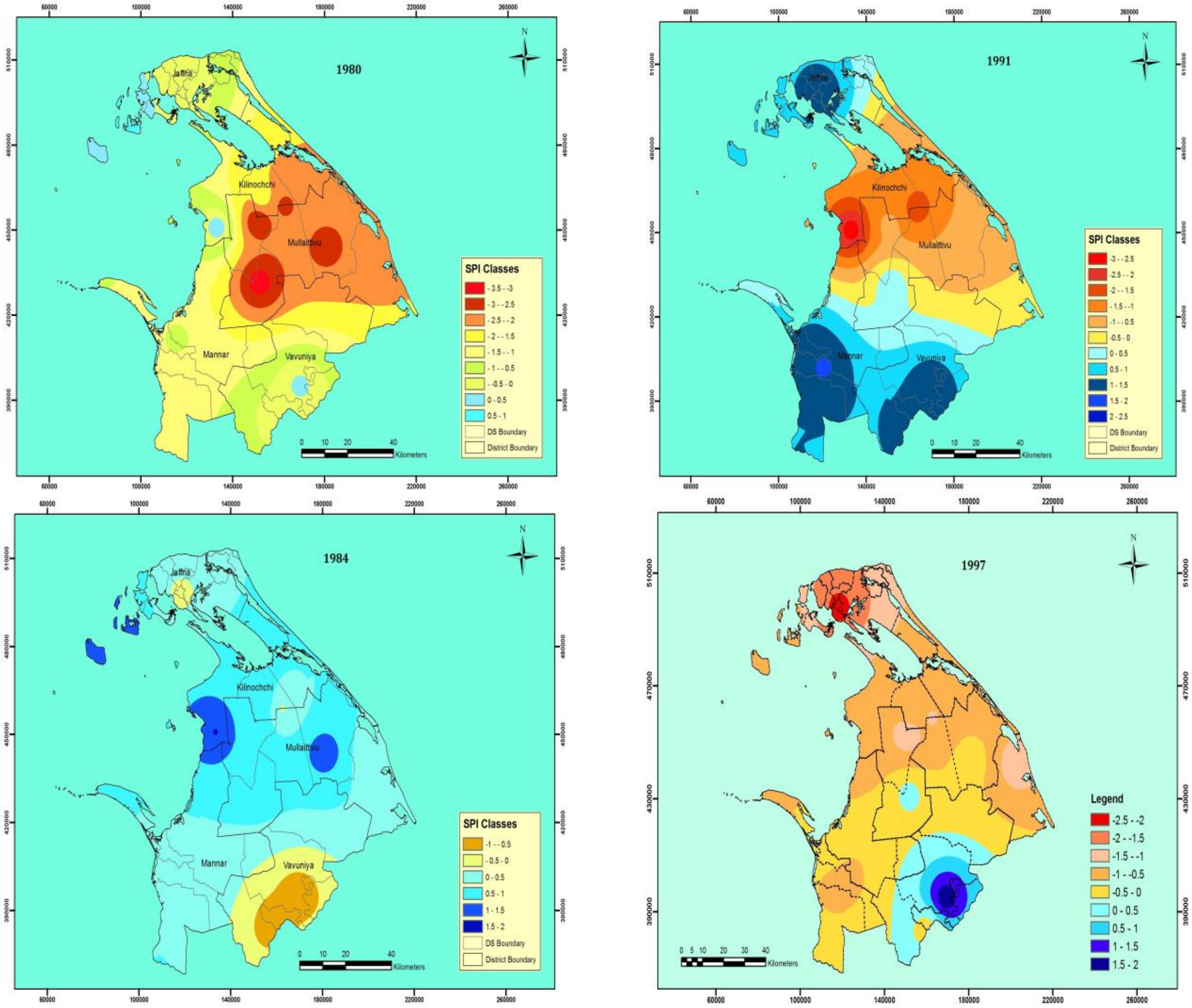


Figure 3: Spatial pattern of SPI-3 in selected years

Seasonal Drought and Flood - Station Wise Analysis

The study area's SPI analysis has revealed spatial differences in flood and drought seasons from 1972 to 2022. Notably, no critical droughts occurred in any of the stations during the initial inter-monsoon season. However, several extreme floods were recorded at various stations during different years. Table 2 enlists the exceptional flood years and stations for the first inter-monsoon season.

Table 2: Extreme Flood Occurrences during the FIMS

Station	Year
Akkarayankulam	1984,2001
Ambalapperumalkulam	1984
Iranaimadu	1984,2008,2011
Kanukkerny	1984,
Karukkaikulam	1984,2008
Murungan	2008
Muththiayankaddu	1984,2008
Nainathivu	1984,2008
Pallavarayankaddu	1984,2001,2009
Pavatkulam	2008
Thirunelvely	2008,2009
Vavunikkulam	1984
Vavuniya	1977,1984

Three major floods have been identified at the Iranaimadu and Pallavarayankaddu stations, respectively. Additionally, the study area has experienced multiple instances of both moderate and mild floods, as well as droughts. Of particular note is the one severe drought identified at the Pavatkulam station, which stands in stark contrast to the relatively frequent occurrences of drought throughout the study area. The table below provides a detailed overview of the floods and droughts recorded at each site during the first inter monsoon season (FIMS) (Table 3).

Table 3: Details of Flood and Drought of Every Station During the FIMS

Stations	No. of Floods	Severity of Times	No. of Droughts	Severity of Times
Akkarayankulam	4	1 in 10 years	3	1 in 14 years
Ambalaperumalkulam	6	1 in 7 years	7	1 in 6 years
Iranaimadu	5	1 in 8 years	6	1 in 7 years
Kanukkerny	7	1 in 6 years	1	1 in 42 years
Karukkaikulam	6	1 in 7 years	6	1 in 7 years
Murunkan	4	1 in 10 years	4	1 in 10.5 years
Muththaiyan kaddu	8	1 in 5 years	1	1 in 42 years
Nainathivu	3	1 in 14 years	2	1 in 21 years
Pallavaryankaddu	5	1 in 8 years	2	1 in21 years
Pavatkulam	6	1 in 7 years	7	1 in 6 years
Thirunelveli	5	1 in 8 years	3	1 in 14 years
Vavunikkulam	6	1 in 7 years	7	1 in 6 years
Vavuniya	4	1 in 10 years	7	1 in 6 years

During the Spatial Interpolation of Monthly and Seasonal Rainfall Data in the Northern Region of Sri Lanka, several instances of extreme droughts and floods were detected in the chosen rainfall stations. The Akkarayankulam station experienced an extreme drought in 2009, but no extreme floods were observed during the second inter-monsoon season. In the Ambalapperumalkulam station, an extreme flood occurred in 1979, whereas an extreme drought was identified in 1989. The Iranaimdu station did not record either extreme drought or extreme flood in 1981. The Kanukkerny station, on the other hand, witnessed an extreme flood in 1993 and an extreme drought in 2009. The Murungan station witnessed the maximum number of extreme droughts during the second inter monsoon season (SIMS). A severe flood was observed in Murungan during the SIMS in 1993.

No occurrences of extreme floods or droughts were observed in the Muththaiyankaddu and Nainathivu stations during the SIMS. The Pallavarayankaddu station, however, recorded an extreme flood in 2004 and an extreme drought in 2008. The Pavatkulam station experienced an extreme drought in 1990. In the Thirunelvely station, an extreme flood was detected in 1985, whereas an extreme drought was recorded in 2007. In the Vavunikkulam station, an extreme flood occurred in 1993 and an extreme drought in 2009. The Vavuniya station experienced extreme floods in 1972 and 1979, with no extreme drought being recorded in the forty-two years since then. In addition to these stations, several floods, severe floods, severe droughts, and droughts were observed across the selected stations in the Northern Region during the SIMS. (Refer to Table 4)

Table 4: Details of Flood and Drought of Every Station During the SIMS

Stations	No. of Floods	Severity of Times	No. of Droughts	Severity of Times
Akkarayankulam	5	1 in 8 years	7	1 in 6 years
Ambalaperumal	5	1 in 8 years	6	1 in 7 years
Iranamadu	7	1 in 6 years	6	1 in 7 years
Kanukkerny	7	1 in 6 years	5	1 in 8 years
Karukkaikulam	4	1 in 10 years	4	1 in 10 years
Murungan	4	1 in 10years	4	1 in 10 years
Muthaiyan kaddu	6	1 in 7 years	4	1 in 10 years
Nainathivu	4	1 in 10 years	5	1 in 8 years
Pallavaryankaddu	6	1 in 7 years	4	1 in 10 years
Pavatkulam	6	1 in 7 years	3	1 in 14 years
Thirunlveli	6	1 in 7 years	4	1 in 10 years
Vavunikulam	5	1 in 8 years	5	1 in 8 years
Vavuniya	6	1 in 7 years	4	1 in 10 years

Throughout the North East Monsoon season (NEMS), an array of floods at varying degrees caused a significant impact in the Northern Region of Sri Lanka (refer to Table 5). It is noteworthy that the period of NEMS witnessed the highest incidence of floods, ranging from moderate to severe, as well as extreme occurrences. The table provided below furnishes details pertaining to the years of such events and the respective magnitudes of flooding. Additionally, it is imperative to state that there were no occurrences of extreme droughts during the NEMS in the study area spanning from 1972 to 2022 (Figure 4).

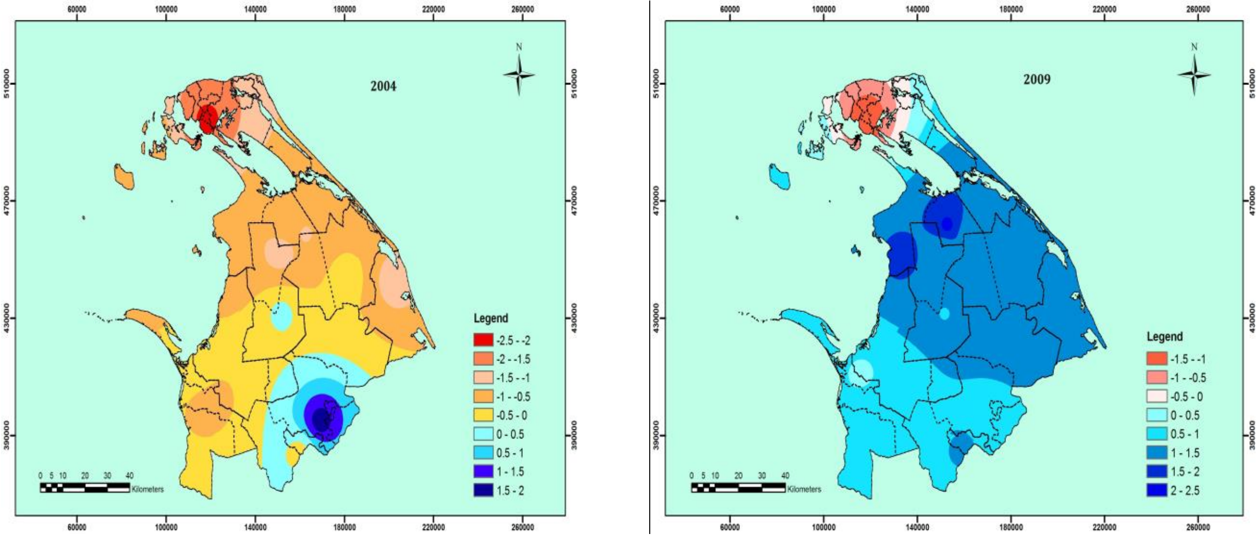


Figure 4: Spatial variations of SPI-3 during the SIMS

Table 5: Details of Flood During NEMS

Stations	Extreme flood	Severe flood	flood
Akkarayankulam	1984,1998,2001	2002	1973,1993,2011
Ambalapperumalkulam	1973,1984	1983,2011,1998, 2002	1979,2001
Iranaimadu	1984	1986,1998	1973,1983,1993,2001,2010
Kanukkerny	1984	1977, 1990, 2011,	1973,1983,1988,1990, 1992,1998,2001,2022
Karukkaikkulam	1984	1983	1993,1998,2000,2001,2022
Murungan	1984,1993	1983,1998	1985,2000,2022
Muththaiyankaddu	2011,2022	1993,2001	1985,2000,2022
Nainathivu	1984	1996,1998	2009
Pallavarayankaddu	1984,1998,2022	1973	
Pavatkulam	1984,2022	1983	1973,2000,2011
Thirunelveli	1984,1998,2001	1990,1993	1975,1983
Vavunikkulam	1984	1983,2011,1993	1990,2001
Vavuniya	2011	1984,1998,2022	1983,2000,2008

The NEMS witnessed an increased frequency of catastrophic floods in Akkarayankulam, Ambalapperumalkulam, Pallavarayankaddu, and Thirunelvely. Among them, Ambalapperumalkulam experienced the most intense floods while normal floods were predominantly recorded in Iranaimadu and Kanukkerny. (Please see Table 6 for details.)

Furthermore, Kanukkerny and Iranaimadu stations were identified as the regions with the highest number of floods. The NEMS also reported occurrences of droughts and severe droughts, which are listed in the following table along with the aforementioned flood details.

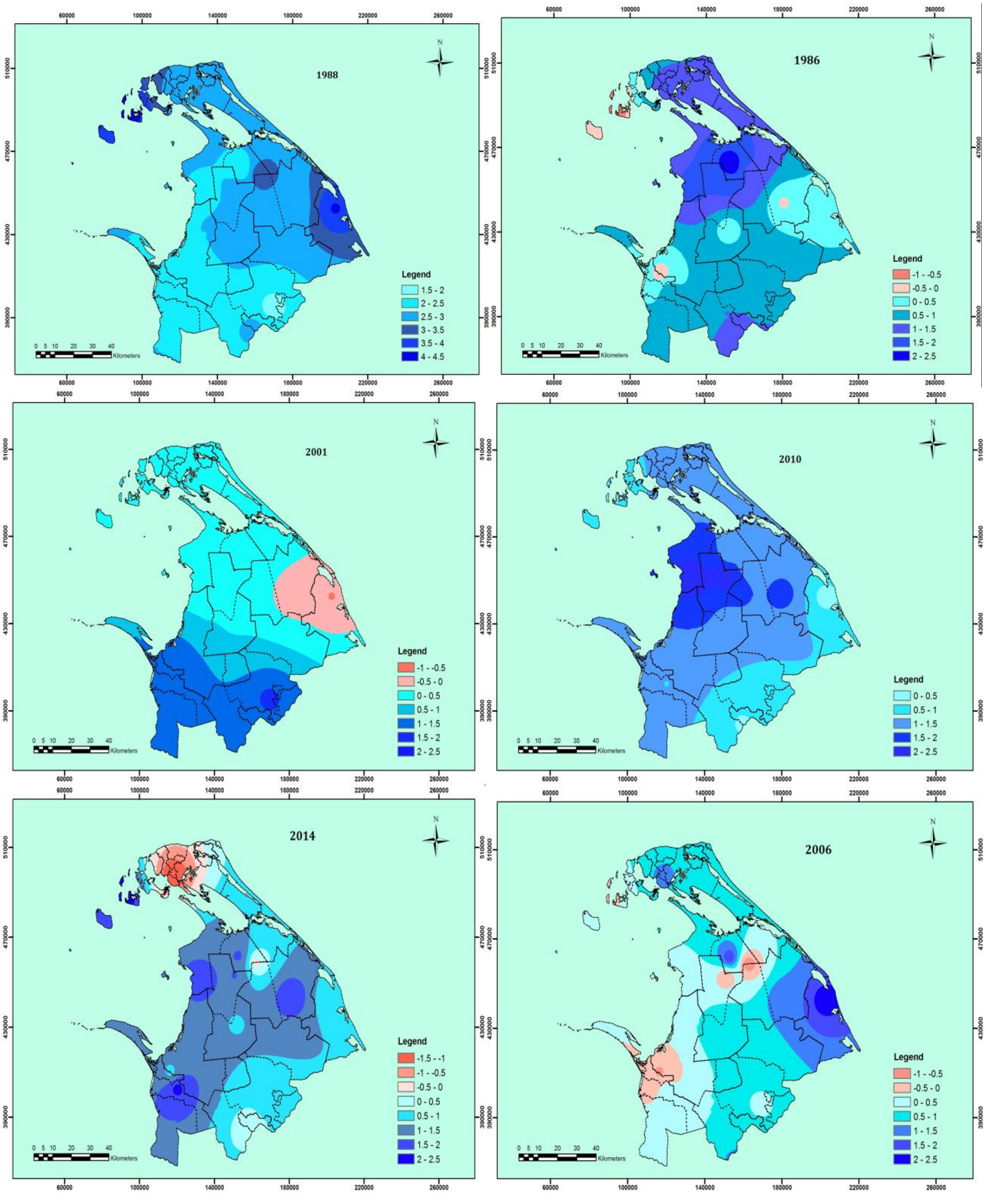


Figure 5: Spatial pattern of SPI-3 during the NEMS in selected years

Table 6: Details of Droughts and Floods at Every Station During the NEMS

Stations	No. of Floods	Severity of Time	No. of Droughts	Severity of Times
Akkarayankulam	7	1 in 6 years	3	1 in 14 years
Ambalaperumalkulam	8	1 in 5 years	4	1 in 10 years
Iranamadu	8	1 in 5 years	3	1 in 14 years
Kanukkerny	12	1 in 3 years	3	1 in 14 years
Karukkaikulam	7	1 in 6 years	5	1 in 8 years
Murunkan	7	1 in 6 years	5	1 in 8 years
Muthaiyan kaddu	7	1 in 6 years	2	1 in 21 years
Nainathivu	4	1 in 10 years	5	1 in 8 years
Pallavaryankaddu	4	1 in 10 years	3	1 in 14 years
Pavatkulam	6	1 in 7 years	3	1 in 14 years
Thirunlveli	7	1 in 6 years	3	1 in 14 years
Vavunikulam	6	1 in 7 years	4	1 in 10 years
Vavuniya	7	1 in 6 years	2	1 in 21 years

It is observed that among all seasons in the Northern Region, the South West Monsoon Season (SWMS) has witnessed a higher frequency of drought incidents (as depicted in Table 7). Additionally, two anomalous floods have been reported during this season owing to unforeseen extreme weather phenomena such as depressions in the Bay of Bengal as a result of mini cyclones and the influence of air masses. The following table gives the details of droughts and floods during the SWMS in the study area.

Table 7: Details of Drought and Flood of the SWMS of the Northern Region

Stations	**Extreme Drought**	**Severe Drought**	**Drought**
Akkarayankulam	Nil	1976	1986, 1994, 1999, 2002, 2008, 2009, 2011, 2022
Ambalapperumalkulam	Nil	Nil	1991, 2008, 2009, 2022
Iranaimadu	Nil	Nil	1973, 1976, 2002, 2008, 2009, 2011
Kanukkerny	Nil	Nil	1991, 2011, 1994, 2009, 2022
Karukkaikkulam	Nil	1976	1987, 1991, 2005
Murungan	Nil	1976, 1991	1999, 2002, 2005, 2006,
Muththaiyankaddu	Nil	Nil	1994, 2022, 1991, 2009
Nainathivu	Nil	1991	1997, 2002, 2005, 2008, 2022
Pallavarayankaddu	Nil	1979	1989
Pavatkulam	Nil	Nil	1986, 2005, 2011, 2022
Thirunelveli	Nil	Nil	2009, 2011, 1976
Vavunikkulam	Nil	1976	1997, 2007, 2009, 2009, 1999, 2008
Vavuniya	1976		1978, 1986, 1999, 2005, 2011, 2022

During the SWMS, higher a number of droughts have been identified in Akkarayankulam station as well as at Iranaimdu, Murungan,Nainathivu and Vavunikkulam stations (Figure 6 and Table 8.).

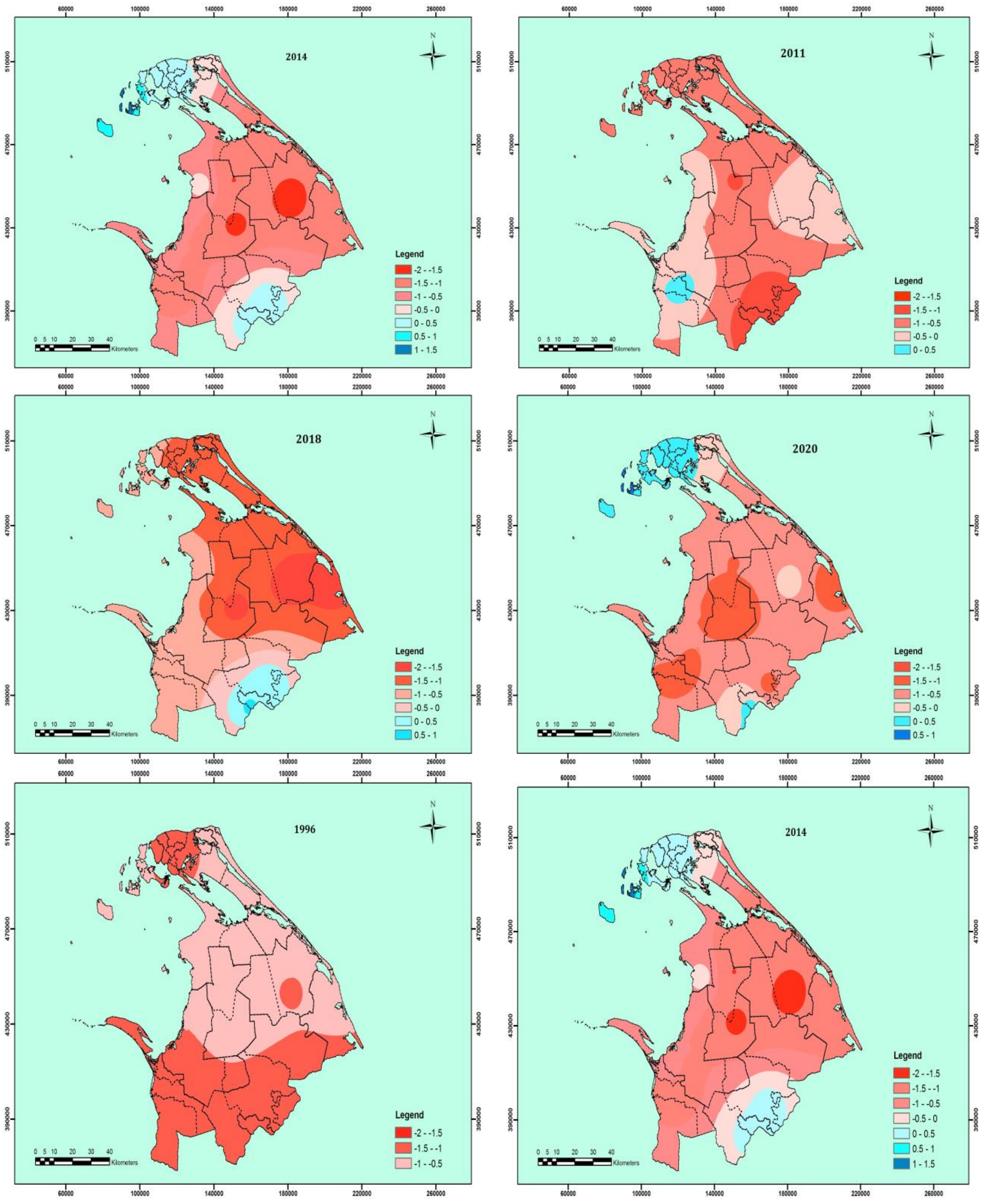


Figure 6: Spatial variations of SPI-3 during the SWMS in the selected years

Table 8: Details of Drought and Flood of Every Station during the SWMS

Station	No. of Floods	Severity of Times	No. of Droughts	Severity of Times
Akkarayankulam	2	1 in 21 years	9	1 in 5 years
Ambalaperumalkulam	3	1 in 14 years	4	1 in 10 years
Iranamadu	2	1 in 21 years	6	1 in 7 years
Kanukkerny	3	1 in 14 years	5	1 in 8 years
Karukkaikulam	3	1 in 14 years	4	1 in 10 years
Murungan	3	1 in 14 years	6	1 in 7 years
Muthaiyan kaddu	2	1 in 21 years	4	1 in 10 years
Nainathivu	3	1 in 14 years	6	1 in 7 years
Pallavaryankaddu	3	1 in 14 years	2	1 in 21 years
Pavatkulam	3	1 in 14 years	4	1 in 10 years
Thirunlveli	3	1 in 14 years	3	1 in 14 years
Vavunikulam	3	1 in 14 years	7	1 in 6 years
Vavuniya	4	1 in 10 years	6	1 in 7 years

DISCUSSION

The Northern region of Sri Lanka exhibits significant susceptibility to the repercussions of climate change, particularly in relation to agricultural practices. Numerous studies are indicative of the anticipated escalation in rainfall and temperature within the Northern Province, surpassing that of the other provinces. The temperature within the study area has witnessed a notable augmentation of 0.84°C between the years 1992 and 2022. Furthermore, a mere 15mm increase in precipitation has been discerned within the Northern Province of Sri Lanka. Alas, there has been a lamentable decline in the number of rainy days by 21. Should the annual total rainfall remain unchanged, this decline in rainy days shall induce a heightened intensity of precipitation for each day. In other words, the escalation in daily rainfall intensity is the underlying cause of flooding within the low-lying regions of the territory. Moreover, the ascending temperatures are responsible for the occurrence of droughts within the Northern Province of Sri Lanka. These prevailing circumstances are anticipated to persist and further exacerbate the climatic perils experienced within the Northern Province of Sri Lanka in the foreseeable future.

It is important to note that climate change adds complexity to the spatial pattern of floods and droughts. With changing climate trends, the frequency, intensity, and duration of these events may be altered, making it crucial to integrate climate change projections into future risk assessments. Rising sea levels associated with climate change also increase the vulnerability to coastal flooding in the Northern Province.

The spatial pattern of floods and droughts refers to the distribution and occurrence of these extreme weather events across different areas. Understanding this pattern is crucial for effective disaster management, water resource planning, and agricultural practices(Grover et al., 2022). Floods and droughts exhibit distinct spatial characteristics due to their underlying causes and contributing factors(De Alwis & Noy, 2019). Flooding typically occurs when there is an excessive amount of rainfall, overwhelmed drainage systems, or the overflow of rivers and other bodies of water. It can be influenced by topography, soil permeability, vegetation cover, and human activities like deforestation and urbanization. Floods often show a localized pattern, affecting specific regions or areas adjacent to rivers or low-lying areas. On the other hand, droughts are often characterized by long periods of below-average precipitation and high evaporation rates, leading to water scarcity(Manawadu & Wijeratne, 2021). Unlike floods, droughts can have a more widespread spatial extent, affecting large regions or even entire countries. These dry conditions can be influenced by atmospheric circulation patterns, such as El Niño and La Niña, as well as climate change. Factors like soil moisture, vegetation health, and groundwater availability also play a significant role in the development and persistence of droughts(Ullah et al., 2022).

The Northern Province of Sri Lanka experiences both floods and droughts, which have a significant impact on the region's socio-economic and environmental conditions. The spatial pattern of these events can be attributed to various factors, including topography, climate patterns, land use practices, and human interventions. Floods in the Northern Province primarily occur during the northeast monsoon season, which typically spans from October to January. This monsoon brings heavy rainfall to the region, resulting in the swelling of rivers and water bodies. The flat topography of the area, combined with inadequate drainage systems, often exacerbates flooding situations. Low-lying regions, such as the Jaffna Peninsula and parts of the Vanni region, are especially vulnerable to inundation. In terms of droughts, the Northern Province faces water scarcity during the dry season, which generally extends from May to September. The region's semi-arid climate and irregular rainfall patterns contribute to prolonged dry spells. Droughts can be intensified by climate phenomena such as El Niño, which disrupts the normal rainfall patterns. Additionally, increasing water demand due to agricultural practices and the growing population further exacerbate the situation.

The spatial distribution of flood and drought events can vary within the Northern Province(Piratheeparajah, 2016). For instance, the eastern coastal areas, including Trincomalee and Batticaloa districts, often experience significant flooding due to their proximity to the east coast and the influence of cyclonic weather systems. On the other hand, the Jaffna Peninsula and the Mannar district are prone to both floods and droughts due to their geographical location and limited access to water resources. It is important to note that human intervention, such as dam construction, irrigation projects, and land reclamation, can also impact the spatial pattern of floods and droughts. These activities can modify the natural water flow and disrupt local ecosystems, potentially increasing the occurrence and severity of such events. To effectively manage and mitigate the impacts of flood and drought events in the Northern Province, it is crucial to adopt a multidimensional approach. This includes implementing better flood control measures, enhancing drainage systems, promoting sustainable water management practices, improving forecasting and early warning systems, and incorporating climate-resilient strategies into land use planning. Additionally, community awareness, education, and capacity building initiatives can empower the local population to cope with and adapt to these challenges.

Occurrences of floods and droughts have been identified in the study area through the adoption of the Standardized Precipitation Index (SPI). Normal and severe floods and droughts did not create much socio-economic impact during such occurrences. However, extreme floods (over +2.00) and droughts (over -2.00) had a significant socio-economic impact. The NEMS & SIMS showed a higher number of floods, while SWMS showed a higher number of droughts according to the SPI. The Northern Region of Sri Lanka receives significant rainfall due to the North East monsoon wind burst in NEMS and SIMS, which creates intense rainfall within a short period, leading to flood vulnerability. Moreover, during these seasons, a number of cyclones have occurred, which result in heavy rainfall within a short period and consequently, the Northern Region of Sri Lanka experiences SPIs over +1.00. On the other hand, SWMS typically gets very little rainfall, which is not more than 75mm. Although the area receives significant rainfall resulting in flood vulnerability during some years, the impact is less than that of the NEMS and SIMS occurrences. During the First Inter Monsoon Season (FIMS), flood situations have been identified in the study area due to the influence of the Inter-Tropical Convergence Zone (ITCZ) and cold air masses movement from the Bay of Bengal. The heavy rainfall during this season is within a short period, leading to flood vulnerability and an SPI in flood level in some months.

Drought during the SIMS, NEMS, and FIMS in the Northern Region of Sri Lanka is caused mainly due to delayed rainfall. Annually, some years receive less rainfall than average, resulting in drought, while some years receive much more than average, resulting in floods. This has been the trend in all seasons at all stations. Over the past 52 years in the study area from 1972 to 2022, Kanukkerny Thirunelveli, Pavtkulam, Vavuniya, and Iranamadu have witnessed the most number of floods (annual and all seasons), while Karukkiakulam, Nainathivu, Murungan, and Vavunikkulam have witnessed the most number of droughts (annual and all seasons).

There exists an intriguing pattern in the spatial distribution of flood and drought within the study area. Flood begins in the eastern region of the Northern area and progresses towards its western counterpart. Conversely, droughts originate on the western coastlines of the Northern region before gradually moving eastwards. A similar trend can be observed during NEMS rainfall, commencing on the Eastern coastline, and throughout SWMS high temperatures are observed on the Western coastlines of Northern Sri Lanka prior to gradually shifting to its Eastern territory. As per the analysis of SPI, the occurrence of floods and droughts in Northern Sri Lanka exhibits discernible spatial variations. The number of annual/seasonal (all seasons) occurrences of droughts and floods in the Western region of the study area was higher than that of the Eastern region; this is due to the Eastern area facing the Bay of Bengal whilst the Western part resides in its shadow. The areas plagued by droughts tend to progress in a westerly direction, whilst flood occurrence tends to increase from west to east based on the frequency of occurrence. For instance, Muththaiyan Kaddu station and Vavunikkulam have a greater number of drought and flood occurrences respectively than Kanukkerny station. Similarly, Akkarayankulam surpasses Iranaimadu station in the incident of drought, whereas in regards to drought frequency, Ambalapperumal supersedes Akkarayankulam. Finally, Pallavaraykaddu has a higher frequency of drought when compared to Ambalpperumalkulam station whilst Murungan station has more drought occurrences than Vavuniya station, thus signifying a progression in drought occurrences from east to west. Following figures elaborated the spatial patterns of number of drought and flood occurrences.

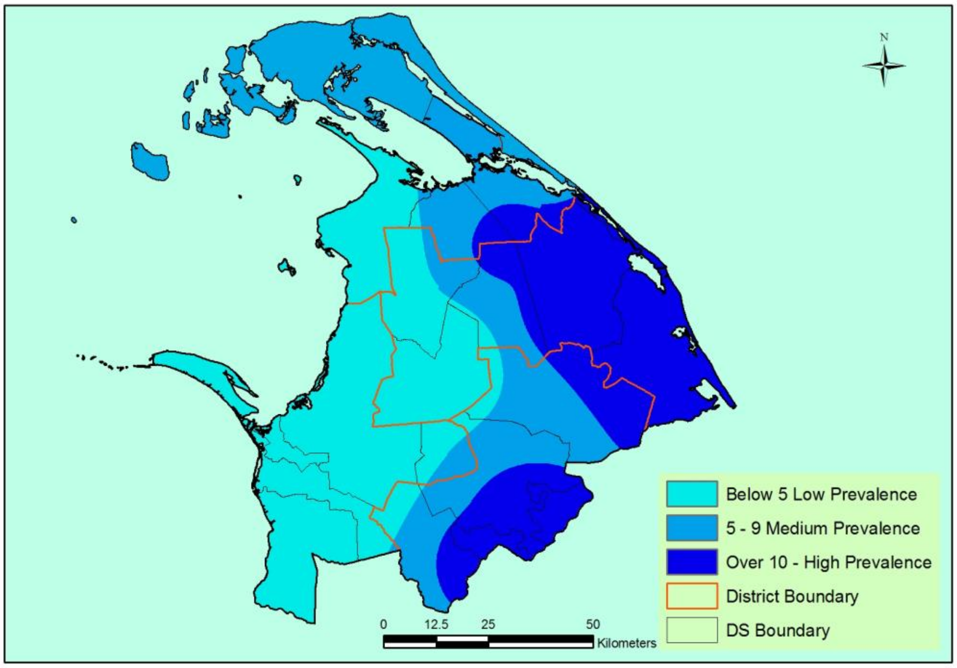


Figure 7: Spatial Pattern of Flood Occurrences in the Northern Region of Sri Lanka during the last 52 years (1972 to 2022)

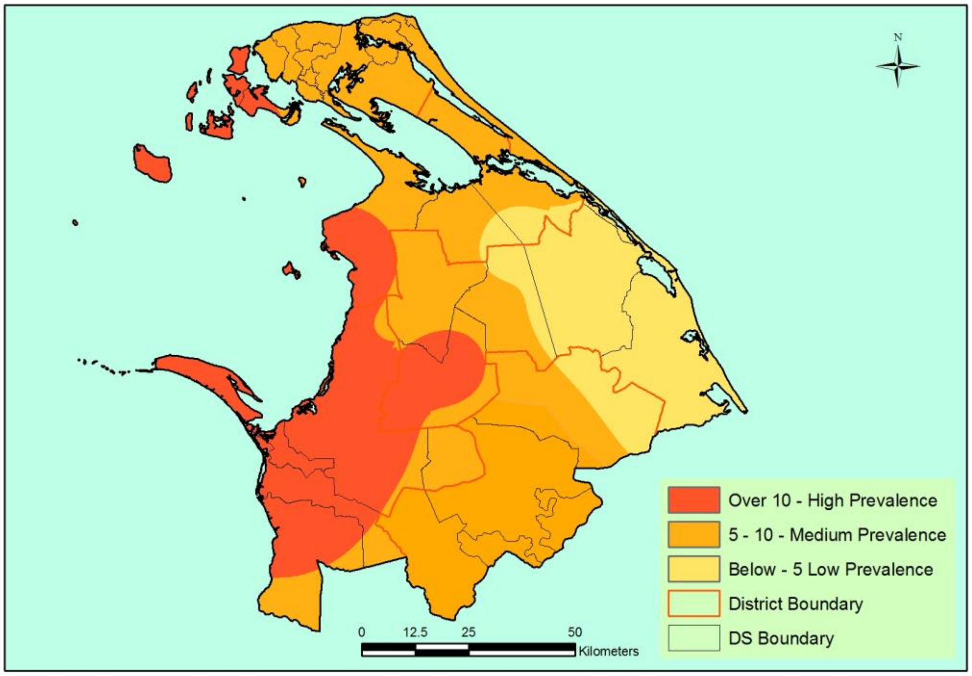


Figure 8: Spatial Pattern of Drought Occurrences in the Northern Region of Sri Lanka during the last 42 years (1972 to 2022)

CONCLUSION

The Northern Province of Sri Lanka experiences certain spatial patterns when it comes to the occurrence of floods and droughts. Analyzing these patterns is crucial for understanding the region's vulnerability to these natural hazards. Spatially, there are variations in the climatic perils prevalent within the Northern Province of Sri Lanka. Specifically, the Eastern part of the Northern Province exhibits the highest frequency of flood hazards, while the Western part of the study area experiences a greater prevalence of droughts. Additionally, the central regions of the Northern Province are significantly impacted by thunderstorms. It is noteworthy that the drought primarily originates in the western part and gradually extends towards the eastern regions, whereas the flood hazards originate in the eastern part of the Northern Province and progress towards the western part.

With respect to the SPI classes, it is observed that the stations at Kanukkerny, Muththaiyankaddu, and Thannimurippu exhibit SPI values exceeding +2.00, denoting higher susceptibility to climatic perils. Conversely, stations such as Murungan, Pallavarayankaddu, and Karukkaikulam have been identified with SPI values below -2.00, implying a lower vulnerability to such hazards. Furthermore, when scrutinizing the seasonal analysis of the spatial pattern of climatic perils, NEMS demonstrates a more pronounced incidence of flood hazards, characterized by higher SPI values. Conversely, SWMS reveals a greater propensity for drought occurrences, as denoted by higher SPI values.

The Northern Province, comprising districts such as Jaffna, Kilinochchi, Mannar, Mullaitivu, and Vavuniya, is prone to seasonal monsoon floods, especially during the northeast monsoon (November to February). The spatial distribution of floods indicates that low-lying areas, floodplains, and regions near major rivers and their tributaries are more susceptible to flooding. River basins such as the Jaffna Lagoon basin, Kanagarayan Aru basin, and Aruvi Aru basin have experienced recurrent flooding. Floods may result from heavy rainfall, tropical cyclones, or the breaching of bunds (artificial embankments) that regulate water flow in irrigation systems. Urban areas, particularly Jaffna city, are also prone to flooding due to inadequate drainage systems and impermeable surfaces.

The Northern Province is characterized by a predominantly dry climate with a distinct dry season, which extends from May to September. The spatial pattern of droughts reveals that certain areas, mainly in the interior regions and non-irrigated zones, face more severe and prolonged drought conditions. Droughts are influenced by the southwest monsoon (May to September) and the El Niño-Southern Oscillation (ENSO) phenomena. Agricultural regions relying on rainfall-dependent farming practices, such as rain-fed cultivation, are particularly susceptible to drought-induced crop failures. Lack of adequate water storage infrastructure and over-reliance on groundwater exacerbate the impact of droughts on livelihoods and food security in the region.

Understanding the spatial patterns of floods and droughts in the Northern Province of Sri Lanka allows for informed decision-making in disaster risk reduction, land-use planning, water resource management, and climate change adaptation strategies. It is imperative for authorities and stakeholders to consider these patterns and associated factors to mitigate the adverse impacts of floods and droughts on communities and the environment in the region.

REFERENCE

Abeysingha, N. S., & Rajapaksha, U. R. L. N. (2020). SPI-Based Spatiotemporal Drought over Sri Lanka. *Advances in Meteorology*, *2020*. https://doi.org/10.1155/2020/9753279

ADB. (2022). *Climate Change Risk Profile of the Mountain Region in Sri Lanka* (Issue May).

Ahmad, M., Uniyal, S. K., Batish, D. R., Rathee, S., Sharma, P., & Singh, H. P. (2021). Flower phenological events and duration pattern is influenced by temperature and elevation in Dhauladhar mountain range of Lesser Himalaya. *Ecological Indicators, 129*, 107902. https://doi.org/10.1016/j.ecolind.2021.107902

De Alwis, D., & Noy, I. (2019). The cost of being under the weather: Droughts, floods, and health-care costs in Sri Lanka. *Asian Development Review*, *36*(2), 185–214. https://doi.org/10.1162/adev_a_00136

Eberenz, S., Lüthi, S., & Bresch, D. N. (2021). Regional tropical cyclone impact functions for globally consistent risk assessments. *Natural Hazards and Earth System Sciences*, *21*(1), 393–415. https://doi.org/10.5194/nhess-21-393-2021

Eckstein, D., Künzel, V., & Schäfer, L. (2021). Global climate risk index 2021: who suffers most from extreme weather events? Weather-related loss events in 2019 and 2000–2019. In *Germanwatch* (Issue March). http://germanwatch.org/en/download/8551.pdf

Fung, K. F., Huang, Y. F., & Koo, C. H. (2020). Assessing drought conditions through temporal pattern, spatial characteristic and operational accuracy indicated by SPI and SPEI: case analysis for Peninsular Malaysia. In *Natural Hazards* (Vol. 103, Issue 2). Springer Netherlands. https://doi.org/10.1007/s11069-020-04072-y

Grover, S., Tayal, S., Sharma, R., & Beldring, S. (2022). Effect of changes in climate variables on hydrological regime of Chenab basin, western Himalaya. *Journal of Water and Climate Change*, *13*(1), 357–371. https://doi.org/10.2166/wcc.2021.003

Ha, T. V., Huth, J., Bachofer, F., & Kuenzer, C. (2022). A Review of Earth Observation-Based Drought Studies in Southeast Asia. *Remote Sensing*, *14*(15), 1–31. https://doi.org/10.3390/rs14153763

Jiang, T., Su, X., Singh, V. P., & Zhang, G. (2021). A novel index for ecological drought monitoring based on ecological water deficit. *Ecological Indicators, 129*, 107804. https://doi.org/10.1016/j.ecolind.2021.107804

Kaklauskas, A., Amaratunga, D., Haigh, R., Binkyte, A., Lepkova, N., Survila, A., Lill, I., Tantaee, S., & Banaitis, A. (2018). A model and system for an integrated analysis of the iterative life cycle of university-industry partnerships. *Procedia Engineering*, *212*(2017), 270–277. https://doi.org/10.1016/j.proeng.2018.01.035

Knoesen, D. M. (2012). Integrating hydro-climatic hazards and climate changes as a tool for adaptive water resources management in the Orange river catchment. *School of Bioresources Engineering and Environmental Hydrology*, *May*, 234.

Kuttippurath, J., Murasingh, S., Stott, P. A., Balan Sarojini, B., Jha, M. K., Kumar, P., Nair, P. J., Varikoden, H., Raj, S., Francis, P. A., & Pandey, P. C. (2021). Observed rainfall changes in the past century (1901–2019) over the wettest place on Earth. *Environmental Research Letters*, *16*(2). https://doi.org/10.1088/1748-9326/abcf78

Li, Y., Chen, Y., Sun, F., & Li, Z. (2021). Recent vegetation browning and its drivers on Tianshan Mountain, Central Asia. *Ecological Indicators*, *129*, 107912. https://doi.org/10.1016/j.ecolind.2021.107912

Liao, X., Song, T., Xiong, Y., Zou, D., Wang, K., Du, H., & Zhao, J. (2021). Soil nematode communities on five oceanic islands across a latitudinal gradient in the north of the South China Sea: Influence of biotic and abiotic factors. *Ecological Indicators*, *129*. https://doi.org/10.1016/j.ecolind.2021.107619

Manawadu, L., & Wijeratne, V. P. I. S. (2021). Anthropogenic drivers and impacts of urban flooding- A case study in Lower Kelani River Basin, Colombo Sri Lanka. *International Journal of Disaster Risk Reduction*, *57*(April 2020), 102076. https://doi.org/10.1016/j.ijdrr.2021.102076

Mehta, D., & Yadav, S. M. (2021). An analysis of rainfall variability and drought over Barmer District of Rajasthan, Northwest India. *Water Supply*, *21*(5), 2505–2517. https://doi.org/10.2166/ws.2021.053

Meinshausen, M., Nicholls, Z. R. J., Lewis, J., Gidden, M. J., Vogel, E., Freund, M., Beyerle, U., Gessner, C., Nauels, A., Bauer, N., Canadell, J. G., Daniel, J. S., John, A., Krummel, P. B., Luderer, G., Meinshausen, N., Montzka, S. A., Rayner, P. J., Reimann, S., … Wang, R. H. J. (2020). The shared socio-economic pathway (SSP) greenhouse gas concentrations and their extensions to 2500. *Geoscientific Model Development*, *13*(8), 3571–3605. https://doi.org/10.5194/gmd-13-3571-2020

Nagamuthu, P., & Rajendram, K. (2015). Occurrences of Flood Hazards in the Northern Region of Sri Lanka. *J. S. Asian Stud*, *03*(03), 363–376. http://www.escijournals.net/JSAS

Piratheeparajah, N. (2016). Temporal and Spatial variation of the Atmospheric Temperature of the Northern province of Sri Lanka. *The International Journal Environmental Science*, *5*(5), 63–67.

Ullah, I., Ma, X., Ren, G., Yin, J., Iyakaremye, V., Syed, S., Lu, K., Xing, Y., & Singh, V. P. (2022). Recent Changes in Drought Events over South Asia and Their Possible Linkages with Climatic and Dynamic Factors. *Remote Sensing*, *14*(13). https://doi.org/10.3390/rs14133219

Yan, Y., Mao, K., Shen, X., Cao, M., Xu, T., Guo, Z., & Bao, Q. (2021). Evaluation of the influence of ENSO on tropical vegetation in long time series using a new indicator. *Ecological Indicators*, *129*, 107872. https://doi.org/10.1016/j.ecolind.2021.107872