CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

This chapter covers the various research works carried out in the field of various types of drought and analysis of its different drought indices. The review of works is classified into different domains, viz. meteorological drought, hydrological drought and agricultural drought. Additionally, Literature of drought frequency analysis and trend analysis test is carried out. Also, development of drought forecasting models is also studied.

2.2 LITERATURE REVIEW ON METEOROLOGICAL DROUGHT ANALYSIS

2.2.1 Literature review on PN, PD, and DI

In rain-fed agriculture, rainfall has a crucial role to play for suitable crop planning. **Ray et al. (2012)** analysed rainfall data for Twenty eight years (1983-2010) for daily, weekly, monthly, seasonal and yearly meteorological drought occurrence at Barapani station of Ri-Bhoi district, Meghalaya. The average annual rainfall of Barapani worked out to be 2,410.40 mm (coming under high rainfall region). The frequency of drought was the highest in 28th week in a tune of 11 times; month of December to a tune of about 14 times. Based on rainfall analysis it was found that during 28 years no scanty drought year was experienced. However, they concluded that there was one moderate drought year which corresponds to the year 1998. Critical dry spells expected to occur during 26th to 28th week of the year.

Drought is a climatic anomaly, characterized by shortage (lack) of rainfall, high evaporation and unsuitable distribution of rainfall. **Nohegaret et al. (2015)** investigated and compared the Standardized Precipitation Index (SPI), Percent Normal Precipitation Index (PNPI) and Deciles Index (DI) indices for drought monitoring in Kahurestan watershed in Hormozgan province in south of Iran. The rainfall data of five stations including Kahurestan, Tedrouye, Dezhgan, Ghalat and Shahgeyb were selected from 1985 to 2010 (26 years). The SPI, PNPI and DI are compared in different stations. Results shows that PNI index due to determine the frequency of droughts and also, accurate showing of drought years with different severities, it is categorized in the first place and DI and SPI are categorized in next place, respectively.

Drought is a natural hazard due to adverse effects in climate change in earth's environment. Drought assessment is very important to manage water resources in lean period. **Mistry and Suryanarayana (2019)** analysed drought years and degree of deficit of annual rainfall are determined by use of Standardized Precipitation Index (SPI-3 to 12 Months), and Percentage Departure from mean (PD) methods. For this study, monthly rainfall data of 102 years (1901–2002), of Banaskantha District, were used. The months of January, February, March, April, May, November, and December have been identified 68, 73, 78, 71, 68, 81, and 79 times as drought months, respectively, in the twentieth century, indicating that these months must be provided with assured Irrigation. From the annual rainfall departure analysis, the drought years have been identified and it is observed that 1901, 1904, 1911,1915,1923,1939,1969, 1987, and 2002 are affected by severe drought and 1974 is affected by extreme drought condition. The study also reveals that 6, 15, and 15% of extreme dry years, severe dry years, and moderate dry years occur among drought years considered, which means 36% years are categorized into moderate to extreme drought years out of the total drought years.

Drought is called a creeping disaster because of the way it develops. It can be categorized as meteorological, hydrological, agriculture and socioeconomic drought. In the present study **Karinki and Sahoo (2021)** studied, meteorological data in terms of monthly rainfall for 45 years (from 1971 to 2016) were used for identification of drought in Anantapur district of Andhra Pradesh in India. Different drought indices like percentage of departure, percent of normal, decile and Standardized Precipitation Index (SPI) were derived. Percentage of departure is identified based on rate deviation of yearly precipitation from the long-term yearly mean precipitation. Percent of normal is obtained by dividing the precipitation by normal precipitation for the time being considered. It interprets the deficient of rainfall from wet season to dry season and vice versa as precipitation deviation from the normal annual precipitation. Decile is calculated by interpolation technique based on ranking given to the rainfall distribution. SPI values were generated based on gamma distribution of precipitation data. Compared with other indices, SPI shows better variation with small change in precipitation because of its statistical nature. Therefore, it is suggested that SPI as a stand-alone indicator needs to be interpreted with caution to assess the intensity of drought.

2.2.2 Literature review on SPI and RDI

Drought is one of the most important natural hazards in Iran and frequently affects a large number of people, causing tremendous economic losses, environmental damages and social hardships. Especially, drought has a strong impact on water resources in Iran. **Zarch et al. (2011)** focused on two important indices; SPI and RDI, for 3, 6, 9, 12, 18 and 24 months' time scales in 40 meteorological synoptic stations in Iran. In the case of RDI computation, potential evapotranspiration was an important factor toward drought monitoring. So, evapotranspiration was calculated by Penman-Monteith equation. The correlation of RDI and SPI was also surveyed. Drought severity maps for SPI and RDI were also presented in the driest year (1999–2000). The present results have shown that the correlation of SPI and RDI was more considerable in the 3, 6 and 9 months than longer time scales. Furthermore, drought severity maps have shown that during 1999–2000, the central, eastern and south-eastern parts of Iran faced extremely dry conditions. While, according to SPI and RDI trends, other parts of the country suffered from severe drought. The SPI and RDI methods showed approximately similar results for the effect of drought on different regions of Iran. Since, RDI resolved more climatic parameters, such as evapotranspiration, into account which had an important role in water resource losses in the Iranian basins, it was worthwhile to consider RDI in drought monitoring in Iran, too.

Drought was a natural phenomenon which differs from other natural hazards by its slow accumulating process and its indefinite commencement and termination. **Das et al. (2012)** discussed about water deficiency and drought occurrence over Kutch district, Gujarat, because nearly 45% of the whole Kutch district was severely suffering by deficiency of water. Earth observation data (LANDSAT ETM+) and Standardized Precipitation Index were used to analyze drought severity. Daily rainfall data over the study area were obtained from Indian Meteorological Department (IMD) for the period of study (1990-2014) and geo-referenced for further analyses. Using Remote Sensing and GIS techniques, rainfall variability map over the period of study has been prepared to show rainfall distribution and land use and land cover map is prepared to show the area under different land use classes and impacts of drought over land uses. Standardized Precipitation Index (SPI) was generated for each block wise and scenario of drought development has been analyzed using decadal data set for the study period (1990-2014). The present study suggests method and techniques for continuous drought monitoring by linking temporal earth observation and rainfall data. The methodology will be very useful for the development of a regional drought monitoring system.

Drought is a complex phenomenon which can be characterised mainly by its severity, duration and areal extent. Amongst these three dimensions, drought severity is the key factor which can be used for drought analysis. Drought indices are typically used to assess drought severity in a meaningful way. DrinC (Drought Indices Calculator) is a software package which was developed for providing a simple, though adaptable interface for the calculation of drought indices. **Tigkas et al. (2015)** aims at presenting the overall design and the implementation of the software along with the utilisation of various approaches for drought analysis. DrinC can be used for the calculation of two recently developed indices, the Reconnaissance Drought Index (RDI) and the Streamflow Drought Index (SDI), as well as two widely known indices, the Standardised Precipitation Index (SPI) and the Precipitation Deciles (PD). Moreover, the software includes a module for the estimation of potential evapotranspiration (PET) through temperature based methods, useful for the calculation of RDI. The software may be used in a variety of applications, such as drought monitoring, assessment of the spatial distribution of drought, investigation of climatic and drought scenarios, etc. The applications of

DrinC in several locations, especially in arid and semi-arid regions, show that it is gaining ground as a useful research and operational tool for drought analysis.

Chronological series of monthly and annual precipitation data recorded in Gabes Watershed, south-eastern Tunisia, were analyzed by **Jemai et al. (2016)** computed rainfall data over the period 1987–2012 with 10 raingauge stations, which corresponds to an observatory period of 25 hydrologic years (from September to August). The results obtained show a great variability in SPI values. The historical evolution of the SPI made it possible to define the periods of excess and deficit, corresponding to wet and dry periods respectively. The wet years were found to be 1989–1990, 1995–1996 and 2006–2007 while the dry years were1987–1988, 1996–1997, 2000–2001, 2001–2002, 2007–2008, 2008–2009 and 2009–2010. The results clearly shows that alternating wet and dry periods, but with drought episodes taking prevalence over rainy fronts throughout the study period. Indeed, a high tendency towards a drop in precipitation and important sequences of drought were observed. Spatial variability of drought throughout Gabes Watershed was examined by geostatistical analysis of SPI, as drought and rainfall distribution vary with latitude, longitude, topography and proximity to the Mediterranean Sea. Also, results obtained showed that, compared to coastal and southern areas, drought was observed to be more important in the West and the North of Gabes Watershed. The SPI showed that moderate droughts are generally more frequent than severe or extreme droughts in most of the Watershed.

Patel et al. (2017) studied floods and droughts which requires the knowledge of wet and dry event sequences. These are the two important extreme conditions which directly or indirectly affects every field of environmental science. These extreme conditions are due to the change in one, of the many but most important parameter, rainfall. The standardized precipitation index is designed to quantify the rainfall for multiple time scales. These time scales reflect the impact of drought/floods on the availability of the different water resources. The modified classification by Agnew is referred for the classification of wet and dry events during the 20th Century for Surat district. The monthly rainfall data from 1901 to 2000 is utilized to determine the SPI values. SPI was calculated for 4, 6, 12, 24 and 48 months' time scales. The area experienced more than 20% years of dry and wet events for the 20th Century. It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for all the time scale. Year 1998 is identified as moderate wet event for all time scale. Years 1936 and 1987 are identified as severe dry events and year 1935 is identified as moderate dry event for all the time scales. No extreme wet event was observed. For extreme dry scenario all the years identified for different time scales are different.

2.2.3 Literature review on SPEI, CZI and MCZI

Wu et al. (2001) studied the Standardized Precipitation Index (SPI) to detect drought and wet periods at different time scales, an important characteristic that is not accomplished with typical drought indices. More and more users employ the SPI to monitor droughts. Although calculation of the SPI is easier than other drought indices, such as the Palmer Drought Index, it is still relatively complex. In China, an index called the China-Z Index (CZI) has been used since 1995 by the National Climate Centre of China to monitor moisture conditions across the country. The calculation of this index is easier than the SPI. A third index, the statistical Z-Score, can also be used to monitor droughts. This paper evaluates the SPI, CZI and Z-Score on 1-, 3-, 6-, 9- and 12-month time scales using monthly precipitation totals for four locations in China from January 1951 to December 1998 representing humid and arid climates, and cases of drought and flood. Advantages and disadvantages for the application of each index are compared. Study results indicate that the CZI and Z-Score can provide results similar to the SPI for all time scales, and that the calculations of the CZI and Z-Score are relatively easy compared with the SPI, possibly offering better tools to monitor moisture conditions.

Drought is a natural phenomenon. It has negative impact on agriculture, ecosystem and livelihood. Standardized Precipitation–Evapotranspiration Index (SPEI) is a new drought index. It considers the rainfall and evapotranspiration to index drought. SPEI base (model) data for 110 years (1901-2011) were utilized by **Abdullah (2014)** for understanding drought evolution in Bangladesh. Twenty eight (28) weather station locations of Bangladesh Metrology Department (BMD) were considered for the analysis and mapping of drought. SPEI data were classified for severe and extreme drought event. Inverse Distance Weight (IDW) method was used to interpolate the point data for spatial mapping of drought severity. It is evident that SPEI can identify drought prone area, duration, onset, extent and end. The finding shows that North Eastern part of Bangladesh is more vulnerable to both extreme and severe drought event. SPEI can be an important tool to understand the climate change induced drought evolution and assessment in Bangladesh.

Pius and Marszelewski (2014) assessed variability of moisture conditions over the years 1961-2005 using the Standardized Precipitation Index (SPI), Standardized Precipitation Evaporation Index (SPEI), and runoff conditions using the Standardized Flow Index (SFI). The examination focused upon the drainage basin of the Drwęca River and its two inflows. The values of the indices were determined in the cycles of 1, 3 and 12 months. Seven precipitation stations, one air temperature measurement station and three hydrological stations were used and analysed that 1961-2005 there was no regularity in the occurrence of wet and dry periods. All the data of the Mann Kendall trend were statistically insignificant. In the case of the SPEI positive statistics (Z) was obtained. Though it was not statistically significant it may inform of upcoming changes to the existing hydro climatic cycle. The correlation between the indices with respect to the monthly values was not statistically significant. That results from the influence of the conditions prevailing in the drainage basin upon transformation of precipitation into runoff. Only the Rypienica River, with the smallest underground inflow, showed correlation indices at the limit of significance. In a longer time period, i.e. from 3 to 12 months, the correlations of indices were statistically significant.

Adnan et al. (2018) studied various drought indices are to monitor drought and its risk management. Precipitation, temperature and other hydro meteorological parameters are the essential parts to the identification of drought. Several drought indices have been developed and are being used around the world. This study identifies the applicability and comparison of drought indices in Pakistan by evaluating the performance of 15 drought indices. The indices include standardized precipitation index, standardized precipitation temperature index, standardized precipitation evapotranspiration index, China Z-Index, deciles index, modified CZI, Z-Score, rainfall variability index, standardized soil moisture anomaly index, weighted anomaly standardized precipitation index, percent of normal precipitation index, self-calibrated Palmer drought severity index, composite index, percentage area weighted departure and reconnaissance drought index. These indices are compared by utilizing long term data of 58 meteorological stations for the period 1951–2014. The performance, efficiency and significance are also tested by applying different statistical tests. The SPI, SPEI and RDI results showed a good capability to monitor drought status in Pakistan. The positive increasing trend (towards wetness) is noted by several of the aforementioned indices at 95% confidence level.

2.2.4 Literature review on Climatic Index

The Crişurilor Plain is located in the West of Romania and is characterized by moderate wet climate; the average of the agricultural years 1975-2000 were 624.8 mm, for rainfall and 10.2ºC, for temperature. The characterization of the drought periods carried out by **Sabău et al. (2002)** studied different climate indexes (de Martonne aridity index, IdM; Seleaninov hydrothermic index, IhS; Donciu climate index, IcD; Domuţa hydroheliothermic index, IhD; Palfai aridity index, PAI) indicates the big variation of the drought periods in function of the index. The correlations established between the assured rainfall (A %) for years and for warm season and climate indexes had the polynomial expression, statistically very significant. The best correlations were registered in maize, following cabbage and wheat crops. There was a tendency of the increase for the correlation coefficient calculated for warm period. The best model at was obtaining in wheat with de Martonne aridity index (IdM, R^2=0.7218), calculated for warm season; in maize with Palfai aridity index (PAI, R^2=0.8153), calculated for warm season and in cabbage with Domuţa hydroheliothermic index (IhD, R^2=0.7945), calculated for agricultural year.

Analysis of drought is very important for the irrigation purpose of a country. **Keka et al. (2012)** analysed drought in the eastern part of Bangladesh and by comparing the yearly rainfall deficiency with the mean yearly rainfall. Yearly drought analysis has also been performed by three climatic indexes. The climatic indexes are De Mortone

Aridity Index, IdM; Seleaninov Hydrothermic Index, IHS; and Donciu Climate Index, IcD. With the help of annual rainfall assurance (A %) yearly drought analysis has been performed by the climatic indexes. Monthly drought analysis has been done with the rainfall data, considering average rainfall and minimum rainfall for a month. In this study 17 meteorological stations have been chosen for analysis. Distribution of rainfall, annual variation of rainfall, yearly drought and percentage of drought affected areas has been presented with the help of different Figures and Tables. Monthly drought analysis shows that generally the month of January, February, March, November and December are drought affected. The month of April faces drought almost every year. May and October face drought occasionally. The months June, July, August and September experience heavy rainfall.

Erratic temporal distribution, highly intensive precipitation and rampant erosion are of major concern for Bangladesh in recent years. **Alam and Sarker (2014)** studied the distribution of precipitation and erosion all over Bangladesh by means of two climate change related precipitation indices named Precipitation Concentration Index (PCI) and Modified Fournier Index (MFI). These indices were calculated by using monthly precipitation records from 18 observatory stations all over Bangladesh for the period of 1981-2010. Mann-Kendall trend test was executed to analyze the trend and Sen's slope method to determine the magnitude of changes for both indices. PCI values depict irregular distribution of precipitation all over the country and mostly negative changes. On the other hand MFI values indicate extreme erosion all through and mostly positive changes for the study period.

Trends and variability of annual precipitation total, annual number of rainy days and two climate change related precipitation indices named Simple Daily Intensity Index (SDII) and Precipitation Concentration Index (PCI) have been investigated by **Iskander et al. (2014)** using daily and monthly precipitation data of 35 observatory stations all over Bangladesh for the study period of 1971-2010. Mann Kendall test was performed to detect the trend and Sen's slope method to determine the magnitude of change. The results indicates statistically significant (95% confidence level) negative trend in 4 stations and significant positive trend in 2 stations for annual precipitation total. Significant positive trend in 9 stations for annual number of rainy days, significant negative trend in 6 stations for SDII and for PCI, and significant negative trend in 6 stations were found all over Bangladesh in this study. The values of PCI indicate strongly irregular precipitation distribution in South Eastern Region (SER) and mostly irregular distribution in other regions. On the other hand values of SDII indicate strong precipitation intensity in SER and mostly moderate intensity in other regions all over the country.

2.2.5 Literature review on Aridity Indices

Choudhary et al. (2013) demonstrates meteorological based drought indices such as Normalized Deviation (ND), De Martonne's Index (IA), Pluvothermic Quotient

(PQ), Negative Moisture Index (NMI) and Standard Precipitation Index (SPI) values to get the spatial pattern of meteorological based drought. Crop yield and production trend was plotted and an equivalent Normalized Difference Vegetation Index (NDVI) threshold was identified to get the agricultural drought risk in Jodhpur district, where the occurrence is high in Jodhpur district. Monthly rainfall data from six stations were used to derive the Standardized Precipitation Index (SPI). The Landsat-7 ETM+ and Landsat-5 TM satellite sensor data was used for calculating Brightness Temperature (BT), Land Surface Temperature (LST). BT was converted to the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI), which are useful indices for the estimation of vegetation health and drought monitoring. The analysis was carried out for a period of 21 years (1991–2011) and from the SPI analysis it is found that in 2002 all of the area under study was affected by drought with greater intensity, can be classified as extreme and severe drought conditions.

Due to rapid growth of population, massive deforestation and anthropogenic activities, noticeable change in climate conditions is being observed in Pakistan. Increased aridity due to climate change is a growing environmental problem of the agricultural. It is essential to assess and monitor aridity to combat the probable land degradation and drought desertification. Identification of arid and semi-arid regions on climatic basis is the first essential step in any project of land reclamation for agricultural and other purposes. A geographic information system is used by **Haider and Adnan (2014)** for the assessment of aridity in Pakistan from long term climatic data of fifty years (1960-2009) collected from fifty four stations situated in the country. In the delineation of climatic zones and delimitation of their boundaries, five well known aridity models viz. De Martonne Aridity index, Erinc Aridity index, Thornthwaite Precipitation Effectiveness index, UNESCO Aridity index and Thornthwaite Moisture index are utilized for this purpose. The study shows that southern parts of the country are dry and more vulnerable to drought while the northern parts have variable types of climate. Almost 75 to 85% of the total area of the country is arid in which most part lies in the south while less than 10% area is humid lies in the north of the country. This study will be a good predicator for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

In India, around 68 percent of the country's area is prone to drought in varying degrees. There are 14 districts in the state of Jharkhand covering 100 blocks with an area of 34843 sq. km (43.7 percent of the state area) which are covered under Drought Prone Area Programme (DPAP) implemented by Government of India. In rain fed agriculture scenario, which exist in the Jharkhand state of India, the rainfall occurrence is the prime deciding factor in evaluating the crop yields. Variability in the rainfall occurrence in the state primarily results due to interaction of various climatic parameters resulting in normal or erratic rainfall. **Pandey et al. (2014)** attempted study in regions of Jharkhand and select drought indices viz; Rainfall Anomaly Index (RAI), Aridity Index (IA) and Departure Index (DI) and he revealed that overall drought proneness is apparently high in Daltonganj and Chaibasa, although both of them have mild droughts in majority of the years. On the contrary in terms of moderate droughts, Dumka has the highest severity followed by Daltonganj, Jamshedpur and Dhanbad whereas Chaibasa and Ranchi has the least percentage.

Aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location. These indicators serve to identify and delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of agricultural land and water resources development. **Sawa et al. (2015)** determine the trend and map out the aridity of the drought prone areas of northern Nigeria. Three decade's (1981–2010) annual rainfall and, minimum and maximum temperature records for 11 synoptic meteorological stations were collected from NIMET Office, Lagos and used. De Martonne's aridity index formula was applied to the data and aridity indices were derived for the region. The derived aridity indices were subjected to time series analysis and classification of the region into aridity zones was carried out based on the derived aridity indices from which an aridity map of the region was produced. Results of the time series analysis show that only Kaduna indicated a decreasing aridity while the other stations exhibit a significantly positive tendency towards increasing dryness. The region is classified into four aridity zones based on the aridity indices as: slightly humid zone (Kaduna and Zaria areas), moderately arid areas (Yelwa, Gusau, Kano and Bauchi), semi-arid regions (Sokoto, Potiskum, Maiduguri) and the arid zone (areas around Nguru, Hadejia and Kano). It is concluded that the drought prone areas of northern Nigeria are witnessing increasing aridity which accounts for the shrinking of most dams and other surface reservouirs in the region. This has necessitated accessing of underground water from even the third aquifer at some locations.

2.3 LITERATURE REVIEW ON HYDROLOGICAL DROUGHT ANALYSIS

2.3.1 Literature review on NDWI and MNDWI

The impact of meteorological and hydrological drought on groundwater resources in coastal deserts in the south of Iran was investigated during 1991-2011, using Standardized Precipitation Index (SPI), Standardized Runoff Index (SRI), and Groundwater Resources Index (GRI). **Bazrafshan et al. (2016)** showed wet and drought spells governed the area in the first and second decades, respectively, which was similarly reflected by the three indices; GRI had a good correlation with SPI and SRI in 48-month time scale. This correlation was simultaneously in the eastern and western coasts and with a 6 months delay in the central plains. The findings can help to provide reasonable managerial strategy in relation to water resources management in the coastal plains.

Drought is a natural disaster that occurs when water availability is significantly below the normal levels during a significant period of time and cannot meet the demand. **Soumyashri and Patil (2016)** focused on hydrological drought assessment in Bhima sub basin, which receives rainfall annually, but in dry season some of the areas start to become drought. This also due to the fact of large difference between river flows during the wet and dry seasons, which is significantly influenced by precipitation, resulting in hydrological drought. It consists of more reliable information's and the main factor in the decision making process. Indices for characterizing hydrological drought are, in general, data demanding and computationally intensive. A very simple and effective index, Streamflow Drought Index (SDI), has been recently proposed. It is based on cumulative streamflow volumes for overlapping periods of 3, 6, 9, and 12 months within each hydrological year at 5 hydrometric stations in Bhima sub basin over the period 1980-2010. Both long and short term drought has very severe impacts on basin. As per SDI methodology the extreme droughts occurred in long term scale (12 month scale) during period of 2008-2009.

Drought is a normal climatic feature, which affects almost all regions. It has become in recent years more intense and frequent, which has a very negative impact on the socioeconomic balance of the countries. **Boudad et al. (2017)** analysed characteristics two types of droughts in the Inouye region of northern Morocco for different time scales (3, 6 and 12 months) using the Standardized Precipitation Index (SPI) and the Stream flow Drought Index (SDI), respectively. The analysis of the trend was based on the test of Mann-Kendall (MK) and regression quantile method. The relationship between SPI and SDI has been apprehended through to the coefficients of correlation of Pearson and Spearman. The results showed that the frequency of episodes of drought varied according the time scale considered. The quantile regression reveals, compared to Mk test, a positive trend at higher quantiles and negative trend at the lower quantiles. Correlation results showed that for the 12-monthscale, there is a strong positive correlation between SPI and SDI at different periods. These results provide an overview of drought trends in the region and therefore would be very useful in applying drought adaptation policies by water resource managers.

Satellite imagery-based spectral indices are essential for monitoring natural resource changes and urban environments. Assessing these indices is vital for natural resource management and environmental sustainability. **Awasthi (2023)** implemented geospatial techniques and satellite imagery (Landsat 5 TM and Landsat 8 OLI/TIRS) to analyze changes in key spectral indices, i.e. Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), and Normalized Difference Water Index (NDWI) over the past three decades (1991–2022) in the low land region of Far Western Nepal. The study examined the temporal trends and intricate relationships between these indices during this time frame. The substantial changes in NDVI, NDBI, and NDWI within the study area have been quantified from 1991 to 2022. The findings revealed significantly elevated NDBI values in 1991, 2001, and 2013 compared to 2022, while NDWI and NDVI values were consistently lower in 1991, 2001, and 2013 compared to 2022. Notably, a negative correlation was observed between NDVI and both NDBI and NDWI, contrasting with the positive correlation found between NDBI and NDWI. The study underscores the potential of combining these spectral indices to evaluate vegetated areas, built-up areas, and water bodies, providing valuable insights for effective land management, urban planning, environmental monitoring, and sustainable water resource management.

2.3.2 Literature review on NDWI, WRI and NDSI

Renza et al. (2010) analyzed the usefulness of traditional indexes, such as NDVI and NDWI along with a recently proposed index (NDDI) using merged data for multiple dates, with the aim of obtaining drought data to facilitate the analysis for government premises. Landsat 7 ETM+ data for the month of June (2001-2009), which merged to get bands with twice the resolution. The three previous indices were calculated from these new bands, getting in turn drought maps that can enhance the effectiveness of decision making.

Hydrological drought occurs due to significant decrease in the availability of water in all its forms appearing in the land phase of the hydrological cycle. For hydrological drought analysis, examination of stream flow statistics and the run-series analysis are the widely sued techniques. However, stream flow analysis may not be effective in the river basins having non-perennial streams. **Mishra and Nagarajan (2013)** studied hydrological drought in Tel river basin covering an area of 2756 km^2 and it lies between 19° 17′ and 20° 00′ N latitude and 82° 30′ and 82° 59′ E longitude located near Bhawanipatna region of Kalahandi district of Odisha, India. The streams and channels in this area are mostly intermittent and usually dry in the non-monsoon season. Hence monitoring and analysis of water Table fluctuation has been considered for hydrological drought analysis in this study. The Standardized Water Level Index (SWI) has been developed to scale the ground water recharge deficit. The point SWI values are then spatially interpolated using the Inverse Distance Weighted (IDW) method to find out the areal extent of drought in the study area.

Helali et al. (2022) studied the effects of drought on changing water area and canopy of the Lake Urmia watershed in the northwest of Iran. For this purpose, the Standardized Precipitation Index (SPI) was calculated in short and medium periods (1-month and 3-month) to determine the dry-spell periods in the Lake Urmia basin. In reviewing this analysis, the annual average has been examined and evaluated. Furthermore, Moderate Resolution Imaging Spectroradiometer (MODIS) and remote sensing data were used to calculate the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI), the Normalized Difference Water Index (NDWI), and the Temperature–Vegetation–Dryness Index (TVDI) to identify the area of water body, water level, and vegetation changes during 20 years (2000–

2020). The Pearson correlation coefficient was also employed to explore the relationship between the drought and the remote sensing-derived indices. According to the results of drought analysis, 2000, 2002, 2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, and 2020 had experienced dry spells in the Lake Urmia basin. The NDWI changes also showed that the maximum area of the Lake Urmia happened in 2000, and its minimum was recorded in 2014. The variation of NDVI values showed that the highest values of vegetation cover were estimated to be 2,850 km2 in.2000, and its lowest value was 1,300 km2 in.2014. The maximum EVI and NDSI were calculated in 2000, while their minimum was observed in 2012 and 2014. Also, the correlation analysis showed that the SPI had the highest correlation with NDVI. Meanwhile, 1-month SPI had a higher correlation than the 3-month SPI with NDVI and EVI. As a concluding remark, NDVI and NDWI were more suitable indices to monitor the changes in vegetation and drought-related water area.

Agricultural drought is one of the most frequent natural disasters in India's southern part. Remote sensing-based drought indices give advantages in terms of continuous monitoring of land surface. The crop production in the Warangal region in India's southern part is adversely affected due to insufficient rainfall and poor irrigation management. **Tapas et al. (2022)** aims to develop a multivariate remote sensing based composite drought index (CDI) to monitor the agricultural drought. Landsat-8 satellite data for all the 11 sub regions of Warangal urban and 15 sub regions of the rural district of Telangana from 2013 to 2020 for the month of May is used to obtain drought indices. The drought indices are used in this study to develop MIDMI and are compared according to the percentage area of the Warangal region under five different drought categories. MIDMI for all the 26 sub regions of the Warangal rural and Warangal urban districts is between 0.4 and 0.6, which makes the Warangal region moderately vulnerable to agricultural drought.

2.4 LITERATURE REVIEW ON AGRICULTURAL DROUGHT ANALYSIS

2.4.1 Literature review on NDVI, VCI, VHI

Agriculture is an economic activity that is highly dependent upon weather and climate in order to produce the food and fiber necessary to sustain human life. The climate variations have direct and indirect effects on agricultural productivity. If these variations continue on a long term period, an issue of agricultural drought and food scarcity occur making agricultural productivity vulnerable. Especially, the effects of climate variation on agriculture are recurrent meteorological phenomenon affecting several parts of the world, in India too. **Nithya and Rose (2014)** studied the biophysical aspects of agricultural vulnerability using the modern methods of remote sensing and GIS. Agricultural vulnerability is determined based on Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI). SPI values of rain gauge stations are interpolated to determine the spatial pattern and threshold value of drought for agricultural vulnerability. Anomaly of the NDVI and NDWI were classified to determine the agricultural drought vulnerability. SPI, NDVI and NDWI were integrated to classify the agricultural vulnerability of the present study area namely Srivilliputhur Taluk of Virudhunagar district. From the study, it is found out that the north east part is highly vulnerable and the western part of the study area is less vulnerable to agricultural drought. The resultant map shows the spatial distribution of the areas facing agricultural drought conditions. The agricultural vulnerability map will help in the preparation of the area for mitigation measures that will in turn reduce the impacts of climate variation on agriculture.

Drought is least understood natural phenomena and it has a direct impact on livelihood. The government bodies spend time and money for drought survey, but this process is a time consuming and challenging. Advantage of Geospatial Technology is that, it is helpful to understand the drought prone area and its severity level through satellite images. This research study was focused on Vaijapur Taluka which is located at latitude of 19°40’ to 20°15’ north and longitude of 74°35’ to 75°00’ which comes under the scanty rainfall region. The annual rainfall of the region is 502.6mm which is below than an average of 750mm, so that it leads to the agriculture drought. **Gaikwad and Kale (2015)** used Landsat 8 images of the year 2013 and 2014 for drought assessment in the post monsoon season. Landsat 8 has Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) on board which provides 11 band data of the earth surface. The post monsoon season starts from October to December in India so that we have compared drought indices of two years. To do so OLI and TIRS images of Landsat 8 for the year 2013 and 2014 and ancillary data such as rainfall, temperature, sown area statistics have been used. The analysis of vegetation cover using NDVI, VCI, and SAVI indices demonstrate the impact of the post monsoon rainfall on agriculture field. According to the research study year 2013 was affected by agricultural drought.

Drought is one of the most widespread and least understood natural phenomena. **Babu et al. (2016)** monitored drought using the climatic variables like rainfall and temperature. The application of remote sensing technology for monitoring drought make the process easy and simple. The potential contribution of easily accessible satellite data to the detection and quantification of regional droughts, in the absence of reliable meteorological data, is the objective of this study. Remote sensing technology is used for monitoring drought for Anantapur district which is second driest region in the country. The Normalised Difference Vegetation Index (NDVI) and Normalised difference water index (NDWI) which are most widely used vegetation indices in recent years that measure and monitor plant growth and vegetation cover from multi-spectral satellite data are computed for Anantapur region for Monitoring drought. The conclusion of this study is NDVI index successfully monitored the drought conditions can be used to assess drought conditions instead meteorological indexes.

Droughts are very common in Bangladesh especially in the north-western part, due to geographical position, variation in Groundwater Table, and the spatial variation in seasonal rainfall pattern. In the present study, three drought indices viz., Vegetation Health Index (VHI), Temperature Vegetation Dryness Index (TVDI), and Short-wave Infrared Dryness Index (VSDI), were calculated utilizing multitemporal Landsat images. Field verification was done for the retrieved parameters needed to calculate the indices i.e., soil moisture content and Land Surface Temperature (LST). **Sultana (2021)** estimated the results derived from various indices and compared to understand the drought pattern in the study area. The VHI revealed that 2014 and 2002 were the most drought-prone year and the drought extent in this region intensified from mild to severe drought. Severe drought was found in northern Lalmonirhat, central Nilphamari, and Thakurgaon, the southern part of Dinajpur, dispersed part of Panchagarh districts and sand bars of the river. It is evident that Thakurgaon, Dinajpur, Gaibandha, and the northern part of Lalmonirhat districts face high agricultural drought risk, Nilphamari, Panchagarh, and Rangpur demonstrate medium risk, and Kuri-gram district shows slight agricultural drought risk. The drought severity was mainly triggered out due to the decreasing trend of vegetation identified by the Normalized Difference Vegetation Index (NDVI) and also for the climbing trend of LST. In the year 2018, drought mainly prevailed due to the increased amount of LST mainly in the Nilphamari district. Several regions such as dried river channels, sand bars, and uncultivated land show high drought conditions due to lack of moisture in this region and reduce water flow impeded by the upstream dams. As drought has great impacts on agriculture, it is expected that this satellite-based drought assessment will be beneficial to improve the understanding of drought in the northwestern regions of Bangladesh.

2.4.2 Literature review on SAVI, LST and TCI

In recent years, the topic of climate change in effect of greenhouse gases increase has been lionized in scientific studies. **Shamsnia and Boustani (2014)** studied meteorological parameters which is highly important in hydrology problems, since the same parameters generally form the climate of a region and is due to variations caused by water, wind, rain, etc. Drought as an environmental disaster is associated with a deficit of water resources. Satellite indices can be used for assessment of different hydrological and climate phenomena. In this research, an index called the Radiant three meteorological satellite indices (NDVI, VCI, SAVI) were used in five regions (Abadeh, Eghlid, Bavanat, Marvdashand Shiraz). The Results showed that the rain effect on vegetation is less for Marvdasht area (9 and 12 months), while it is high for Shiraz (3 months). So it is suggested that in rangelands, 6-month time scale of RDI, in forest areas, long term time scales (9 and 12 months) and in rainfed lands, short term time scales (less than 3 month) can be used for drought Monitoring.

Increasing temperature and altered precipitation patterns, leads to the extreme weather events like Drought which drastically affects the agricultural production. The agricultural drought monitoring, assessment as well as management can be done more accurately with the help of geospatial techniques like Remote Sensing. Raichur District, of Karnataka (India) falls in a plateau region and located between 15º 33' and 16º 34' N latitudes and 76º 14' and 77º 36' E longitudes. It is a drought prone region and falls within the most arid band of the country. The district relies on the traditional agricultural based economy; hence the impact of drought on the agriculture not only affects the production but also the livelihood of common man. **Sruthi and Aslam (2015)** analyzed the vegetation stress in the Raichur district with the calculation of NDVI values and the land surface temperature (LST). The MODIS data is used for the calculation of NDVI as well as Land surface temperature. The Combination of (NDVI) normalized difference vegetation index and LST, provides very useful information for agricultural drought monitoring and early warning system for the farmers. By calculating the correlation between LST and NDVI, it can be clearly noticed that they show a high negative correlation. The correlation between LST and NDVI is -0.635 for the year 2002 and -0.586 for the year 2012. The LST when correlated with the vegetation index it can be used to detect the agricultural drought of a region, as demonstrated in this work.

Agricultural drought monitoring is paramount in order to maintain food security in Indonesia, particularly in Subang and Karawang as the national rice production centres. **Rizqi et al. (2016)** studied satellite-borne remote sensing data for monitoring drought extent in about 184.486 ha of both regencies. Vegetation Health Index (VHI), a vegetative drought indices based on remote sensing data, is studied in this case using long term sequence of 2000, 2005, 2010, and 2015 dry season Landsat data. VHI collates overall vegetation health, which in turn suitable to indicate agricultural drought extent. It measures either moisture vegetation/vegetation condition (VCI) or thermal condition of vegetation (TCI). Both indices were derived from Normalized Difference Vegetation Index (NDVI) and land surface temperature (LST) data respectively. The results revealed that VHI decreased more than 50 percent, from 30.86 in 2000 to 14.66 in 2015. This Figure indicated drought extent intensified in research area, from mild drought to severe drought. The severity was mainly triggered by the rising LST from 27°C in 2000 to 40°C in 2015. In addition, there was a decreasing tendency of NDVI values in recent years, leading agricultural fields more susceptible to drought.

Drought is a natural disaster which causes global damages and affects people. Aziz et al. (2018) carried out comparative study of different drought indices such as Normalized Difference Vegetation Index (NDVI), Deviation NDVI (DevNDVI), Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) from HJ-1A/1B multispectral data is discussed. These indices have shown potential to detect the drought severity. The objective of this study is to monitor drought in the Potohar region using HJ-1A/1B satellite data, from late November to April during 2009–2014. Additionally, results obtained from satellite data have been verified using ground-based rainfall and crop yield data. The results concluded that the Potohar region faced drought condition in 2010, which is further verified by ground data. Furthermore, NDVI and VCI in this region are found more effective than other drought indices. On the basis of validation of individual drought index with crop yield data, each index is assigned weight accordingly. Moreover, the combination of indices has the ability to detect time periods where drought is affecting the yield production. Regular monitoring and mapping of satellite-based drought indices would play an important role in predicting drought conditions.

2.5 LITERATURE REVIEW ON TREND ANALYSIS OF DROUGHT INDICES

2.5.1 Literature review on Mann Kendall trend test and Sen's Slope

Chen et al. (2009) investigated historical trends of meteorological drought in Taiwan by means of long term precipitation records. Monthly and daily precipitation data for roughly 100 years, collected by 22 weather stations, were used as the study database. Meteorological droughts of different levels of severity are represented by the standardized precipitation index (SPI) at a three-monthly time scale. Additionally, change-point detection is used to identify meteorological drought trends in the SPI series. Results of the analysis indicate that the incidence of meteorological drought has decreased in north-eastern Taiwan since around 1960, and increased in central and southern Taiwan. Long-term daily precipitation series show an increasing trend for dry days all over Taiwan. Finally, frequency analysis was performed to obtain further information on trends of return periods of drought characteristics.

Drought is acknowledged as a phenomenon associated with scarcity of water due to reduction in the amount of precipitation over an extended period of time, usually a season, a year or more in length. Droughts are frequently occurring in Upper Krishna basin in Maharashtra where about 80 percent of agriculture land is rain fed. Also, this region is witnessing rapid urbanization due to industrial growth where thirst for water for drinking as well as industrial use is demanding. The study of drought trends is extremely important as it is related with food security and management of scarce water resource, which becomes critical in case of drought events. **Mahajana and Dodamani (2015)** analysed the drought trend of Standardized precipitation index (SPI) at 1-, 6-, 12-, 24- and 48- month time scales, Percent of Normal Precipitation (PNP) at Annual and Water-Year time scales and Seasonal rainfall (winter, pre-monsoon, monsoon and post monsoon time scales) are computed using long time series (1960-2012) of monthly precipitation data at 59 stations in the study area. The statistical significance at 95% confidence level as per Mann-Kendall and Sen's slope estimator are used for drought trend analysis over the Upper Krishna basin in Maharashtra. The PNP drought trend analysis at both annual and water-year time scale is able to detect significant trend at only 5 stations out of all raingauge stations, SPI based drought trend analysis is found to be more sensitive to multiple time scales. As the SPI-1 time scale is able to detect significant trend at only 4 stations, number of stations having significant trend increases as the SPI time scale increases up to SPI-48 at 50 stations. Drought trend of Seasonal rainfall time series vary as per the classes. Pre-monsoon timescale detects significant negative trend at 41 stations with no significant positive trend at any of the stations. Monsoon time scale detects only 2 positive and 1 negative significant trends at total stations. Post-monsoon time scale is not able to detect any significant trend at all stations. The results indicate that, there is negative trend of pre-monsoon rainfall at over 63 percent of area.SPI-48 time scale is able to detect significant trend at over 84 percent of area. This analysis may help to solve problems associated with floods, droughts and allocation of water for agriculture, industry, and hydro-power generation, domestic and industrial use.

Rahmat et al. (2015) showed Trend analysis by means of nonparametric trend tests (Mann-Kendall and Spearman's rho) for five selected meteorological stations in Victoria. For the drought analysis, the Standardized Precipitation Index (SPI) was applied to 3 month and 12 month time scales using monthly mean precipitation data for the time series of over 60 years. The computed SPI values for both time scales showed statistically significant downward trend for all stations. To compare one time period to another, the series were then subdivided into two 33 year periods. For the 3 month basis, three out of five stations showed significant decreasing trends. In contrast, for the 12 month time scale, the results showed downward trends for all stations illustrating conditions becoming drier over the last thirty three years (1977 2010). These results could be associated with the consequences of climate change as it is postulated that droughts would become more common in the future.

The trend analysis test was carried out by **Achugbu and Anugwo (2016)** using non parametric Mann-Kendall trend test for Kano using a long term 100 years rainfall data. In other to assess the short term, seasonal, annual and long term droughts, the study employed the Standardized Precipitation Index (SPI) to 3, 6, 9, 12 and 24 month time scales using the rainfall time series data. The SPI values computed for all the time scales revealed a non-significant increasing trend for the entire study period (1911 2010), while period 1911-1995 revealed a significant decreasing trend especially in August, September and October. For comparison between different time periods, the 100 years series was sub-divided into 30 years overlapping time period. Period 1951 1980 and 1961-1990 revealed the highest number of statistically significant downward trend. The Z values from Mann-Kendall test ranges from 4.05 to -2.86, which shows how erratic the rainfall could be in Kano. All the analyzed months for periods 1911 1940, 1971-2000, 1981-2010 and 1941-1970 (except May in 1941-1970) showed a general increasing trend for all the time scales. However, periods 1971-2000 and 1981-2010 showed a significant increasing trend which implies that rainfall over the station is at the increase. The value of the slope ranges between -0.053 and 0.118 for all the time scales. High slope values were more prevalent in the higher time scales.

2.6 LITERATURE REVIEW ON DROUGHT FORECASTING METHODS

2.6.1 Literature review on ANFIS and FUZZY Logic approach

Drought affects natural environment of an area when it persists for a longer period. So, drought forecasting plays an important role in the planning and management of natural resources and water resource systems of a river basin. During last decade neural networks have shown great ability in modeling and forecasting nonlinear and non-stationary time series. **Mishra and Desai (2006)** compares linear stochastic models (ARIMA/SARIMA), recursive multistep neural network (RMSNN) and direct multi-step neural network (DMSNN) for drought forecasting. The models were applied to forecast droughts using standardized precipitation index (SPI) series as drought index in the Kansabati River Basin, which lies in the Purulia district of West Bengal, India. The results obtained from three models and their potential to forecast drought over different lead times are presented in this paper.

In order to achieve effective agricultural production, the impact of drought must be mitigated. An important requirement for mitigating the impact of drought is an effective method of forecasting future drought events. **Luong Bang et al. (2015)** presents the correlations between sea surface temperature anomalies (SSTA) and both the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) at four areas monitoring El Nino–Southern Oscillation (ENSO) activities at the CAI river basin in Vietnam. The correlation analyses for selecting potential variables serves as a forecasting mechanism, and SSTAs events in Nino and Nino 4 zones are used to construct Adaptive Neuro–Fuzzy Inference System (ANFIS) forecasting models. Different ANFIS forecasting models for SPI and SPEI (1–, 3–, 6–, and 12–month) are trained and tested. The results of our research show that the best performing models are M5, M11, and M13. For drought forecasting in the short–term (1– or 3–month models), the SPI should be used, because it has a better performance than the SPEI. Drought forecasting with seasonal or long–term indexes (6– or 12–month models) should use the SPEI, because the SPEI performs better than SPI in these cases. Also, find that the ANFIS forecasting model (M11) for SPEI–12 is the best forecasting model. Furthermore, the ANFIS method with input variables constituting SSTA events can be successfully applied in order to establish accurate and reliable drought forecasting models.

Drought as an environmental occurrence, is an essential part of climatic variability. Droughts are the product of keen water shortage causing severe and sometimes disastrous economic and social consequences. The Standardized Precipitation Index (SPI) provides the forecasting of drought. The SPI also detects moisture shortage more rapidly which has a reply time scale of approximately 3, 6, 12, 24, 48 months. **Rahman (2021)** studied fuzzy logic to focus on modeling problems characterized by imprecise or ambiguous information. It also needs a complete understanding of the drought causing factors, severity classification and to interpret the drought forecasted output variables. In this study, the number of linguistic terms referred to as fuzzy sets, is assign to variable rainfall. The degree of membership (from 0 to 1) of a real valued input (SPI) to a particular fuzzy set A (ED, SD, MD, N, MW, SW, EW) is specified by a membership function μA(x). Fuzzification of linguistic variables is classified into linguistic labels by transfer membership functions for each of the variable.

Oyounalsoud et al. (2023) aims to develop a new meteorological drought index based on fuzzy logic (FL) and Neuro-fuzzy models to describe and predict droughts. The developed models were compared to nine conventional drought indices and correlated with multiple drought indicators. Different combinations of inputs (such as maximum temperature, mean temperature, precipitation, and potential evapotranspiration) were tested to develop the models. Observed weather data from Alice Springs, Australia, were used to examine the developed models and train the adaptive Neuro-fuzzy inference system (ANFIS) model. This study showed that the rainfall anomaly drought index (RAI) was the best conventional drought index, with the highest correlation (0.718) between the drought index and upper soil moisture (drought indicator). Moreover, when the average output of the best-performing FL models was used for training, the best ANFIS model had a correlation of 0.809 with upper soil moisture. The best ANFIS model in terms of correlation with conventional drought indices had a correlation of 0.941 with the RAI when the normalised average output of the best-performing conventional drought indices was used for training. To validate the developed models, drought assessment was conducted for five stations in different climate zones and seasons. The validation results showed that the developed models had similar performance to the best-correlated conventional drought index (RAI) in most cases. The developed models yielded better predictions compared to the conventional index in the subtropical and tropical regions. Overall, the developed soft computing drought indices based on fuzzy logic and ANFIS outperformed conventional methods, thus effectively contributing to more precise drought prediction and mitigation.