Spatial and temporal drought analysis in the Krishna river basin of Maharashtra, India

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Abstract: Droughts can be distinguished by three vital characteristics—spatial coverage, intensity, and duration. The objective of the present study was to study the temporal and spatial variation of drought incidences by using the Standardized Precipitation Index (SPI) and Percent of Normal Precipitation (PNP) at multiple time scales; computed using monthly precipitation data (1960–2012) in the study area of 59 rain gauge stations. Drought climatology based on these drought indices (PNP and SPI) has been studied for finding out their suitability for drought monitoring over Krishna basin in Maharashtra. Study results indicate that at dry and wet conditions, the SPI performs better than PNP in monitoring drought at multiple time scales. However, SPI-1 fails to recognize drought conditions in pre-monsoon and post-monsoon months. The spatially interpolated droughts maps are prepared which displays the variation of drought severity across the study area. The ranking of stations has been done as per drought severity to identify severely drought prone areas.

Subjects: Georisk & Hazards; Water Engineering; Water Science

Keywords: Standardized Precipitation Index (SPI); Percent of Normal Precipitation (PNP); spatial variation; temporal variation; drought climatology

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PUBLIC INTEREST STATEMENT
Drought is one of the major water-related natural hazards. The investigation of spatial and temporal variation of rainfall is of great importance in water resources planning and management as it is related with food security and management of scarce water resource, which becomes critical in case of drought events. The aim of the present study was to study drought climatology over the Krishna basin in Maharashtra, at both local and regional level using two drought indices, namely, Percent of Normal Precipitation (PNP) and Standardized Precipitation Index (SPI). It was found that the SPI performs better than PNP in monitoring drought at multiple time scales. The drought analysis was also effective in managing Kharif, Rabi, and summer crops. The spatially interpolated drought maps, ranking of rain gauge stations will help the water managers/district administrators for taking appropriate measures in drought relief and prioritization of drought mitigation works.
1. Introduction
Drought is acknowledged as a significant natural disaster which leads to food, fodder, and water shortages along with destruction of vital ecological system. Drought is a natural hazard having negative effect on society and environment which is intensified by increasing water demand (Mishra & Singh, 2010). Drought is a phenomenon associated with scarcity of water due to delay in rainy season and/or reduction in “Normal” rainfall. Droughts can be experienced anywhere such as areas having little or high rainfall. It brings misery to large sections of the population and habitat. The drought characteristics vary significantly amid regions such as the Western Europe, North American Great Plains, southern Africa, Australia, and northwestern India (Wilhite & Buchanan-Smith, 2005).

Drought is an environmental disaster which has concern with hydrology, environment, ecology, meteorology, geology, and agricultural scientists. The surface as well as ground water resources are affected by drought and can lead to reduced-productivity as well as crop failure, reduction in water supply, declined water quality, reduced power generation, disturbed riparian habitations, suspended entertaining events, and economic as well as social events (Riebsame, Changnon, & Karl, 1991).

Demand of water has been increased many folds to cater a growing population in developing countries and for maintaining living standards as well as for recreation in the developed countries. Rise in conflicts for water sharing has been increased amongst urban population (drinking and domestic use), expansion of agriculture in rural sector (livelihood and food security), generation of power (hydropower and thermal power plants), and industrial sectors (processing and cleaning). The conflicts for water sharing between countries, states, regions, and districts had made people enemy of each other. The situation gets worsened in drought period when limited water resources get depleted faster than rejuvenation. Also water scarcity is also added by factors, such as water contamination, variation of rainfall pattern due to climate change, etc.

Indian economy is largely based on agriculture, as approximately 70% of the total population depends on it for their livelihood. Almost 75–90% of the yearly rainfall of India occurs in four months of the rainy season due to the southwest monsoon. Owing to both spatial and temporal abnormalities in monsoon precipitation, droughts frequently occurs in most part of the country. The net sown area in the country is about 140 Mha, out of which the 68% of the area is susceptible to drought and 50% area is classified as severely drought prone. (Kamble, Ghosh, Rajeevan, & Samui, 2010).

Knowledge of the probability of occurrence of droughts along with duration, intensity, and spatial extent is critical in the planning as well as management of scarce water resources. To compare spatial and temporal variation of historical droughts with current conditions, drought indices are used and thus provide decision-makers a tool to measure drought events and reduce drought impacts.

The interpretation of raw data in analyzing drought conditions over an area is made simple by a single value of drought Index (Pai, Latha, Guhathakurta, & Hatwar, 2011). The Percent of Normal Precipitation (PNP) and Standardized Precipitation Index (SPI) are widely used worldwide to analyze the spatial and temporal variation of Meteorological drought occurred due to reduction in precipitation over a period of time in a region. To quantify precipitation variation at multiple time scales, the SPI was developed by McKee, Doesken, and Kliest (1993). As per their definition, a drought event at any time scale occurs when the SPI is negative and reaches −1. A drought event terminates when the SPI becomes positive. Drought classification based on SPI is provided in Table 1. After conceptualization, the SPI is used by many researchers to quantify drought in their studies. The main advantage of the SPI is that dry and wet periods can be monitored over a wide range of time scales starting from 1 to 72 months (Edwards & McKee, 1997).

In Asia, the SPI is getting recognition in the study of the magnitude, intensity, and spatial variation of droughts. Pai et al. (2011) examined droughts of various intensities at district as well as national level over India using PNP and SPI. They observed that district-wide drought climatology over India based on PNP is found to be highly influenced by aridity of the region, while that based on SPI is not biased. They also found that for district-wide drought monitoring, SPI is more suitable whereas for the nation-wide drought monitoring, both PNP and SPI are suitable during the southwest monsoon season. Mishra and Desai (2005) analyzed temporal variation of drought using SPI values for...
multiple time scales in the Kansabati river basin, India by developing quantitative relationships between frequency, drought severity and area. They found out that the local drought in the basin can be assessed by drought severity—area—frequency curves. Xie, Ringler, Zhu, and Waqas (2013) investigated the spatio-temporal variability of drought frequency by calculating SPI for 3-, 6-, and 12-month time scales using gridded precipitation data in Pakistan during 1960–2007. Their PCA of the calculated SPI fields revealed that the drought incidence in Pakistanis is characterized by a large spatial extent of affected area. A 16 years cycle having an intensive drought period lasting for some years is noticed by them. Mishra and Nagarajan (2011) examined drought characteristics using SPI in the Tel river basin in Kalahandi district of Odisha, India. Their study demonstrated that the study area is affected by severe and extreme droughts from time to time.

Drought climatology for Europe was studied by Hughes and Saunders (2002) by SPI at multiple time scales for the period of 1901–1999. Their study has shown that SPI is a simple and effective tool in analyzing European drought. Mihajlović (2006) analyzed the meteorological drought for the period of 2003–2004 at 32 stations in the Pannonian part of Croatia by means of the SPI at multiple time scales of 1, 3, 6, and 12 months. It was also shown that the drought progression from start to its end can be monitored by SPI at multiple time scales.

Many researchers had studied droughts in India using PNP. Ramdas (1950) defined drought when weekly rainfall is 50% of the Normal or less. Using PNP, Appa Rao (1991) categorized the drought prone and chronically drought affected areas. The various statistical features of country-wide drought incidences were examined by Chowdhury, Dandekar, and Raut (1989). A decreasing trend in the drought affected area in India was observed by Sen and Sinha Ray (1997). A detailed study consisting of the variability of drought incidence over districts of Maharashtra was done by Gore and Sinha Ray (2002). The probability of occurrence of drought at subdivision-wide and national-wide scale was done by Sinha Ray and Shewale (2001). Guhathakurta (2003) studied the probability of district-wide droughts in India.

In India, crop seasons are categorized as Kharif season, Rabi season, and hot weather/summer season. The Kharif season commences from June 15 to October 14. Paddy and groundnut are examples of Kharif crops. The Kharif season coincides with the rainfall season due to the southwest monsoon which occurs in June–September. About 80% of annual rainfall occurs during southwest monsoon, around 15% in northeast post-monsoon (October to December) and about 5% pre-monsoon (January to May). The Rabi season commences from October 15 to February 28/29 and coincides with post-monsoon season. Wheat and Gram are examples of Rabi crops. One or two intermittent rains are sufficient for Rabi crops. They survive on the soil moisture retained at the end of Kharif season and augmented by the ground water. Also the low temperature in the winter season causes very less evaporation losses.

It is very difficult to develop a single definition of a drought which is having diverse geographical and temporal distribution and also affecting the wide variety of sectors (Heim, 2002). The aim of this

| SPI values | Class            |
|------------|------------------|
| >2         | Extremely wet    |
| 1.5 to 1.99| Very wet         |
| 1.0 to 1.49| Moderately wet   |
| −0.99 to 0.99| Near normal     |
| −1 to −1.49| Moderately dry   |
| −1.5 to −1.99| Severely dry    |
| <−2        | Extremely dry    |
study was to investigate the Meteorological drought, its spatial and temporal variation by the SPI and PNP at multiple time scales over the Krishna basin in Maharashtra. Also, an attempt is made to find out which of these two indices is better for drought monitoring over the study area. This paper evaluates the SPI on 1-, 3-, 6-, 9-, 12-, 18-, 24-, 36-, and 48-month time scales computed using long time series (1960–2012) of monthly precipitation data at 59 stations in the study area. PNP is analyzed using Annual precipitation and Water-Year precipitation of the same time series.

2. Study area and data used
A part of the Krishna basin which comes under administrative boundary of the state of Maharashtra, is selected to analyze the spatio-temporal variation of Meteorological drought. The Krishna river basin comes under semi-arid southern region. It ranks fourth considering annual discharge, and fifth largest basin in terms of surface area. The basin lies between 73°17′ to 81°9′ east longitudes and 13°10′ to 19°22′ north latitudes. It extends 701 km in terms of length and 672 km in width. In the Krishna river basin, predominant land is used for agriculture where the annual Normal rainfall (1969–2004) is 859 mm. Krishna basin occupies eight percent of Indian Territory with surface area of about 258,948 km². The basin area is shared by three states of erstwhile Andhra Pradesh (75,948 km², 30%), Karnataka (111,650 km², 44%), and Maharashtra (69,425 km², 26%). Out of total river length of about 1,400 km, Maharashtra shares 306 km while the remaining river flows through Karnataka (483 km) and at last Andhra Pradesh (306 km) (The Krishna basin report, India-WRIS, 2014). The study area under research is shown in Figure 1.

The monthly rainfall data is compiled from daily rainfall data of 59 rainfall stations in the Krishna basin in Maharashtra from 1960 to 2012 is used for the analysis. The mean rainfall varies from 5610 mm at Mahabaleshwar situated in Western Ghats of Maharashtra where the river originates to 498 mm at Dhond in the plateau.

3. Methodology

3.1. Steps in calculating SPI
The SPI was developed by McKee et al. (1993) and McKee Doesken, and Kleist (1995) to compute precipitation deficits on multiple time scales. The brief procedure to calculate SPI is as follows.
The probability density function (PDF) is determined to describe the long-term time series of precipitation observations.

The cumulative probability of an observed precipitation amount is computed.

The inverse normal (Gaussian) function, with mean zero and variance one, is then applied to the cumulative probability resulting in the SPI.

The detailed procedure is referred from McKee et al. (1993-1995).

### 3.2. Steps in calculating PNP

PNP is a simple form of determining the amount of precipitation at any region or location. It is very effective when used for rainfall season for climatologically similar regions. It is the ratio of actual precipitation to Normal precipitation determined in percentage. The Normal precipitation is generally considered to be a 30-year mean. PNP can be calculated for a day, week, month, annual year, year, and rainfall season. When calculated for annual year, monthly precipitation totals from January to December is considered, while for water year, monthly precipitation totals from June to May is considered. Table 2 denotes the weather classification based on PNP.

\[
P_{\text{PNP}} = \frac{P}{P_{\text{Normal}}} \times 100
\]

where \(P_{\text{Normal}}\) = Long Period Average (LPA). It is the mean rainfall value of particular time scale over a specified period.

Definition of a drought is region specific. The U.S. Weather Bureau identified drought when the rainfall of 21 days or above is less than 30% of the Normal value (Henry, 1906). In this study, we have considered the Meteorological drought which is defined by the India Meteorological Department as the seasonal rainfall deficiency exceeding 25% of the long-term average value of the rainfall. A local drought is considered to be “moderate” if the rainfall deficiency at that place is in between 26% and 50% of the Normal value and “severe” if it is more than 50% of the Normal value.

### 4. Results and discussion

In temporal analysis, temporal variation of droughts by SPI and PNP drought indices, weather classification by SPI at multiple time scales, and month wise variation of weather at SPI-1 time scale is done.

#### 4.1. Temporal variation of droughts over the study area

PNP analysis is done under two categories namely water year and annual year. In water year, monthly precipitation totals from June to May are considered, while for annual year, monthly precipitation totals from January to December is considered. SPI analysis is done using SPI-12 time scale for the month of May and December. SPI-12 of May resembles to water year (June-May) and SPI-12 of December resembles to annual year (January–December) of PNP index.

For local drought analysis under PNP index, district wise classification is used and for regional drought analysis, nation wise classification is used as per Table 2. Three severe droughts viz. 1972, 2003, and 2012 which are common as per PNP and SPI were compared by using Pearson Correlation co-eff. Local droughts as per rain gauge stations in these three drought years were compared using PNP and SPI index.

| Season rainfall classification | Local drought | Regional drought |
|-------------------------------|---------------|-----------------|
| No drought                    | >75% of LPA   | 0–10% of area is under local drought |
| Mild meteorological drought   | <75% of LPA   | 10–20% of area is under local drought |
| Moderate meteorological drought | 50–74% of LPA | 21–40% of area is under local drought |
| Severe Meteorological drought | <50% of LPA   | >40% of the area is under local drought |
From Table 3 it is observed that (i) Pearson Correlation co-eff. between SPI-12 and PNP is nearly equal to 1. (ii) SPI has three classes (moderate, severe, and extreme) of drought as compared to two (moderate and severe) classes of PNP. (iii) Number of moderate drought incidences as per PNP is more than that of SPI-12. (iv) Sum of severe and extreme droughts as per SPI is more than severe drought as per PNP. (v) Number of rainfall stations under severe drought class as per annual year is more than water year.

### 4.2. Weather classification at multiple time scales of SPI

The weather classification by SPI is classified as per Table 1 and the results are tabulated in Table 4. Since the number of months available in each time scales differ from each other, all values are converted into percentage for easy comparison and displayed in Figure 2. It is observed from Figure 2 that there is decreasing trend in Wet class while increasing trend for Dry class from SPI-1 to SPI-12. SPI-1 shows most wet conditions. Dry conditions are more prominently shown by SPI-48. SPI-3 shows more percentage of normal rainfall than any other time scales.

### 4.3. Month wise variation of weather at SPI-1 time scale

Month wise variation is done by SPI-1 time scale, which resembles to average monthly rainfall over the study period and gives fair picture of monthly rainfall pattern.

From Table 5 it is observed that even though rainfall is very scanty over January–March, large positive SPI values are generated. Drought conditions are not observed in January–April and November–December. May has only one incidence of moderately dry condition. June–October has nearly equal numbers of Wet and Dry conditions.

### Table 3. Local drought classification as per PNP and SPI-12

| Drought classification | 1972 SPI December | PNP 1972 annual | 2003 SPI December | PNP 2003 annual | 2012 SPI December | PNP 2012 annual | 1973 SPI May | 1973 PNP water year | 2004 SPI May | 2004 PNP water year |
|------------------------|------------------|-----------------|------------------|-----------------|------------------|-----------------|-------------|---------------------|-------------|---------------------|
| Moderate               | 7                | 21              | 11               | 32              | 17               | 28              | 6           | 21                  | 14          | 35                  |
| Severe                 | 14               | 34              | 16               | 21              | 15               | 12              | 12          | 33                  | 26          | 17                  |
| Extreme                | 34               | –               | 24               | –               | 3                | –               | 36          | –                   | 10          | –                   |
| Total                  | 55               | 55              | 51               | 53              | 35               | 40              | 54          | 54                  | 50          | 52                  |
| Pearson co-eff.        | 0.92             | 0.89            | 0.94             | 0.91            | 0.87             |                 |             |                     |             |                     |

### Table 4. Weather classification based on multiple time scales of SPI

| SPI series | 2.00 or more | 1.50 to 1.99 | 1.00 to 1.49 | −0.99 to −0.99 | −1.00 to −1.49 | −1.50 to −1.99 | −2.00 or less | Total (months) |
|------------|--------------|--------------|--------------|----------------|----------------|----------------|---------------|----------------|
|            | Extremely wet| Very wet     | Moderately wet| Near normal | Moderately dry | Severely dry  | Extremely dry |               |
| SPI-1      | 22           | 52           | 131          | 387           | 26             | 12             | 7             | 636            |
| SPI-3      | 15           | 27           | 62           | 469           | 35             | 17             | 10            | 634            |
| SPI-6      | 15           | 26           | 55           | 446           | 52             | 23             | 14            | 631            |
| SPI-9      | 17           | 24           | 51           | 441           | 54             | 25             | 17            | 628            |
| SPI-12     | 18           | 23           | 49           | 439           | 55             | 23             | 17            | 625            |
| SPI-18     | 17           | 25           | 48           | 433           | 55             | 23             | 17            | 619            |
| SPI-24     | 17           | 26           | 47           | 427           | 56             | 26             | 14            | 613            |
| SPI-36     | 18           | 23           | 48           | 416           | 55             | 29             | 12            | 601            |
| SPI-48     | 16           | 25           | 50           | 398           | 60             | 27             | 13            | 589            |
4.4. Spatial variation of drought severity over the study area

The study area is bifurcated using Theissen Polygon tool in ArcGIS 10.2, into 59 polygons corresponding to 59 rainfall stations. Each of the polygons represents the influential area of the rainfall station as per its location in the study area measured in sq. km. and is expressed as fraction of the study area. The rainfall stations closely spaced will be assigned less area and vice versa (Figure 3). Even though some stations may designate drought conditions, a regional drought is acknowledged only when some major portion of the total study area is under drought.

Regional weather is classified as per Table 1 for SPI and Table 2 for PNP to all 59 rain gauge stations in the study area from 1960 to 2012. Area wise regional weather classification of every year is performed and the results are tabulated in Table 6.

From Table 6 it is observed that number of severe drought incidences in PNP analysis increases as compared to SPI. Number of Moderate drought incidences as per PNP water year is more than SPI-May. Number of Mild drought incidences as per SPI-May is more than PNP water year while it is nearly same for SPI-December and PNP-Yearly. The area wise weather classification for PNP-Water year is performed for all Severe and Moderate drought years. Sr. No. 1–7 are Severe droughts while Sr. No. 8–19 are Moderate droughts. The results are tabulated in Table 7 and displayed in Figure 4.

Table 5. Month wise variation of weather on multiple time scales of SPI-1

| SPI values | Class         | January | February | March | April | May | June | July | August | September | October | November | December |
|------------|---------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| >2.00      | Extremely wet | 1       | 8        | 2     | 1     | 2   | 1    | 1    | 1      | 1         | 1       | 1        | 1        |
| 1.50 to 1.99 | Very wet     | 15      | 14       | 4     | 3     | 2   | 2    | 2    | 2      | 2         | 2       | 2        | 2        |
| 1.00 to 1.49 | Moderately wet | 32    | 26       | 20    | 5     | 4   | 5    | 5    | 6      | 5         | 5       | 4        | 11       |
| −0.99 to 0.99 | Near Normal | 5       | 5        | 27    | 43    | 44  | 37   | 36   | 35     | 36        | 36      | 44       | 39       |
| −1.00 to −1.49 | Moderately dry | 0  | 0        | 0     | 0     | 1   | 4    | 5    | 5      | 4         | 7       | 0        | 0        |
| −1.50 to −1.99 | Severely dry | 0      | 0        | 0     | 0     | 2   | 2    | 3    | 3      | 2         | 0       | 0        | 0        |
| <−2.00     | Extremely dry | 0      | 0        | 0     | 0     | 1   | 2    | 1    | 1      | 1         | 0       | 0        | 0        |
From Table 7 it is observed that drought year 1972–1973 is the severest of all with 51% of study area under severe drought and 39.4% of moderate drought followed by 2003–2004 with 23.4% of study area under severe drought and 65.8% of moderate drought.

4.5. Drought analysis for managing the Kharif, Rabi, and summer/hot season crops

Table 8 shows the classification of rainfall stations by drought severity as per SPI-12 (December) and PNP (Yearly), similarly Table 9 shows the classification of rainfall stations by drought severity as per SPI-12 (May) and PNP (Water-Year) for various drought years. From Tables 8 and 9 it is observed that in comparison with SPI-12 analysis, PNP analysis shows more number of stations under drought. It is observed that even though the average PNP is greater than 100% for the year 1994–1995; the area is witnessed by Moderate drought as per regional drought classification shown in Table 7.

Drought analysis by SPI-12 (December) and PNP-(Water-Year) designates the water stress condition for January–December and June–May, respectively. By comparing average SPI-12 and PNP from Tables 8 and 9, it is observed that the drought severity is increased for all Water Years at par with antecedent Annual year except 1985–1986, 1986–1987, 1992–1993, 2003–2004, and 2001–2002 where the drought severity is reduced. This is due to non-seasonal rainfall from January to May. The increase in drought severity for water year hampers the Summer/Hot season crops which are water stressed due to failure of monsoon and vice versa. Thus SPI-12 (May) and PNP (Water Year) in
comparison with SPI-12 (December) and PNP (Yearly), helps to analyze the state of Summer/Hot season crops. Drought analysis by SPI-12(December) and PNP-Yearly designates the Water Balance due to southwest monsoon and northeast post-monsoon rains which terminates by the end of December. The rainfall stations under Moderate droughts (PNP: 50–74% and SPI-12: −1.00 to −1.49) for all drought years is witnessed by failure of Rabi crops with reduced productivity of Kharif crops. The rainfall stations under Severe droughts (PNP: <50%) and Severe/Extreme dry conditions (SPI-12: <−1.49) for all drought years is witnessed by failure of both Kharif as well as Rabi crops.
4.6. Spatial interpolation of SPI values

The Inverse Distance Weighting (IDW) method is used for spatial interpolation of SPI Values over the entire study area. IDW weights the influence of each SPI value by a normalized inverse of the distance from the rain gauge station to the interpolated point. It is assumed by IDW method that SPI value has more influence at the rain gauge station and it diminishes with distance. The SPI value of neighboring stations is also considered by the IDW approach. The spatial display maps for SPI values were prepared by using Arc GIS 10.2 for severe drought years and are displayed in Figures 5–7. The 1972 drought was most severe and can be observed by spatial coverage of red color. The 2003 drought is little severe with reduction in red color. The 2012 drought is very less severe with very few red spots.

4.7. Identification of severe drought prone areas

As per McKee et al. (1993), SPI greater than −2 is classified as Severely Dry. The summation of drought months having SPI value >−2 for all time scales is performed. The ratio of sum for each station to the highest value from all stations is multiplied by 10. This method will assign rank from 1 to 10. Rank 1 will be the least severe drought prone area while rank 10 will be the highest severe drought prone area as per Table 10. From Table 10 it is observed that Gadhingalaj station is least affected by droughts whereas Paud station is most affected by droughts.

5. Conclusion

Drought climatology over Krishna basin in Maharashtra is examined at both local and regional level using PNP and SPI. The PNP and SPI analysis was helpful to identify local and regional droughts.
### Table 9. Drought classification of rainfall stations as per SPI-12 (May) and PNP (water-year)

| Year       | SPI-12 (May) | PNP (water-year) | Average |
|------------|--------------|------------------|---------|
|            | Extremely dry| Severely dry     | Moderately dry | Total | SPI-12 | Severe drought | Moderate drought | Total | Average PNP (%) |
|            | −2.00 or less| −1.50 to −1.99   | −1.00 to −1.49 |       |        | <50%          | 50–74%          |       |                 |
| 1971–1972  | 3            | 2                | 13           | 18    | −0.72  | 3             | 22              | 25    | 78.11             |
| 1972–1973  | 36           | 12               | 6            | 54    | −2.03  | 33            | 21              | 54    | 49.29             |
| 1982–1983  | 1            | 8                | 17           | 26    | −0.80  | 1             | 31              | 32    | 76.58             |
| 1985–1986  | 2            | 9                | 11           | 22    | −0.91  | 4             | 23              | 27    | 73.09             |
| 2000–2001  | 1            | 3                | 16           | 20    | −0.56  | 1             | 23              | 24    | 83.87             |
| 2002–2003  | 4            | 6                | 17           | 27    | −0.92  | 4             | 28              | 32    | 74.08             |
| 2003–2004  | 10           | 26               | 14           | 50    | −1.56  | 17            | 35              | 52    | 58.08             |
| 1966–1967  | 0            | 3                | 8            | 11    | −0.32  | 1             | 16              | 17    | 88.89             |
| 1968–1969  | 3            | 4                | 9            | 16    | −0.56  | 3             | 15              | 18    | 83.62             |
| 1978–1979  | 0            | 3                | 7            | 10    | −0.26  | 2             | 12              | 14    | 90.96             |
| 1984–1985  | 0            | 1                | 7            | 8     | −0.30  | 0             | 13              | 13    | 90.14             |
| 1986–1987  | 0            | 3                | 8            | 11    | −0.56  | 1             | 19              | 20    | 81.68             |
| 1987–1988  | 7            | 5                | 8            | 20    | −0.37  | 4             | 16              | 20    | 94.28             |
| 1992–1993  | 0            | 1                | 8            | 9     | −0.45  | 0             | 16              | 16    | 84.78             |
| 1994–1995  | 0            | 5                | 11           | 16    | 0.21   | 4             | 15              | 19    | 103.65            |
| 1995–1996  | 0            | 4                | 5            | 9     | −0.43  | 1             | 14              | 15    | 86.96             |
| 2001–2002  | 0            | 2                | 13           | 15    | −0.47  | 0             | 20              | 20    | 86.44             |
| 2008–2009  | 0            | 0                | 10           | 10    | −0.26  | 0             | 13              | 13    | 90.82             |
| 2011–2012  | 1            | 5                | 10           | 16    | −0.49  | 3             | 19              | 22    | 82.77             |

**Figure 5. Spatial variation of 1972 drought.**

![1972 Drought Dec](image)
However, there were significant differences in analysis of local and regional droughts. Since SPI is a normalized Index, the variability of SPI is proportional to that of the precipitation variance. SPI performs better than PNP in monitoring drought at multiple time scales. Drought severity of climatologically different locations or regions can be compared by SPI. From Table 4 it can be concluded that SPI-1 fails to recognize drought conditions in pre-monsoon and post-monsoon months. SPI-1 shows exacerbated picture of very wet conditions in January–March, even though rainfall is almost nil during these months. SPI-1 time scale evaluates wet or dry conditions only from June to October i.e.
Table 10. Ranking of rain gauge stations as per Local droughts at multiple time scales

| Station name    | SPI-1 | SPI-3 | SPI-6 | SPI-9 | SPI-12 | SPI-18 | SPI-24 | SPI-36 | SPI-48 | Total | Rank |
|-----------------|-------|-------|-------|-------|--------|--------|--------|--------|--------|-------|------|
| Mahabaleshwar   | 6     | 12    | 13    | 12    | 14     | 15     | 11     | 0      | 0      | 83    | 3    |
| Radhanagari     | 8     | 6     | 9     | 11    | 15     | 15     | 13     | 1      | 0      | 78    | 3    |
| Chandgad        | 10    | 9     | 14    | 14    | 11     | 28     | 27     | 39     | 39     | 191   | 7    |
| Velhe           | 7     | 5     | 4     | 4     | 1      | 5      | 8      | 12     | 14     | 60    | 2    |
| Ajra            | 9     | 11    | 12    | 13    | 12     | 8      | 10     | 14     | 24     | 113   | 4    |
| Shahuwadi       | 7     | 10    | 12    | 15    | 13     | 15     | 14     | 12     | 13     | 111   | 4    |
| Patan           | 8     | 10    | 14    | 14    | 14     | 12     | 12     | 24     | 122    | 4    |
| Paud            | 12    | 18    | 23    | 25    | 22     | 33     | 38     | 47     | 58     | 276   | 10   |
| Panhala         | 10    | 7     | 9     | 9     | 11     | 2      | 0      | 0      | 0      | 55    | 2    |
| Medha           | 5     | 9     | 11    | 14    | 15     | 14     | 12     | 1      | 0      | 91    | 3    |
| Gargoti         | 10    | 10    | 12    | 13    | 15     | 18     | 21     | 31     | 29     | 159   | 6    |
| Bhor            | 8     | 9     | 17    | 22    | 22     | 22     | 20     | 12     | 5      | 137   | 5    |
| Kolhapur        | 8     | 10    | 16    | 14    | 10     | 14     | 8      | 17     | 21     | 118   | 4    |
| Shirala         | 9     | 11    | 16    | 17    | 21     | 18     | 23     | 31     | 44     | 190   | 7    |
| Godhingalaj     | 7     | 8     | 7     | 9     | 0      | 0      | 0      | 1      | 2      | 32    | 1    |
| Satara          | 6     | 13    | 13    | 14    | 20     | 20     | 18     | 10     | 14     | 128   | 5    |
| Wai             | 4     | 10    | 14    | 17    | 19     | 23     | 20     | 15     | 24     | 146   | 5    |
| Kagol           | 9     | 6     | 12    | 14    | 17     | 17     | 12     | 1      | 0      | 159   | 6    |
| Ambegaon        | 3     | 10    | 11    | 14    | 9      | 8      | 5      | 0      | 0      | 44    | 2    |
| Pune            | 6     | 8     | 10    | 8     | 7      | 5      | 0      | 0      | 0      | 96    | 3    |
| Koregaon        | 5     | 8     | 12    | 17    | 13     | 14     | 4      | 1      | 1      | 75    | 3    |
| Tuljapur        | 6     | 11    | 15    | 16    | 14     | 13     | 16     | 14     | 12     | 117   | 4    |
| Karad           | 5     | 10    | 17    | 27    | 30     | 24     | 21     | 17     | 11     | 162   | 6    |
| Hatkanangale    | 9     | 12    | 14    | 20    | 19     | 15     | 7      | 0      | 0      | 96    | 3    |
| Islampur        | 10    | 11    | 13    | 19    | 20     | 21     | 19     | 17     | 22     | 152   | 6    |
| Solapur         | 6     | 10    | 16    | 18    | 19     | 23     | 18     | 1      | 0      | 111   | 4    |
| Jamkhed         | 4     | 8     | 18    | 17    | 21     | 16     | 12     | 11     | 10     | 117   | 4    |
| Akalkot         | 8     | 12    | 15    | 14    | 12     | 15     | 18     | 10     | 1      | 105   | 4    |
| Junnar          | 7     | 12    | 19    | 26    | 29     | 19     | 12     | 0      | 0      | 124   | 4    |
| Khed            | 7     | 10    | 13    | 13    | 11     | 6      | 0      | 1      | 8      | 69    | 3    |
| Barshi          | 3     | 9     | 18    | 24    | 31     | 30     | 28     | 23     | 23     | 189   | 7    |
| Asti            | 5     | 12    | 22    | 30    | 28     | 23     | 24     | 12     | 7      | 163   | 6    |
| Pandharpur      | 7     | 6     | 9     | 13    | 16     | 17     | 10     | 8      | 0      | 86    | 3    |
| Sangola         | 6     | 9     | 10    | 12    | 9      | 6      | 3      | 0      | 0      | 55    | 2    |
| Sangli          | 8     | 6     | 9     | 10    | 9      | 3      | 0      | 0      | 0      | 45    | 2    |
| Shiraz          | 8     | 7     | 13    | 13    | 11     | 16     | 13     | 22     | 14     | 117   | 4    |
| Viga            | 5     | 8     | 15    | 16    | 12     | 17     | 10     | 13     | 24     | 120   | 4    |
| Ahmednagar      | 4     | 8     | 18    | 17    | 21     | 16     | 12     | 11     | 10     | 117   | 4    |
| Lasgaon         | 9     | 13    | 19    | 23    | 25     | 27     | 28     | 27     | 27     | 198   | 7    |
| Madha           | 5     | 9     | 10    | 15    | 14     | 19     | 13     | 2      | 9      | 96    | 3    |
| Miraj           | 9     | 8     | 10    | 12    | 12     | 14     | 2      | 4      | 4      | 75    | 3    |
| Parenda         | 6     | 6     | 9     | 18    | 20     | 34     | 35     | 23     | 15     | 166   | 6    |
| Saswad          | 4     | 7     | 13    | 16    | 19     | 9      | 2      | 0      | 0      | 70    | 3    |
| Jath            | 11    | 10    | 13    | 14    | 11     | 30     | 34     | 34     | 46     | 203   | 7    |

(Continued)
S-W monsoon period. From frequency distributions of weather conditions from Table 3, it can be concluded that SPI-1 values are most positively skewed while SPI-48 values are negatively skewed. SPI-9, SPI-12, and SPI-18 values have Normal distribution. Sum of severe and extreme droughts as per SPI is much more than severe drought as per PNP, while number of moderate droughts are more in PNP. Water year drought analysis will have more influence in managing summer crops, since we can assess the availability of soil moisture at the end of water year; similarly Yearly drought analysis will have more influence on managing Kharif and Rabi crops. Number of rainfall stations under severe drought class as per Annual rainfall is more than Water Year. The Theissen polygon method to assign influence area to each rain gauge station seems to be appropriate for regional drought analysis. The spatially interpolated drought maps will help water managers and district administrators for taking measures in drought relief and contingency planning. The ranking of rain gauge stations will help the water managers and administrators to allocate funds and deciding priority for drought mitigation works.

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Table 10. (Continued)

| Station name | SPI-1 | SPI-3 | SPI-6 | SPI-9 | SPI-12 | SPI-18 | SPI-24 | SPI-36 | SPI-48 | Total | Rank |
|--------------|-------|-------|-------|-------|--------|--------|--------|--------|--------|-------|------|
| Mohol        | 4     | 9     | 17    | 27    | 27     | 26     | 26     | 10     | 5      | 151   | 5    |
| Karmala      | 5     | 9     | 19    | 28    | 31     | 22     | 13     | 13     | 1      | 141   | 5    |
| Mangalvedha  | 6     | 12    | 14    | 17    | 16     | 25     | 35     | 19     | 28     | 172   | 6    |
| Dahiwadi Man | 5     | 9     | 12    | 15    | 11     | 17     | 11     | 10     | 11     | 101   | 4    |
| Karjat       | 7     | 9     | 21    | 26    | 27     | 21     | 21     | 22     | 8      | 162   | 6    |
| Malshiras    | 7     | 9     | 14    | 19    | 17     | 10     | 8      | 0      | 9      | 93    | 3    |
| Indapuri     | 4     | 8     | 16    | 17    | 9      | 2      | 0      | 0      | 0      | 56    | 2    |
| Khandala     | 7     | 7     | 16    | 23    | 25     | 23     | 30     | 25     | 13     | 169   | 6    |
| Parner       | 3     | 15    | 24    | 31    | 36     | 29     | 25     | 14     | 22     | 199   | 6    |
| Vaduj        | 5     | 11    | 15    | 15    | 17     | 15     | 10     | 11     | 20     | 119   | 4    |
| Shrigonda    | 7     | 17    | 20    | 22    | 17     | 21     | 18     | 19     | 10     | 151   | 5    |
| Baramati     | 6     | 10    | 18    | 24    | 17     | 16     | 17     | 13     | 2      | 123   | 4    |
| Phaltan      | 5     | 7     | 11    | 12    | 12     | 10     | 11     | 15     | 9      | 92    | 3    |
| Shirur       | 10    | 13    | 19    | 18    | 12     | 10     | 9      | 20     | 29     | 140   | 5    |
| Dhond        | 5     | 11    | 20    | 26    | 24     | 16     | 11     | 13     | 11     | 137   | 5    |
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