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ORIGINAL ARTICLE

# Spatial and Temporal Pattern Assessment of Meteorological Drought in Tumakuru District of Karnataka during 1951-2019 using Standardized Precipitation Index

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## ABSTRACT

**Tumakuru district of Karnataka state is situated in the semi-arid climatic region which is considered most sensitive area/zone in response to climate change. This study analyses the spatio-temporal changes of meteorological drought in the Tumakuru district during 1951-2019. To understand the spatial and temporal characteristics of drought, annual and seasonal drought trends were examined using standardized precipitation index. Based on three-seasons, pre-monsoon (January -May), southwest monsoon (June -September), northeast monsoon (October-December) the annual SPI were calculated. Characteristics, classification and the threshold value of drought classes were determined. The correlation between precipitation and SPI was similar and showed the strong correlation. The wettest (1962 & 2006), and driest years (1968,1954, 1965, & 1976) during the study were identified. The higher frequency distribution of the driest years addresses roughly 57% drought years detected for Madhugiri and Tumakuru (1) in SW-monsoon of the total years of study, in pre-monsoon Kunigal have 21.73%, and in NE-monsoon it was 50.72 % at Kunigal. In the district southwest monsoon is long spell rainy season which is contributing 54% of total rainfall and advantageous for early stage of Rabi and maturation of Kharif crops. Maximum evaporation from soil and vegetation measured by potential evaporation which is the criteria of the water consumption by crops. In the event of monsoon failure and very less rainfall during southwest monsoon, farmers could not able to sow new crops and existing rain-fed crops would be decimated.**

## INTRODUCTION

The scope of development, water resource management, and planning is affected by an adverse change in climatic conditions (Dikici 2020). Conceptual definition of drought expressed in relative terms e.g. a long period of dry season, whereas operational definition defines the starting of drought, severity, and end of dry periods (Wilhite et al. 1985). Usually drought severity, duration, and its frequency analysis for a given time period comes under operational definition of drought (Mishra and Singh, 2009). Drought happens in any environmental zone, and their properties (recurrence, time duration, and seriousness) may vary. Quantitative evaluation of drought characteristics and their improvement is necessary for understanding distinctive types of drought at scales from the local to the worldwide (Kallis 2008). American Meteorological Society summed up drought definitions into four types of categories: hydrological, meteorological, agricultural and socio-economic drought (Policy Statement, 1997). These four classes are related to various segments of the hydrologic cycle (Peters, 2003). For the most part, precipitation is the primary and major factor in the hydrologic cycle. Drought is defined as the costliest natural disaster characterized by the prolonged insufficiency of rainfall or having significantly less availability of water during a long time over a huge area. In the past, many researchers have investigated the spatial fluctuation of the dry season utilizing drought indices and precipitation attributes (Zerouali et al. 2021; Lu et al. 2017; Mishra and Nagarajan 2011; Chiang et al. 2021; Du et al. 2013; Kumar et al. 2012; Edossa et al. 2010; Guhathakurta et al. 2017; Das 2020; Mehr et al. 2020; Bazrafshan et al. 2014). Drought characteristic risk portrayed as having below ordinary precipitation because of numerous factors on different time scales (months to long time) and it can change spatially as well as a drought can have impacts on different areas, particularly on hydrology, agriculture, environments and society (Diani et al. 2019). Hence, drought evaluations depend on the time, severity and affected region. As a hydroclimatic disaster, drought represents terrible intimidation to the economy, environment and society (Rossi et al. 1992). Meteorological Drought defined by lack of rainfall and duration of this period over a region (Mishra and Singh, 2010). When over a region received long term average rainfall value less than 25% of seasonal rainfall, occurs meteorological drought. If this seasonal rainfall average value is between 26% to 50% is known as moderate drought and further, it is classified as severe drought if received rainfall deficit is more than 50% of its long term average value (Department of Agriculture and Cooperation, 2019). Meteorological drought restricts the agricultural water resources during drought conditions and it leads to reduction of crop yield (Lu et al. 2017). Agriculture is the essential land use across the world, and it is exceptionally sensitive to climate change, and also known as a major cultural, economic and social activities (Howden et al. 2007). According to a prediction by 2050 worldwide food demand will be high and indicating that agricultural production should be double (Tilman et al. 2011). Agriculture drought, generally refers an insufficient quantity of moisture in the soil to fulfil the need of a particular agriculture crop at a specific point of time. Crop water demand relies upon existing weather conditions, growing stage of plant, biological properties of specific plant and bio-physical properties of soil. Many drought indices have been developed and derived to understand the agricultural drought based on combination of temperature, rainfall and soil moisture, in other words soil moisture deficiency is strongly responsible for crop failure (Mishra and Singh, 2010; Van Loon 2015). Hydrological drought is related to the inadequacy of water on the surface and subsurface because of deficiency in precipitation for a long time (Van Loon, 2015). The annual precipitation gained by the India was 117.7cm (109%) of normal rainfall which is 118.7 cm since 1901(Sciences 2021). Only southwest monsoon season from June to Septemnber receive more than 75% of annual rainfall (India Meteorological Department, 2021), which is known to most rainy season in India and play a vital role for kharif crop (Kumar et al. 2012). Rainfall distribution of the Karnataka state vary from 5051 mm to 408 mm. Highest annual rainfall observed at Western Ghats and minimum rainfall observed in the eastern parts of Chitradurga (UNESCO IHE 2011). 13% of total rainfall was received in pre-monsoon season, 71 % of the total rainfall received in south-west monsoon and 16% rainfall received during northeast monsoon (Anon 2016). The study area, Tumakuru district is one of the district of Karnataka state situated in southeast part of the state. The annual rainfall value of district during 1951-2019 vary from 2429.99 mm (at Tumakuru) to 136.30mm (at Gubbi) and it observed that rainfall increase with the altitude and it decrease as the altitude decrease. The terrain elevation is 720m at Tumakuru (1) and 136.30 at Gubbi. Southwest monsoon is very important rainy season and total 54% of the rainfall received in these four months (June-September). According to Koppen's classification, Tumakuru district witnesses two climatic zones. North Tumakuru lies in very dry which has less than minus 60% moisture avalaibility and adjoining area of Mysore and Tumakuru comes in semi-arid with less than 50% moisture. (Beck et al. 2018; Aparecido et al. 2016). District is categorized into three agro-climatic zones by University of Agricultural Sciences (UAS) Bangalore. Zone 4 is central dry zone, (Madhugiri, Pavagada, Koratagere, C.N. Halli, Sira and Tiptur), zone 5 is eastern dry zone (Gubbi and Tumakuru), and zone 6 is southern dry zone (Turuvekere and Kunigal) (UNESCO IHE, 2011). These different types of agro-climatic zones of the district permit the cultivation of different crops. In the district, kharif is major cropping season and about 70% of the cultivated land occupied by ragi and groundnut followed by maize, paddy and red gram and drained by southwest monsoon. When in the south monsoon season does not received the sufficient rainfall during the crop growth, and less rainfall and soil moisture inadequacy causes extreme moisture stress and wilting the plant. The motivation behind this study is to research precipitation inconstancy and its spatial pattern over the Tumakuru district. In this research, the SPI was adopted due to its great characteristics in drought recognition. Standardized precipitation index (SPI) was broadly used during the primary decade of the 21$^{st}$ century (Li et al. 2014). Standardized precipitation index work on the basis of probability of rainfall for any time scale. Due to its ability to compute for different time scale, this index is very useful for long term hydrological and short term agriculture drought (Zakhem and Kattaa 2016; Rahman et al. 2017). SPI index is suited to compare the different conditions of drought with many time scales. Many researchers have done work on meteorological drought in the country but no one attempted on spatio-temporal change and expansion of drought in Tumakuru district. So, the overall purpose of this research is to endow the explication of the various time scale drought variability in meteorological drought over Tumakuru district through standardized precipitation index (SPI). The objectives are as follows (1) investigating the spatial and temporal distribution of meteorological drought in the district; (2) characteristics of rainfall in the Tumakuru district during 1951-2019 through applying the SPI technique; and (3) understanding the variation in rainfall characterizing the changes in drought pattern. This research work confers in-depth perusal of the trend in rainfall variations using Standardized Precipitation Index technique over 69 years of precipitation data as well as output of pattern of rainfall and wettest and driest years in the study area.

## STUDY AREA

Tumakuru District is located in the South-Eastern part of Karnataka, India. It is known as an open tract except for the South of Kunigal taluk, where the land is hilly and woody. The area is extending between latitude 12°44'31" N to 14°21'2" N and longitude 76°21'2" E to 77°30'12" E, with an altitude from 531 m to 761 m above sea level. The district covers an area of about 10,603 km$^2$ (Fig. 1). The eastern part of the Tumakuru district is covered by a narrow range of granite hills. The western region of the Tumakuru district is covered by a long range of hills running up to S-E. The district is surrounded to the north by Anantapur district (Andhra Pradesh state), in the south by Mandya and Ramanagara, in the east by Chikkaballapur and Bangalore, in the west by Hassan and Chikmagalur. The area is covered by arid and semi-arid climatic zones and has average rainfall variations from 884 mm at Kunigal to 502 mm at Pavagada. The climate of the Tumakuru is almost free from extremes, only Pavagada taluk is relatively hot. The mean of rainfall demonstrates that the amount of rainfall is maximum in the south-eastern part around Kunigal and it dramatically diminishes towards the north at Pavagada. The maximum rainfall observed 2429.11 mm at Tumakuru in 1962 and the minimum rainfall observed 136.30 mm at Gubbi in 1976. The temperature of the region reaches a peak of around 34º C in April and declines to 16 º C in December (Disaster and Plan 2019). The humidity is highest during the SW monsoon and lowest during the months of February and March. The district has no perennial rivers. In the north, the Tumakuru district is drained by Pennar and lower Tungabhadra and in the south drained by lower Cauvery.

## DATA AND METHODOLOGY

### Rainfall Data

Daily gridded precipitation data were extracted from the India Meteorological Department (IMD) for the period 1951–2019. This daily gridded rainfall data (IMD4) archived from National Data Centre, Pune was interpolated at a high spatial resolution of 0.25°×0.25° longitude and latitude (Pai et al., 2014). This precipitation data is used to compute the drought index for eleven grid stations because of the accessibility of the long-term daily rainfall dataset. This rainfall data had a temporal resolution of one day and converted into monthly through averaging estimations. To ascertain the SPI the monthly rainfall data from 11 meteorological grid stations (Fig.1) in the Tumakuru district has been used.

### Satellite Data

ALOS PALSAR – Radiometric terrain correction (RTC) digital elevation model having a high spatial resolution of 12.5m for calculating the elevation of all stations. The elevations range of stations vary between 531m (Pavagada) and 761m (Tiptur) m above the sea level (Table 2). It was converted to ellipsoid heights using the ASF Map Ready *geoid_adjust* tool. (Laurencelle et al. 2015). This high-resolution data was used to extract the drainages of the district. The river and stream networks were outlined utilizing the spatial analyst tool of ArcGIS software by filling the sinks, generating the flow direction, assessing the flow accumulation, and depicting the stream and river line. The flow direction is dictated by recognizing the adjoining cells which have the highest positive distance weighted drop (Jenson and Domingue 1988; (Sah and Das, 2017).

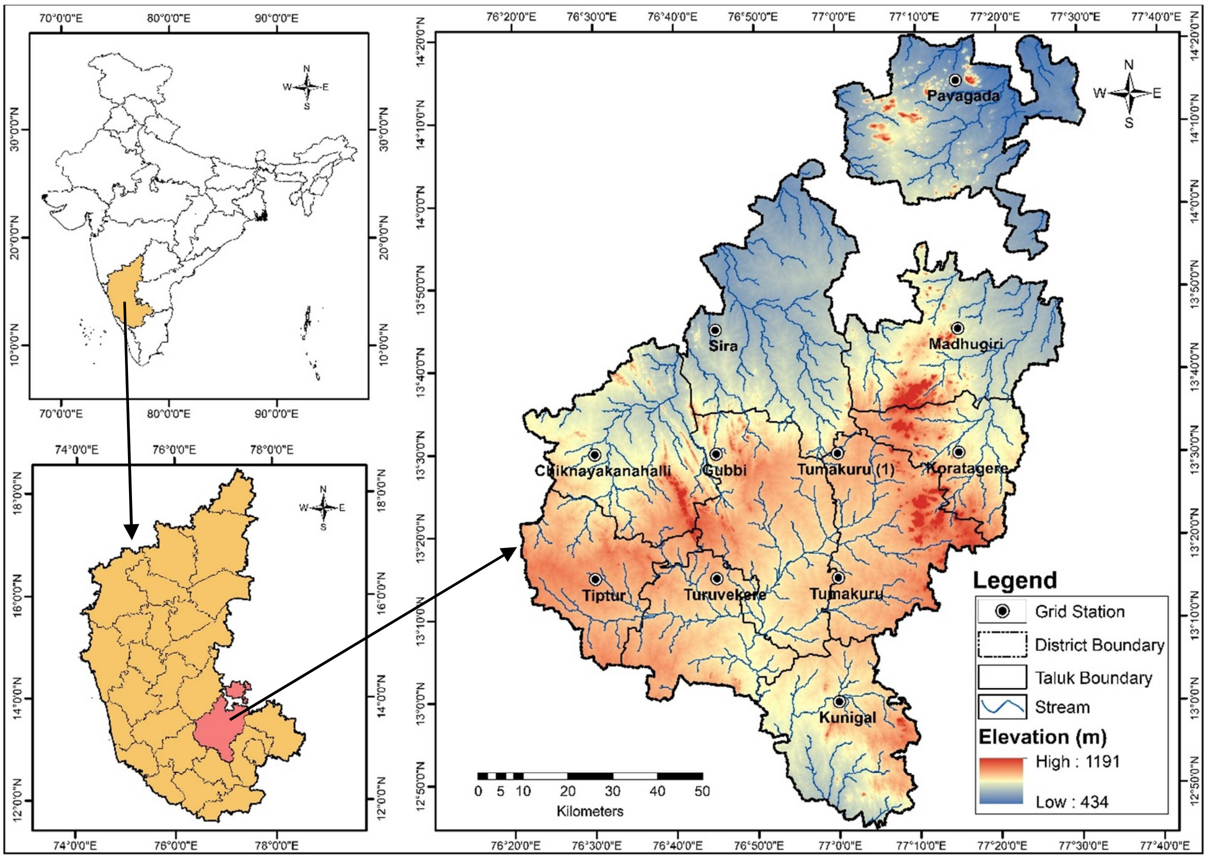


**Fig.1.** The geographic location of the Tumakuru district in India and Elevation and Grid points/stations used in this study

## Methods

### Inverse Distance Weighted (IDW)

Spline interpolation methods is known to produce extreme value of data along edges of the study region and the kriging interpolation technique revealed that the tendency of kriging method has under-estimated the data value, compared with real values Wu et al. (2016). To avoid these above error, IDW method was used in this research. The benefit of IDW is that it is simple to understand, easy in computation and is more efficient. Disadvantage is that there is no error indication and if the distributed sampled point is uneven, and output quality of result can decrease. The IDW technique is a basic and deterministic interpolation technique that works based on Tobler's First Law of Geography (Tobler 1970) that expects that sample values near to the unmeasured points have more impact on the interpolated value than farther points.

$$Z_j = \frac{\Sigma_i z_i / d_{ij}^n}{\Sigma_i 1 / d_{ij}^n}$$

$Z_j$ is indicating the unknown value and it reminds to estimate the value of unsampled points. $Z_i$ is the value of the known point. $D_{ij}$ is Euclidian distance from unsampled points to a known point. $n$ is a user-selected exponent that directly influencing the weight of $Z_j$ and is working as a medium of the inverse of spatial and temporal in between unsampled points and nearer points.

### SPI

Standardized precipitation index was formulated by McKee et al. (1993) to demonstrate the precipitation deficiency at various time scales that indicate the meteorological drought which entirely depends on rainfall data. The SPI is widely used to express the characteristics of the probability and amount of precipitation that include the long-term monthly rainfall data at multiple time scales. Two primary benefits emerge from the utilization of the SPI index. First, SPI depends on precipitation data only and ease of computing (Guttman, 1999). Second, the index makes it conceivable to depict drought on different time scales (Tsakiris and Vangelis 2004). The fundamental analysis of the SPI is that it depends entirely on precipitation information, not considering different factors that play a vital role to decide drought conditions like wind speed, evapotranspiration and temperature data, etc. The calculation and analysis of standardized precipitation index (SPI) compute through meteorological drought monitoring (MDM) software which is developed by Agricultural and Meteorological Software (AgriMetSoft) (Salehnia et al. 2017). MDM was downloaded from https://agrimetsoft.com/MDM. The standardized precipitation Index used $\Gamma$ distribution probability to detect the variation in precipitation.

This long-time rainfall data needs to be fitted in gamma probability that transformed into a normal distribution through equal probability transformation. The higher positive value of SPI with more than median precipitation indicates the wet sequences and the higher negative value less than median precipitation corresponds to dry periods.

The formula includes distribution probability density function is formulated by:

$$f(x_i) = (1 / (\beta^{\alpha} \Gamma(a)) \; x_i^{\alpha-1} \; e - x_i / \beta \qquad (1)$$

In this formula, $\alpha > 0$ is the shape and $\beta > 0$ is the scale parameters as well as indicate the monthly amount of precipitation. Where $x_i$ indicate the precipitation within $i$ consecutive months.

$$x_{\mathrm{i}}^{(j)} = \Sigma_{k=1}^{\mathrm{i}} P_{jk}, \; \mathrm{j} = 1,2,3, ..., N \qquad (2)$$

Here $P_{jk}$ indicate the precipitation data value of $k^{th}$ month of the $j^{th}$ Year. N denotes the number of years.

The value near the normal distribution curve having a larger value of shape parameter. For the estimation of α the gamma functions $\Gamma$ expressed by:

$$\Gamma(a) = \int_0^\infty y^{a-1} e^{-y} dy \quad (3)$$

Therefore, fitting the gamma distribution to a given frequency of rainfall sum for a station to be estimated $\alpha$ and $\beta$ (Edwards and McKee 1997) using maximum likelihood for estimating the optimal values of $\alpha$ and $\beta$ parameters adopting the maximum likelihood methods (Thom 1966):

$$\alpha = (1/4A)\ (1 + \sqrt{(1 + (4A / 3))}) \quad (4)$$

$$\beta = \bar{x}_i / \alpha \quad (5)$$

$$A = \ln(\bar{x}_i) - (1/n) \Sigma_{j=1}^{n} \ln((x_i)_j) \quad (6)$$

Where $\bar{x}$ showing the amount of mean precipitation and $n$ is the observation record number. $A$ is determined through the above formula.

The wet intensity and dry periods corresponding threshold for SPI can be classified based on SPI categories respectively as given in Table 1 (Mckee et al. 1993).

**Table 1.** Categorization of wet and dry grade according to the initial classification of SPI values, (Mckee et al. 1993)

| Threshold values | Category | SPI value | Drought severity |
|---|---|---|---|
| 2.0 ≤ SPI | Extremely wet | Above 0 | Non-Drought |
| 2.0 < SPI < 1.5 | Very wet | Above 0 | Non-Drought |
| 1.49 < SPI < 1.0 | Moderately wet | Above 0 | Non-Drought |
| -1.0 ≤ SPI ≤ 1.0 | Nearly normal | 0.0 to -0.99 | Very little arid |
| -1.49 < SPI <-1.0 | Moderate dry | -1.0 to 1.49 | Moderately arid |
| -2.0 < SPI < -1.5 | Severe dry | -1.5 to -1.99 | Severely arid |
| SPI ≤ -2.0 | Extreme dry | -2 or less | Extremely arid |

## RESULTS AND DISCUSSION

### Drought Characteristics and Analysis of SPI

Drought intensity, frequency and duration of drought are generally used to depict the characteristics of drought. The intensity of drought shows the seriousness of drought during the drought duration, which can be determined by the aggregated deficiency with the SPI value continuously below 0. Drought frequency alludes to the quantity of drought in a particular period, which is determined by the proportion of the number of drought months that occurred in the total months in a particular period. Duration of drought shows the number of months lies in drought conditions from the start to the end of the dry season. (Spinoni et al. 2014). The result from the SPI program has been a huge contribution of ArcMap GIS to create drought severity maps for the study area. To acquire a spatial coverage of the drought index, each point of the rain gauge station is allocated a region of impact using the IDW technique. By permitting joins between spatial feature and attribute information, a drought severity map with the spatially varying seriousness has generated. To describe the temporal change in drought during pre- monsoon, SW-monsoon, and NE-monsoon were averaged at each rainfall stations for each SPI accumulation period (January-May, June-September and October- December respectively). At that point, the annual SPI value was averaged of monthly aggregated SPI .

### Season-wise Rainfall Analysis

Pre-monsoon season from January to May has not contributed significant amount of precipitation (19% of the total rainfall); maximum average rainfall was 191.7mm in Kunigal and minimum average of rainfall detected 84.3mm in Pavagada. As shon in Fig.2, SW-monsoon (June- September) season was leading rainfall season in the study area that contributed about 54% of the aggregate precipitation (where almost 25% contributed by the Kunigal and Tumakuru). SW-monsoon had mean rainfall varying from 465 mm in Kunigal to 284 mm in Pavagada. During the NE-monsoon (October to December), 27% rainfall of total has been recorded. The mean seasonally precipitation (October–December) in the investigation region from 1951 to 2019 was 227.7mm and a minimum average of 133.7 mm for Kunigal and Pavagada. While the result of NE-monsoon presented the highest value of average rainfall 749 mm in Kunigal (1956), however, 1.9 mm observed as the minimum average rainfall in 1965.

### Statistical Parameters and Variability Analysis of Annual Rainfall

Statistical parameters of rainfall in Tumakuru district at 11grid points/ stations during 1951–2019 are summed up in Table 2. The minimum ever recorded precipitation was 136.30 mm for Gubbi stations (in 1976- the driest year) and the maximum precipitation observed at Tumakuru which was 2429.11mm (in 1962- the wettest year). The average annual precipitation of the study area is varying from 884.31 mm/year (Kunigal) with 257.8mm standard deviation and 502.04 mm/year rainfall (Pavagada) with 275.4 mm standard deviation.

### Rainfall Trend and Temporal Distribution of SPI at Tumakuru District

The $R^2$ values showed that the patterns of yearly precipitation were not as significant at all stations and it shows a slight shortage of extreme drought over the whole Tumakuru district. The yearly precipitation showed a mixed type of fluctuation. Annual pattern of SPI and rainfall clearly indicate that linear regression equation of Tiptur station showing the highest positive slope value of $R^2$ comes about 0.1887 which explain that 18% of variability in the annual rainfall and gradually it has significant increasing trend. Tiptur area were

**Table 2.** Descriptive statistics of grid stations, elevation and annual rainfall data over the period 1951-2019

| Stations | Long | Lat | Time Series | Elev. (m) | Max (mm) | Min (mm) | Mean (mm) | SD (mm) |
|---|---|---|---|---|---|---|---|---|
| C. Halli | 76.5 | 13.5 | 1951-2019 | 652 | 2073.87 | 273.60 | 612.62 | 253.4 |
| Gubbi | 76.75 | 13.5 | 1951-2019 | 683 | 1091.50 | 136.30 | 551.84 | 194.0 |
| Koratagere | 77.25 | 13.5 | 1951-2019 | 677 | 1363.19 | 291.14 | 624.41 | 211.9 |
| Kunigal | 77 | 13 | 1951-2019 | 674 | 1553.00 | 351.01 | 884.31 | 257.8 |
| Madhugiri | 77.25 | 13.75 | 1951-2019 | 664 | 1247.30 | 136.84 | 585.28 | 220.8 |
| Pavagada | 77.25 | 14.25 | 1951-2019 | 531 | 2282.16 | 223.32 | 502.04 | 275.4 |
| Sira | 76.75 | 13.75 | 1951-2019 | 578 | 1286.97 | 242.80 | 628.47 | 221.9 |
| Tiptur | 76.5 | 13.25 | 1951-2019 | 761 | 1135.34 | 347.49 | 683.90 | 193.6 |
| Tumakuru (1) | 77 | 13.25 | 1951-2019 | 720 | 2429.11 | 337.02 | 796.27 | 290.0 |
| Tumakuru | 77 | 13.5 | 1951-2019 | 717 | 1914.99 | 206.73 | 653.35 | 278.2 |
| Turuvekere | 76.75 | 13.25 | 1951-2019 | 742 | 2282.70 | 275.90 | 712.98 | 289.9 |

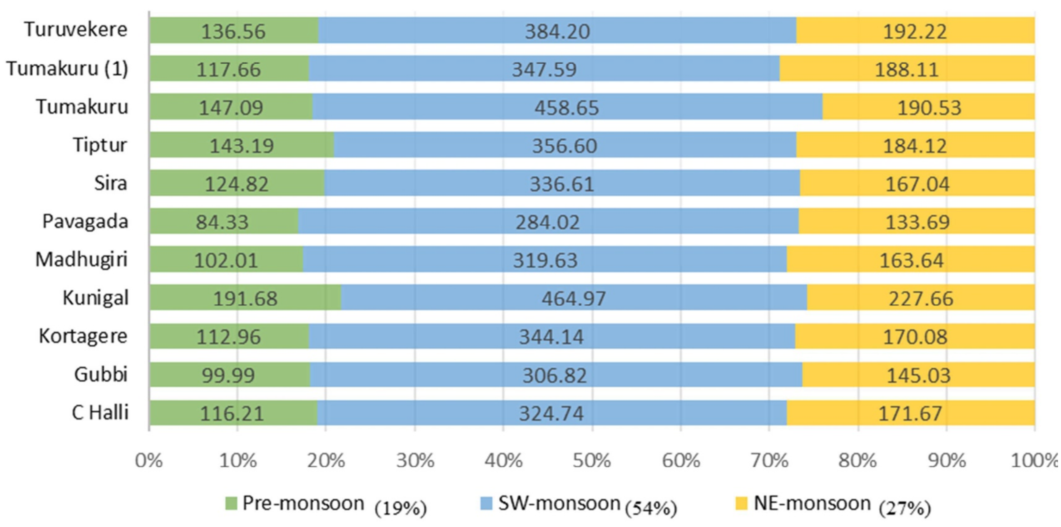


**Fig.2.** Percentage occurrence of rainfall in different seasons and stations

detected under the dryness condition during 1956-61 and the result of Tiptur rainfall trend line variation illustrated relatively higher significant trends with values of 4.222 mm/year. The average of Annual SPI -0.63 in Chiknayakanahalli (2003) and 1993-97, 2001-2003 have been found the continuous drought year and yearly precipitation decreased at the rate of -1.194mm/year in the Chikkanayakanahalli stations with a large fluctuation in 1962 and the $R^2$ value (0.0088) of the station indicate most of the negative trends in this station. $R^2$ value of rainfall variability indicate the 0.0088% variation in rainfall during 69 years of study.

**Seasonal Detection and Monitoring of the Wet and Dry Period**

In this study (from 1951 to 2019), the standardized precipitation Index (SPI) has been calculated based on the season as well as annually and a spatial interpolation map has been prepared. The severity of drought has varied with time and a blend of wetness and dryness years have been noticed. Within 69 years of the study period, Tumakuru (1) had only one station having a single drought year in pre-monsoon. Apart from that, none of the stations from all three seasons has not been affected from drought. Therefore, each season during the study period has experienced some serious or moderate drought. The entire pre-monsoon season has encountered a maximum of 15 years of drought in Kunigal. The highest SPI detected in 2006 at Turuvekere which was 2.76 in SW-monsoon, and the lowest SPI was -1.74 observed in 1965 at Tumakuru (1) in NE-monsoon.

**Spatial Pattern of Drought**

**Annual:** The spatial extension of annual SPI drought years portrayed in the figure 3 indictae the wettest condition (j) and driest condition (k) of the area. During 1951-1955, the district had wetness. Moreover, the dryness between 1952-1953 was existing in Tumakuru, Tiptur and Kunigal grid stations. Similarly, during 1963, 1972, 1983, 2006 and 2007 almost whole district was affected by severe drought except Turuvekere grid station. The dryness in the years 1956, 1959, 1961 was mainly in the southwest part of the area and suffered severe drought. In 1957-1958, 1960, 1964-1968, 1979, 1980, 1987, 1988, 1999, 2003, 2008, 2015 and 2019 wetness was found in most part of the district, with some drought in 1967 at Gubbi and Turuvekere. While the north-eastern part of the district, from 1984-1987, 1994, 1999, 2000, 2004 and 2018 Pavagada grid station had severe drought. Moderate drought events occurred in 1959 (except Pavagada), 1961(except the northern part of Madhugiri), 1972, 1981 (except Kunigal), 1983, 2016 and most of the eastern part of the district in 2018 and the remaining stations were wetter during 1954, 1958, 1964, 1968, 1988, 1999, 2008, 2015, and 2019 and Tumakuru was wetter.

**Pre-monsoon:** To characterize the drought intensities of the SPI, the classification of drought given in Table 3 is utilized. Figure 3, show the driest (a), wettest (b) and normal (c) condition of the drought. Southern part of the district is struck by the drought in years 1955, 1956, 1957, 1959, 1966, 1967, 1988, 1990, 1998, 2001, 2002, 2015 and 2016. It means, mostly south and south-eastern parts of the district is affected by drought events during the investigation period (1951–2019). The years 1955, 1957, 1981, 1988 and 2002 imprint the most fragile dry years. The year 1998 was most dreadful when most of the district was under dry condition, followed by the years 1957 and 1981 with the highest percentage of the total area of the district, influenced by drought events.

**SW-monsoon:** The years 1955, 1963, 2006, 2009 and 2018 were the driest period of the SW-monsoon season and 1954, 1964, 1967, 1978, 1981, 1984, 1986, 1987, 1989, 2007 2008, 2013, 2014 and 2015 showed the retreating period of dryness. From a drought perspective, 2006 and 2018 were more effective because of their impact on meteorological drought. The year 1967 had a more noteworthy number of grid stations under wetness compared to the rest of the years in the time scale. The year 2006 had almost all number of grid points under drought except Turuvekere. Even though in 2018 Turuvekere and neighbour station Tiptur come under wet conditions. Further, the extent of the region under severe and moderate drought was huge in 2006. Some other years having broad dry territories in SW-monsoon including 1953, 1955, 1959, 1963, 1973, 1979, 1991, 2009 and 2018. During these years, 1955, 1963, 1973, and 2018 were accounted wide spreading dry years in the district.

**NE-monsoon:** The spatial variability of northeast monsoon drought severity is presented in Fig.3 (g,h,i) with the average of season SPI. Results showed that district experienced very wet to severe

**Table 3.** The intensity of the SPI series at a different time scale

| Category | Pre-Monsoon | SW-Monsoon | NE Monsoon | Annual |
|---|---|---|---|---|
| Minimum SPI Value | -0.58 (2003) | -1.71 (1954) | -1.74 (1965) | -0.89 (1968) |
| Maximum SPI Value | 1.98 (2004) | 2.85 (1962) | 1.72 (1956) | 1.70 (1962) |
| Positive SPI Frequency | 65 | 39 | 46 | 60 |
| Negative SPI Frequency | 16 | 39 | 35 | 25 |

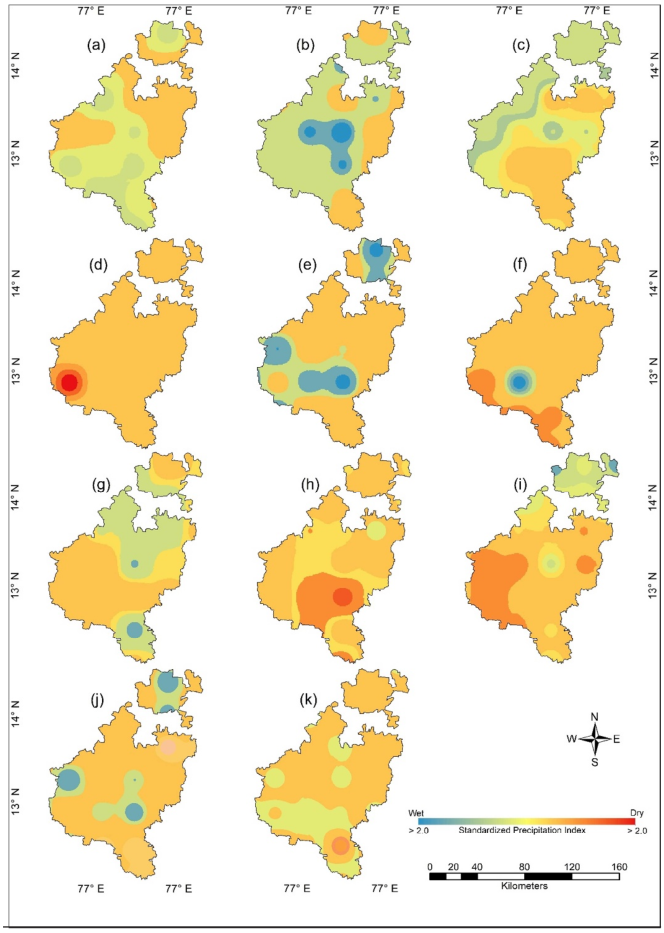


**Fig. 3.** Spatial pattern of pre-monsoon (a,b,c), southwest monsoon (d,e,f), northeast monsoon (g,h,i) and annual (j & k)SPI in the response of drought frequency during the period 1951-2019

dry conditions in almost years under examinations though the wet condition was seen in this season for the years 1953, 1958, 1959, 1964, 1987, 1988, 1989, 1999, 2001, 2004, 2010 and 2011, 2012, 2013, 2017, 2018 and 2019. The highest positive SPI in NE-monsoon was noticed 1.72 at Kunigal in 1956 and the lowest mean SPI was observed -1.74 at Tumakuru grid station in 1965 (Table 3). Severe drought conditions were knowledgeable about almost all the grid stations of the district during the years of 1954, 1996, 1998 2005, 2006 and 2008. In the period of 69 years spatial dissemination of drought frequency, Gubbi was the critical grid station that encountered the most continuous drought years from 1965-1971.

### Season-wise SPI

Chikkanayakanahalli had the strongest wet event noticeably in 1962 that is 2.20 (extremely wet) for SW-monsoon, in 1962 was 1.70 (very wet) for Pre-monsoon and 1.30 (moderately wet) in 1966 for NE-monsoon. Various drought hazard frequencies with SPI ≥ 1.00 were observed in the SW-monsoon. It was seen that 2003 was characterized by moderate drought with SPI -1.29 in past 69 years which was the driest year in this station. In Gubbi, moderate drought events occurred with SPI -1.37 in SW-monsoon in the year of 1976 as well as SPI < -1 observed in 1961 and 1972 respectively. In addition, the continuous drought detected in the SW-monsoon during years from 1965-1972. NE-monsoon also appeared under the moderate drought in 1959 with the SPI -1.22. The most positive value of SPI in Gubbi was reported 1.74 in 2004, which shown the wettest year of this station in NE-monsoon. Koratagere station experienced maximum number of drought years in SW-monsoon. It was seen that normal drought events with SPI ≥ 1 was examined in 2003 (-0.58, Pre-monsoon) and 1989 (-0.98, NE-monsoon). But moderate drought was identified in 1990 (SW-monsoon) with SPI -1.19. Highest negative SPI -1.58 was observed in the SW-monsoon at Kunigal. In pre-monsoon, the station experienced a short time drought than SW-monsoon. Hence, moderate and near-normal drought frequently happened in this station. Only 2009 was the year that faced moderate drought in NE-monsoon that had SPI -1.03. In Madhugiri, 1975 was witnessed the most wettest year with SPI 1.75 compared to all seasons and the driest season was the NE-monsoon with SPI -1.49 in 1964. The SPI trend of pre-monsoon exhibits an upward trend in 2004 (1.48) and downward in 1973 (-0.29). In Pavagada SPI increased toward the positive in 1962 up to 2.79 and drastically decreased in 1963 (0.55) at SW-monsoon. The SW-monsoon moderate drought years were 1961 and 1994. Sira grid station only one of the stations that shown the non-huge expanding pattern and recognized without moderate or extreme drought events during the research period. All seasons of this station were under near-normal drought. Tiptur grid station was identified most of the negative SPI in SW-monsoon compared to all grid stations. Moderate drought events occurred in 1954, 1970, 1976 and 2006. The maximum SPI 1.53 for SW-monsoon was in the year 2009. The highest negative SPI were detected in 1954 that was -1.71, -1.04 in 1970, -1.15 in 1976 and -1.26 observed in 2006. While pre-monsoon and NE-monsoon seasons had recognized the near-normal drought with the minimum SPI recorded -0.31 (pre-monsoon) in 1953 and -0.91(NE-monsoon) in 1958. At Tumakuru station most of the years identified as near normal and moderate drought in all three seasons as compared to other stations. In the pre-monsoon there were 16, SE-monsoon has 32 and NE-monsoon has 35 years of drought. While moderate drought events were recognized in SW-monsoon and NE-monsoon. SW-monsoon witnessed moderate drought in 1976 and 1990 with SPI -1.58 and -1.35 respectively. Tumakuru has maximum SPI 2.85 in SW-monsoon. Tumakuru (1) is the only station that had positive value in pre-monsoon without any single drought year. Tumakuru (1) had the highest SPI 1.98 and a minimum SPI 0.04 in Pre-monsoon. SW-monsoon result illustrated the maximum SPI 1.32 in 1998 and the minimum SPI -1.17 in 1975. The NE-monsoon distribution of the SPI found the near-normal drought with a minimum SPI -0.68 in 1967 and moderately wet conditions found with a maximum SPI 1.48 in 1956. Analysis of time series SPI of Turuvekere indicates how the pattern of dryness and wetness were changed during 1951-2019. The SPI increased 2006 with 2.76 in SW-monsoon, while the pattern of SPI in pre-monsoon was varying between moderate wet to near normal drought with SPI 1.24 to -0.31 (Fig. 4).

## CONCLUSION

In this research SPI computation based on the IMD (India Meteorological Department) monthly precipitation data shows well characterize historical drought in the entire district. This study detected significant wetness periods at some particular seasons and years in the entire district. However, the SPI demonstrates a genuinely huge negative pattern in some years. The patterns of precipitation were showed the annual precipitation of Chikkanayakanahalli, Kunigal, and Pavagada diminishing but the trend of precipitation in Gubbi, Madhugiri, Sira, Tiptur, Tumakuru, Tumakuru (1) and Turuvekere were increasing. Precipitation changes in the Kortagere remain almost constant. Spatially, the entire district showed a dry pattern in 1961, 1963, 2006 and 2007 at annual analysis, while the year 2006 was more articulated in SW-monsoon as well as with multiple grid stations in NE-monsoon. 2006 was the driest year that contributed to almost every season as a drought year except pre-monsoon. Wetness and dryness patterns were identified through the SPI based on season and annual time scales, and the spatial variability was assessed by applying the IDW interpolation technique by using ARC/Map software. In terms

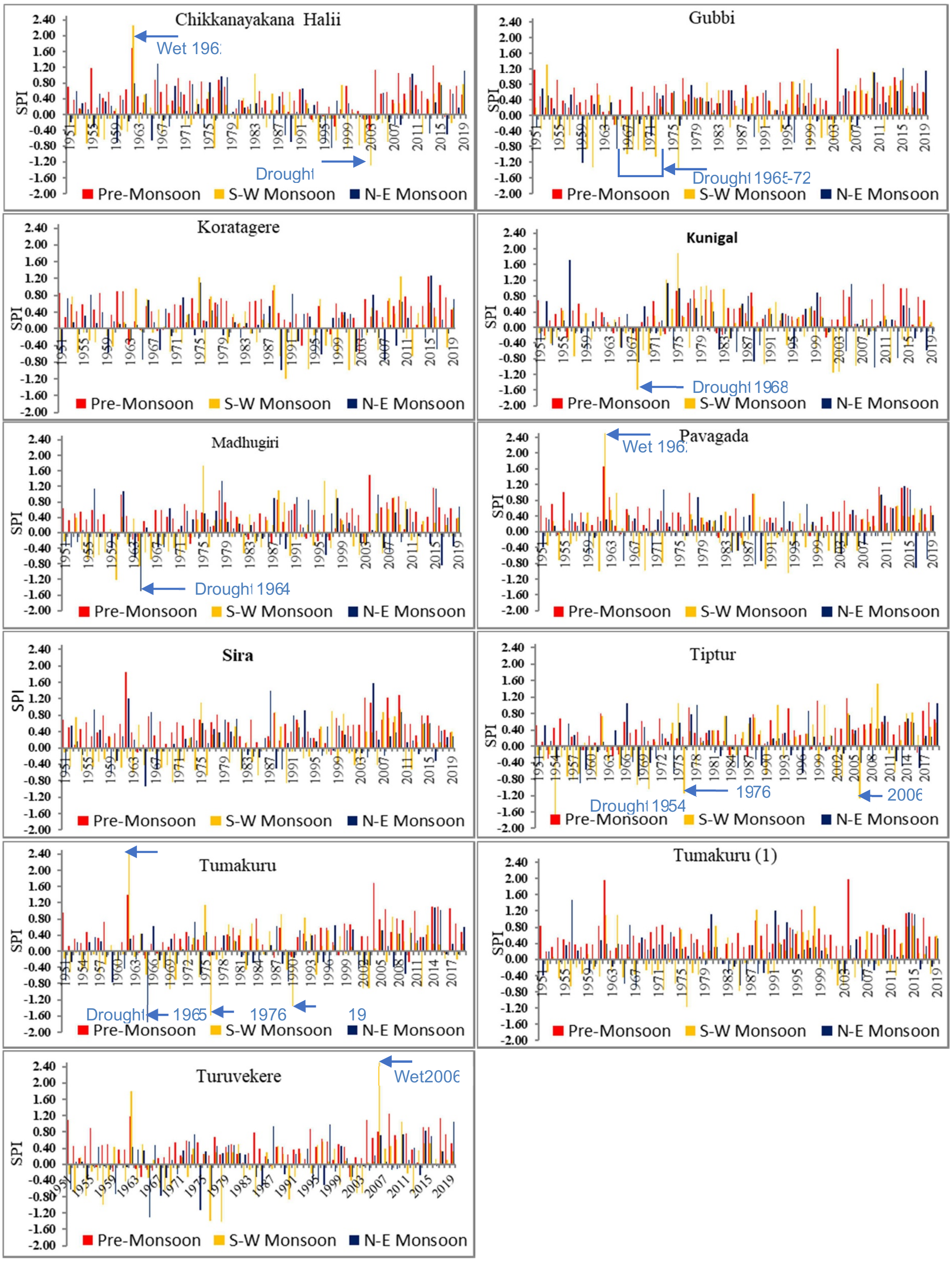


**Fig. 4.** Temporal distribution of SPI series at different seasons (Pre-monsoon, SW-monsoon and NE- Monsoon) over the Tumakuru region during 1951-2019

of the spatial distribution of drought the study reveals that the frequency of drought most of the years occurs in southwest monsoon. In Karnataka state arid and semi-arid zones are mostly dependent on the southwest monsoon for agriculture crop. The majority of kharif crop in district like Tumakuru are early and growing stage in these four months (June-September) of southwest monsoon. Due to water deficiency during the growing stage from emergence to maturity (In India it is defined as four consecutive weeks), due to high moisture stress plant can't survive. The result of the study found that in arid and semi-arid zones like Tumakuru district, this type of behaviour of climate change during the growing stage of agriculture plant, means that meteorological drought can easily change into agricultural drought. Therefore, southwest monsoon is most devastating season in these zones. The Standardized Precipitation Index can define nicely the variation of drought in Tumakuru. Results of the study not just helpful for understanding the spatial and temporal change in drought characteristics but also helpful in drought prediction and drought monitoring etc.

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