CrossMark

Analysis of Rainfall in Assessing the Drought in Semi-arid Region of Karnataka State, India

V. Jayasree [1,2] · B. Venkatesh [1,2]

Abstract The present study focuses on drought analysis with an aim to understand the drought vulnerability, estimate and map the drought duration and severity in drought prone North Interior Karnataka region, India. A detailed analysis were carried out using rainfall data of more than 178 (with greater than 30 years data) stations to understand the drought characteristics. Rainfall descriptive variability, percentage occurrence of drought incidences and spatial distribution of rainfall were derived. In order to evaluate the drought severity and its extent and to map, method proposed by Ponce et al. (2000) and the Geographic Information System has been used. The method by Ponce et al. (2000) characterize drought based on intensity, duration and recurrence interval using mean annual precipitation of a location. The results obtained for the study area indicate that, the region is mostly semi-arid with drought occur for more than 50 % of the time. The majority of the drought events are of moderate intensity with few extreme intensity events. Further, it is noticed that, in many station, the rainfall show a decreasing trend. Since, rainfall in this region are mostly declining due to climatic change, the area would experience increasing drought severity in the forthcoming years. The outcome of the study would be useful in understanding the drought pattern, severity and extent in the study area which can be used by scientists and water management professionals to plan drought mitigation measures.

Keywords Drought · North Interior Karnataka · Deccan Plateau · Drought severity · Mapping the extent · Geographic information system

---

✉ B. Venkatesh
bvenki30@yahoo.com

1 Peoples Foundation for Scientific Socio-Economic Development, Bangalore 560 001 Karnataka, India

2 Hard Rock Regional Centre, National Institute of Hydrology, Hanuman Nagar, 2nd Stage, Belgaum 590 019 Karnataka, India

1 Introduction

Drought is one of the most damaging climate related hazards to impact society. Drought studies are getting more attention in the recent past because of changing climate resulting from global warming and its impact on increasing drought like situations in many parts of the World. Although drought is a naturally occurring phenomenon throughout most parts of the World, its effects have tremendous consequences for the physical, economic, social and political elements of our environment. Drought is a slow creeping disaster and it can last any number of days and the severity cannot be predicted. It has extensive spatial dimension and thus can have serious implication on the socio-economic stability of an entire region. As it is not possible to avoid droughts, drought preparedness can be developed and drought impacts can be managed.

Being a natural hazard as well as a disaster (Paulo et al. 2012), drought is characterized by its severity, duration and areal extent. Together with these, characteristics such as frequency and vulnerability are also important as these characteristics are beneficial in developing drought policies, monitoring systems, mitigation strategies and preparedness plans.

Drought is characterised by simple mathematical indices. This index is a single number that characterise an aspect of drought at a particular region. Drought planners usually rely on these indices to decide when to start interventions and decide mitigation and adaptation strategies (Ponce and Pandey 2000). There are a variety of indices that describe drought based on the classification whether it is meteorological, agricultural, hydrological or socio-economical. As basic definition of drought is defined as precipitation deficit, it is treated as the most important meteorological variable controlling formation and persistence of drought. There are a number of studies which reported precipitation as principal indicator of drought (Alam et al. 2013; Asati 2012; Abdulrahim et al. 2013; Bhakar et al. 2006) and have studied rainfall characteristics to define droughts. Drought indices use rainfall data either singly or in combination with other meteorological elements to derive the characteristics of drought (WMO 1975). Some of the commonly used drought indices are the PDSI (Palmer 1965), the Deciles (Kinninmonth et al. 2000), the SPI (McKee et al. 1993, 1995), vegetation condition index (Liu and Kogan 1996) national rainfall index (Gommes and Petrassi 1994) and many others with rainfall data as input to most of these indices. Comprehensive review on these indices can be found in specific publications (Richard and Heim 2002; Hayes 2007; Tsakiris et al. 2007; Mishra and Singh 2010).

Droughts have a strong temporal and spatial component because of the variability in rainfall (Sen 2008). Drought vulnerability defined in terms of severity and extent are very much useful for decision makers who can conceptually visualize the hazard risk and convey information to other sectors to ensure that they will act timely and effectively to tackle the drought related losses. Mapping of the drought disaster is one of the adaptation strategies to consequences of increasing climatic variability and changes.

India being a drought prone country with nearly 1/6th of its geographical area affecting about 12 % of its population. During the last century, India witnessed worst droughts in the years 1917–18, 1965–66 and 1986–87, 2002, 2009 and 2012 (Manual for drought management 2009, Ministry of Agriculture and external affairs. Food and Public distribution). Drought disasters have become a national priority for the Indian Government particularly as climate change causes erratic monsoons. Drought prone areas of the country are mostly found in arid, semi-arid and sub-humid regions which experience very less average annual rainfall. Arid region of Rajasthan and east of

Western Ghats, which falls under rain-shadow region are the most drought prone areas in the country (Jain et al. 2007).

Karnataka ranks second, next only to Rajstahan in India, in terms of total geographical area prone to drought (Nagaraja et al. 2011). Among its 30 districts, 18 are drought prone. These districts fall mainly in the Deccan plateau to the lee ward side of Western Ghats. As almost 90 % of the population in this semi-arid region is dependent on agriculture for their livelihood, drought events brings devastating effects on agriculture as well as economy of the region. According to reports, the state faced severe most consecutive droughts during the years 2001–02, 2002–03 and 2003–04, 2009 and 2012 which resulted in huge economic loss to the State. In spite of the frequent drought occurrences in these region, there are no comprehensive contingency plans for drought mitigation or preparedness for facing the drought. Some attempts were made at State level, but these efforts are lacking at district level or taluk level where such interventions would be more significant. Therefore, there is a need to understand the drought characteristics and mapping of the same from the bottom level so as to make the interventions more effective and meaningful. Thus the present study is aimed at understanding the drought vulnerability by developing a methodology which can be used to develop contingency plans for drought management and mitigation.

In this study, an attempt has been made to analyse the rainfall characteristics to define drought vulnerability in the drier belt of Karnataka, India. The study is intended to understand rainfall characteristics that define drought conditions in a semi-arid region comprising of seven districts in North Interior Karnataka. In addition to the classification based on aridity indices, spatial and temporal rainfall variability was also studied to define drought characteristics. Drought intensity, duration and frequency were estimated using the methodology developed by Ponce et al. (2000). Severity of drought was also estimated and its spatial variability has been mapped using geographic information system. The outcome of the study would be useful in understanding the drought pattern, severity and extent in the study area which can be used by scientists and water management professionals so as to plan drought mitigation measures.

2 Materials and Methods

2.1 Study Area

The study has been carried out for most drought prone districts in Northern Karnataka comprising of seven districts namely Bagalkot, Bidar, Bijapur, Gulbarga, Koppal, Raichur and Yadgir distributed within 34 taluks. Geographically the area lies in the Deccan Plateau located between 15° 09′ to 18° 25′ N and 74° 54 to 77° 42 E comprising of total area of 59943 sq.km which constitutes almost 31.2 % of the total geographical area of the state. The total population in the region is about 9265783 as per 2011 census. Agro ecologically, this region forms the hot, semi-arid plateau region of the state. Agriculture is the main occupation in the region; farming and agriculture related business are the major source of income for most of the people in the district. Land use is broadly classified as forest, cultivable lands, barren and rocky lands of which cultivable lands form the major portion. According to ASCR, 2008–09 almost 83 % of the land is under cultivation of which 70 % of gross cultivated area is rain-fed and rest of 30 % area is supplemented with irrigation. Irrigation projects constructed on Bhīma and Krishna rivers form the major source of irrigation.

Being situated in drier areas of the State with high temperature and less humidity, region receives very less rainfall. On an average, the region receives about 650 mm of rainfall in about 50 days. Monsoon rainfall contribution is almost 75–80 % which generally breaks by mid-June and lasts till end of October. Both rainfall and temperature are highly variable both spatially

2.2 Data Used

Daily rainfall data available for 178 rain gauge stations in the study districts have been collected from Directorate of Economics and Statistics, Karnataka. These stations are maintained by various organisations such as meteorological department, water resources development organisation, Karnataka forest department and private agencies and estates. These data have compiled and checked for quality and consistency. The missing and erroneous data have been corrected using standard procedures using HYMOS software. Locations of rain gauge stations have been presented in Fig. 1 (Fig. 1 Raingauges with locations in the study region).

2.3 Methodology

2.3.1 Aridity Index

An aridity index is a numerical indicator of the degree of dryness of the climate at a given location which serves to identify and locate regions that suffer from deficit of available water. A number of methods have been recommended in literature to estimate the aridity index. In
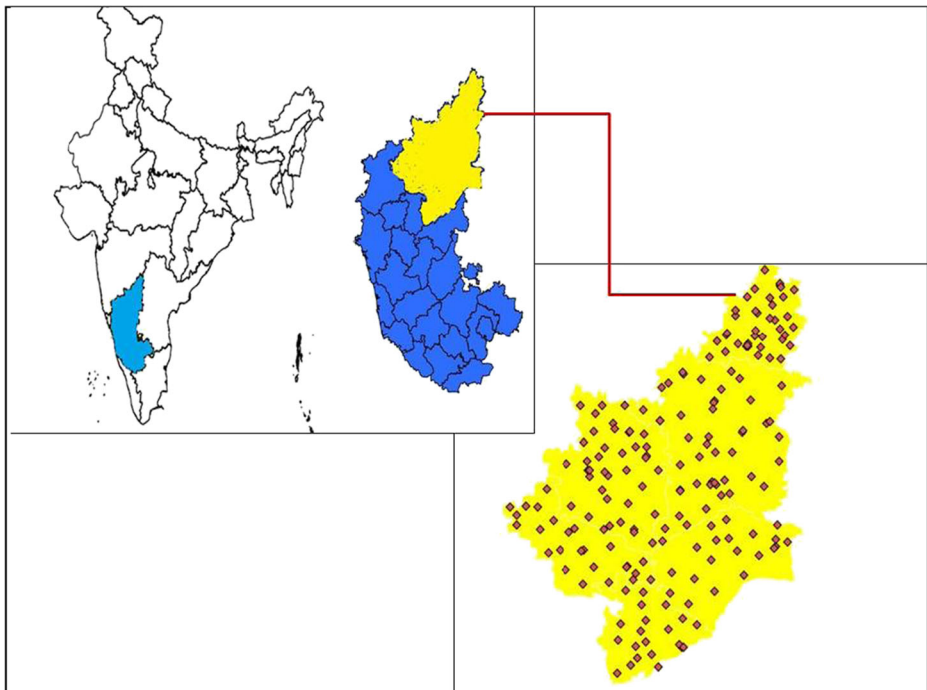

Fig. 1 Rain gauges with locations in the study region

this study, a method proposed by De Martonne (1926) which uses precipitation and temperature data to estimate aridity index has been used to estimate the aridity index. The aridity index can be calculated using the formula

$$AI = \frac{\left[\dfrac{P}{T+10} + \dfrac{12p}{t+10}\right]}{2}$$

Where P is the mean annual precipitation in mm, T is the mean annual temperature in deg C, p is the precipitation of the driest month in mm and 't' is the temperature of the driest month in deg C. Climate types proposed by De Martonne (1926) is as under

Aridity index value	Climatic class
<5	Arid
5–12	Semi-arid
12–20	Dry sub humid
20–30	Moist sub-humid
30–60	Humid
>60	Wet

2.3.2 Rainfall Variability Index (RVI)

Rainfall variability index ((δ) is calculated as

$$\delta i = \frac{Pi - \mu}{\sigma}$$

Where δi is the rainfall variability index for the year i, Pi is the annual rainfall for the year, μ and σ are the mean annual rainfall and standard deviation for the data period chosen for the study. A drought year occurs if δi is negative.

According to WMO (1975), rainfall time series can be classified into different climatic regimes.

$$
\begin{aligned}
P &< \mu - 2\sigma && \text{--- extreme dry} \\
\mu - 2\sigma &< P < \mu - \sigma && \text{--- dry} \\
\mu - \sigma &< P < \mu + \sigma && \text{--- normal} \\
P &> \mu + \sigma && \text{--- wet}
\end{aligned}
$$

2.3.3 Drought Characterisation

Drought intensity, duration and frequency were estimated using the conceptual model developed by Ponce et al. (2000) as shown in Table 1. The conceptual approach is applicable to subtropical and mid latitude regions, and is limited to meteorological droughts lasting at least 1 year.

In the Ponce et al. (2000) methodology, the climate types, which encompass the climatic spectrum from super-arid to super-humid, are defined in terms of ratio of mean annual precipitation P_{ma} to (mean) annual global terrestrial precipitation P_{agt}. The ratio, $P_{ma}/P_{agt} = 1$

Table 1 Conceptual model of drought intensity, duration and frequency

Type	Classification
Super-arid	$P_{ma}/P_{agt} < 0.125$
Hyper-arid	$0.125 \leq P_{ma}/P_{agt} < 0.25$
Arid	$0.25 \leq P_{ma}/P_{agt} < 0.5$
Semi-arid	$0.5 \leq P_{ma}/P_{agt} < 1$
Sub-humid	$1 \leq P_{ma}/P_{agt} < 2$
Humid	$2 \leq P_{ma}/P_{agt} < 4$
Hyper-Humid	$4 \leq P_{ma}/P_{agt} < 8$
Super-Humid	$P_{ma}/P_{agt} \geq 8$

represents the middle of the climatic spectrum. This enables the division of climatic spectrum in sub-tropical and mid-latitudinal regions into the following eight types

The conceptual model is also defined in terms of ratio of annual potential evapotranspiration E_{ap} to mean annual precipitation P_{ma}. The ratio $E_{ap}/P_{ma} = 2$ describes the middle of climatic spectrum. To complement to the description, the length of rainy season Lrs is also indicated. The drought duration varies between 1 year at extremes of climatic spectrum and 6 year at the middle. The Station Index (S) is defined as;

$$S = \frac{P_{ma} - P}{P_{ma}}$$

Finally, the regional annual index RI for each year, is the average of station index of all the stations during that year

$$RI = \frac{1}{N} \sum_{1}^{N} S$$

For drought events lasting more than 1 year, intensity is the summation of individual annual intensities. Longer drought durations are associated with higher intensities.

The dry periods (droughts) are generally followed by corresponding wet periods. Therefore recurrence interval (reciprocal of frequency) is always greater than the drought duration. Drought recurrence intervals increase from 2 year on the dry side of climatic spectrum (super arid) to 100 years on the wet side (super-Humid).

For any year for which P is the annual precipitation, drought intensity is defined as the ratio of the deficit (P_{ma}-P) to the mean P_{ma}. For any year an intensity of $\{(P_{ma}-P)/P_{ma}\} = 0.25$, is classified as moderate (Table 2).

Table 2 Drought intensity classification for duration of one year

Classification	Type
$(P_{ma}-P)/P_{ma} = 0.25$	Moderate
$(P_{ma}-P)/P_{ma} = 0.50$	Severe
$(P_{ma}-P)/P_{ma} = 0.75$	Extreme

3 Results & Discussion

3.1 Summary of Statistical Parameters

Statistical parameters of daily time series at selected stations in the study area have been presented in the following Table . The areal average rainfall and rainy days estimated for the study area using Thiessen polygon method show that the region receives 629 mm of rainfall in about 46 days. Rain generally starts after mid-June and lasts till mid-October.

Rainfall is highly variable in the study region. Western and North-western districts, Bijapur, Koppal and Bagalkot receive average annual rainfall of 539, 558 and 576 mm falling within 43, 38 and 50 days. Raichur district in the central part of the study region receives 581 mm in about 41 days. Eastern districts Gulbarga and Yadgir gets about 668 mm (within 49 days) and 731 mm (in 56 days) of rainfall. Bidar situated in the northern part of the study region receives comparatively higher rainfall. Coefficient of variation of annual rainfall is also very high in the study region with high variation occurring in the eastern part of the study area.

Out of the total annual rainfall, the contribution of monsoon rainfall is about 62.8 % falling within June to September period. Mid-August and September months receive higher rainfall and February has the lowest rainfall. Contribution of non-monsoon rainfall is only about 20 %.

While the annual minimum rainfall varied between 101.5 and 372.6 mm for stations in the region, annual maximum ranged between 638 mm to 1285 mm. Maximum one day rainfall observed varied from 62.3 to 140.3 mm in the study region. The highest mean monthly total is 160 mm in September and lowest is 3 mm in February. Data from individual stations show very high spatial and temporal variation in rainfall and rainy days.

Inter-annual and intra-annual variations were also analysed which show pronounced variation in the rainfall pattern. The monsoonal (June-November) and non-monsoonal (December to May) rainfall patterns were also analysed separately which showed that the monsoonal rainfall followed the annual rainfall variations.

3.2 Spatial Variability of Rainfall

The isohyets map prepared by Inverse distance weight method (IDW) in ArcView 3.2 GIS platform of the study area is presented in Fig. 2. Figure 2 Isohyets map of the study area). From the Table 3 and the map, we can see that rainfall has high spatial variability across the region.

The isohyets map show that rainfall gradient is trending towards east and north in the study area. Western districts are comparatively lesser rainfall. The region, being situated mostly in the lee-ward side of the Western Ghats, rainfall in the region is dependent on the exposure of monsoon winds and the distance from the mountain belt.

3.3 Aridity Index

For few stations, based on availability of temperature data, aridity index which defines the dryness of the region has been developed using the method provided by De Martonne 1926 detailed under section 2.3.1. Results are presented Table 4. It can be seen from the table that the area is falling under semi-arid to dry-sub humid category

Fig. 2 Isohyets map of the study
area
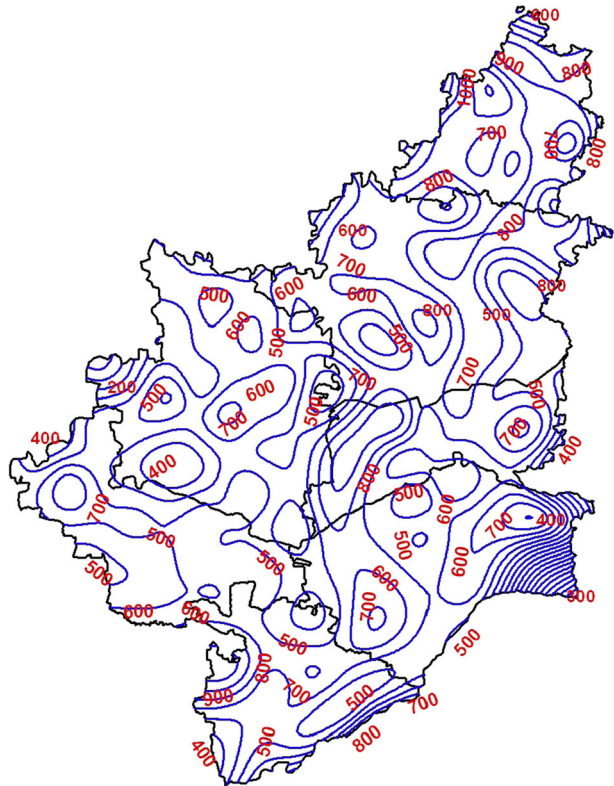
3.4 Rainfall Variability

Annual rainfall variability indices for few rain gauge locations are presented in the following graphs (Fig. 3 Annual rainfall variability indices for few stations in the study area).

Annual rainfall variability indices for the observed study stations showed that most of the stations had more dry years than normal or wet years. For 90 % of the stations considered, drought conditions persisted between 2002–2004. The percentage occurrence of drought conditions at few stations are shown in Fig. 4 (Fig. 4 Percentage of drought occurrences at selected locations). Out of the 178 stations considered, 88 % of the stations had more than 50 % of the drought occurrences which indicate the extent of drought conditions in the study area.

3.5 Drought Intensity, Duration and Severity

Drought analysis for the study area was carried out for the 178 stations falling within the geographical area of the study region. The length of data varies from 30 to 58 years. These data were subjected to the analysis using the methodology detailed by Ponce et al. (2000). The average drought intensity-duration and frequencies were calculated and presented in Table 6. The period chosen for the calculation of index starts with 1950 because most of the station has data from then onwards.

Table 3 Statistical parameters of annual rainfall time series at selected locations in study region

l.no	Rg-Name	District	Avg-rain-mm	Std-rain	CV(%)	Avg-Days	Std-Days	Min-rain-mm	Max.rain-mm	Min-days	Max-days
1	Badami	Bagalkot	590.6	157.6	26.7	62	14	314.5	1010.8	35	95
2	Bagalkot	Bagalkot	598.5	178.0	29.7	59	13	293.0	970.0	31	94
3	Hundgund	Bagalkot	661.8	202.4	30.6	65	15	302.7	1177.6	31	126
4	Jamakhandi	Bagalkot	561.6	151.9	27.0	60	17	301.8	950.1	34	152
5	Lokapur	Bagalkot	512.2	167.8	32.8	40	14	300.0	1055.8	18	82
6	Madakavi	Bagalkot	553.0	158.4	28.6	47	17	313.8	1065.6	23	132
7	Savalgi	Bagalkot	553.3	171.4	31.0	45	14	346.6	1032.9	24	92
8	Aurad	Bidar	840.7	236.5	28.1	63	18	383.3	1317.0	30	103
9	Basavakalyan	Bidar	737.8	205.0	27.8	60	11	315.6	1326.0	35	82
10	Dubalgundi	Bidar	772.8	226.0	29.2	52	13	479.7	1274.2	34	96
11	Humnabad	Bidar	809.2	210.8	26.0	63	13	352.0	1271.7	30	94
12	Manhally	Bidar	881.7	209.5	23.8	54	10	576.9	1287.6	38	76
13	Rajeshwar	Bidar	805.9	185.1	23.0	62	16	513.6	1303.3	32	90
14	T.Kushmoor	Bidar	908.3	237.2	26.1	54	12	422.5	1308.2	29	86
15	Almatti Dam	Bijapur	566.3	162.0	28.6	51.3	13.3	286.2	859.0	24	74
16	Bijapur ARS	Bijapur	555.4	163.6	29.5	40.0	16.0	250.4	813.0	15	73
17	Chadachan	Bijapur	554.0	207.3	37.4	44.0	11.7	201.7	1182.5	24	74
18	Halasangi	Bijapur	514.5	180.4	35.1	34.6	10.3	198.1	995.5	18	61
19	Hippargi	Bijapur	434.4	134.8	31.0	31.2	8.1	222.3	657.7	21	47
20	Horti	Bijapur	470.4	163.6	34.8	37.9	9.3	215.0	958.0	22	62
21	Indi	Bijapur	636.2	204.0	32.1	53.8	10.0	329.0	1436.1	34	77
22	Kadlewad	Bijapur	454.9	170.4	37.5	31.9	9.4	154.1	948.2	17	56
23	Mamdapur	Bijapur	455.2	163.6	35.9	34.4	9.3	133.1	986.6	15	62
24	Ramanahalli	Bijapur	525.2	201.8	38.4	34.6	10.5	130.1	051.0	12	61
25	Sasabele	Bijapur	404.5	155.9	38.6	30.3	7.5	167.0	858.0	11	45
26	Afazalpur	Gulbarga	675.3	190.2	28.2	60.2	17.7	303.8	1228.8	26	54

Table 3 (continued)

Lno	Rg-Name	District	Avg-rain-mm	Std-rain	CV(%)	Avg-Days	Std-Days	Min-rain-mm	Max.rain-mm	Min-days	Max-days
27	Chincholi	Gulbarga	873.1	299.8	34.3	58.3	15.0	333.4	1538.0	31	54
28	Gogi	Gulbarga	657.3	262.1	39.9	41.1	51.7	268.8	1465.2	13	43
29	Gulbarga IB	Gulbarga	750.3	208.9	27.8	64.8	14.0	365.6	1273.6	33	42
30	Hunsagi	Gulbarga	515.4	177.8	34.5	49.6	51.5	311.5	987.0	18	43
31	Jewargi	Gulbarga	778.8	265.0	34.0	56.2	16.2	366.6	1470.7	24	52
32	Kalgi	Gulbarga	691.1	192.7	27.9	48.1	11.7	347.3	1189.8	27	39
33	Kamalapur	Gulbarga	726.6	230.3	31.7	46.7	10.2	365.5	1239.8	17	38
34	Kembhavi A	Gulbarga	572.5	186.5	32.6	51.0	52.8	279.1	1119.3	15	41
35	Narhona	Gulbarga	559.0	181.7	32.5	41.4	11.5	290.0	989.7	19	41
36	Sedam TQ Off	Gulbarga	844.2	206.0	24.4	66.9	17.5	367.7	1336.5	29	51
37	Yedrami	Gulbarga	645.7	223.0	34.5	33.5	8.2	309.9	1253.0	18	42
38	Alawandi	Koppal	468.5	192.8	41.2	31.9	12.3	199.0	987.0	16	76
39	Dotihal	Koppal	436.0	173.3	39.7	30.2	9.9	209.0	993.5	9	52
40	Gangavathi IB	Koppal	608.0	195.5	32.2	44.5	10.1	295.6	1121.3	20	66
41	Kanakagiri	Koppal	523.7	222.5	42.5	33.2	11.3	245.8	1018.6	17	68
42	Koppal	Koppal	605.9	183.0	30.2	45.5	14.1	305.0	1316.3	19	78
43	Nawali	Koppal	485.8	149.4	30.8	25.4	6.9	228.0	791.0	14	44
44	Yelburga	Koppal	576.2	154.1	26.7	41.8	10.8	214.7	935.6	16	64
45	Arakere	Raichur	607.7	214.6	35.3	33.5	8.4	220.8	1059.1	15	52
46	Deosugur	Raichur	597.2	172.1	28.8	45.3	13.7	234.4	852.1	17	72
47	Gabbur	Raichur	508.5	201.2	39.6	31.3	10.9	206.2	994.5	10	66
48	Jalahalli	Raichur	589.3	194.9	33.1	34.7	9.4	230.4	1066.9	17	56
49	Manvi	Raichur	610.0	157.1	25.8	43.4	10.2	253.7	1150.1	24	62
50	Raichur Obsy	Raichur	690.0	188.6	27.3	58.2	13.1	386.2	1215.7	26	87
51	Sirwar	Raichur	574.6	236.0	41.1	36.5	11.8	248.5	1511.8	19	72
52	Turvihal	Raichur	530.3	230.2	43.4	36.4	7.8	174.1	1066.8	22	55

Table 3 (continued)

Lno	Rg-Name	District	Avg-rain-mm	Std-rain	CV(%)	Avg-Days	Std-Days	Min-rain-mm	Max.rain-mm	Min-days	Max-days
53	Yermarus	Raichur	619.5	197.0	31.8	52.0	17.0	219.5	1142.1	15	92
54	Balichakra	Yadgir	626.5	253.9	40.5	50.7	51.8	358.9	1543.6	19	41
55	Gurumittakal	Yadgir	752.0	258.8	34.4	57.4	50.1	302.8	1309.9	21	42
56	Kakkera	Yadgir	630.5	188.6	29.9	52.2	62.1	330.0	992.2	18	28
57	Shahapur	Yadgir	798.9	257.5	32.2	55.9	44.4	413.4	1418.4	25	55
58	Shorapur	Yadgir	688.4	268.4	39.0	59.7	44.4	304.9	1679.9	23	55
59	Saidapur	Yadgir	665.3	235.3	35.4	53.4	49.8	291.5	1306.0	17	43
60	Yadgir TQ Office	Yadgir	853.2	246.7	28.9	65.9	42.2	424.3	1547.1	36	55

Table 4 Aridity classification at selected locations in the study region

Sl.no	Station name	District	Aridity type
1	Badami	Bagalkot	Semi-arid
2	Bagalkot	Bagalkot	Semi-arid
3	Bilgi-Bldg	Bagalkot	Semi-arid
4	Ilkal	Bagalkot	Semi-arid
5	Jamakhandi	Bagalkot	Semi-arid
6	Rabakavi	Bagalkot	Semi-arid
7	Aurad	Bidar	Dry-Sub-Humid
8	Basavakalyan	Bidar	Semi-arid
9	Bhalki TQ Off	Bidar	Dry-Sub-Humid
10	Bidar TQ Off	Bidar	Dry-Sub-Humid
11	Dubalgundi	Bidar	Semi-arid
12	K Chincholi	Bidar	Semi-arid
13	Kamathana	Bidar	Semi-arid
14	Lakhangaon	Bidar	Semi-arid
15	Manhally	Bidar	Dry-Sub-Humid
16	Tkushnoor	Bidar	Dry-Sub-Humid
17	Bijapur	Bijapur	Semi-arid
18	Devarahippargi	Bijapur	Semi-arid
19	Sindhgi	Bijapur	Semi-arid
20	Tikota	Bijapur	Semi-arid
21	Indi	Bijapur	Semi-arid
22	Talikote	Bijapur	Semi-arid
23	Managuli	Bijapur	Semi-arid
24	Ramanahally	Bijapur	Semi-arid
25	Mamdapur	Bijapur	Semi-arid
26	Afazalpur	Gulbarga	Semi-arid
27	Aland	Gulbarga	Semi-arid
28	Chandrapur	Gulbarga	Semi-arid
29	Chincholi	Gulbarga	Dry-Sub-Humid
30	Gulbarga Obsy	Gulbarga	Semi-arid
31	Nalwar	Gulbarga	Semi-arid
32	Narayanpur	Gulbarga	Semi-arid
33	Sedam TQ Off	Gulbarga	Semi-arid
34	Dotihal	Koppal	Semi-arid
35	Gangavathi IB	Koppal	Semi-arid
36	Kanakagiri	Koppal	Semi-arid
37	Koppal	Koppal	Semi-arid
38	Kukkanur	Koppal	Semi-arid
39	Yelburga	Koppal	Semi-arid
40	Arakere	Raichur	Semi-arid
41	Deodurga	Raichur	Semi-arid
42	Kallur	Raichur	Semi-arid
43	Kurkunda	Raichur	Semi-arid
44	Manvi	Raichur	Semi-arid

Table 4 (continued)

Sl.no	Station name	District	Aridity type
45	Raichur Obsy	Raichur	Semi-arid
46	Yermarus	Raichur	Semi-arid
47	Gurmittakal	Yadgir	Semi-arid
48	Saidapur	Yadgir	Semi-arid
49	Shahapur	Yadgir	Semi-arid
50	Yadgir TQ Off	Yadgir	Semi-arid

The estimates of drought intensity and duration for stations located within Bagalkot district indicated that the district had an average drought intensity of about 0.54 with variations between 0.30 and 0.88 between stations. While average duration of drought were 2.37 years, longest duration observed was 3.57 years. Bijapur district had an average intensity of 0.59 which varied between 0.2 and 1.11, with average duration of 2.26 years and average return period of 3.7 years. Longest duration with frequency more than 4 years was observed in few stations of the district. In Bidar district, average drought intensity is 0.52 with variation between 0.31 and 0.99. average duration was 2.3 years. Longest duration of 4.2 years was observed for Hallikhed in this district.
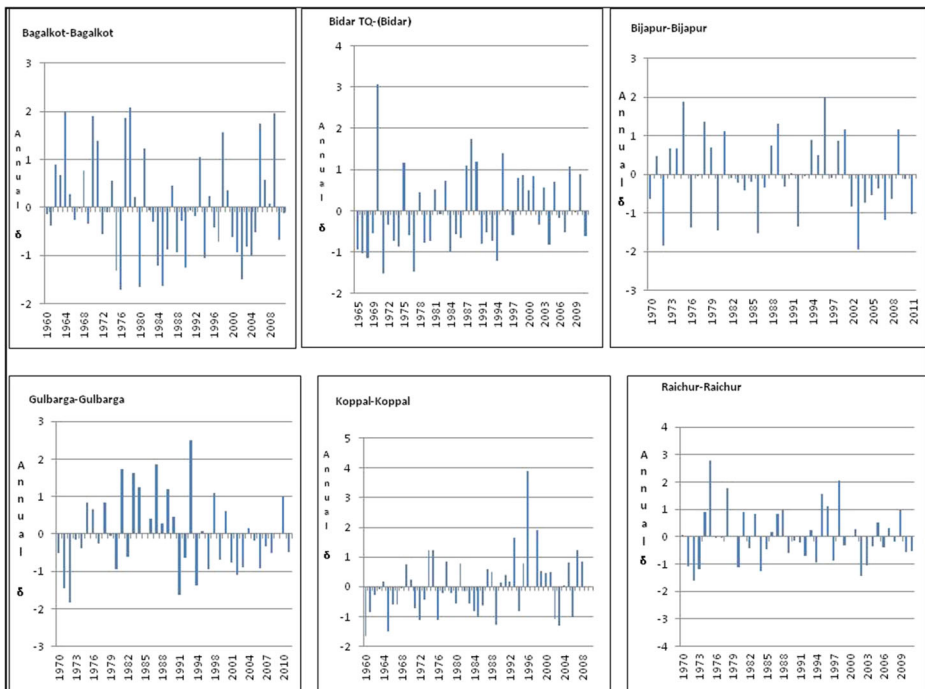
Fig. 3 Annual rainfall variability indices for few stations in the study area
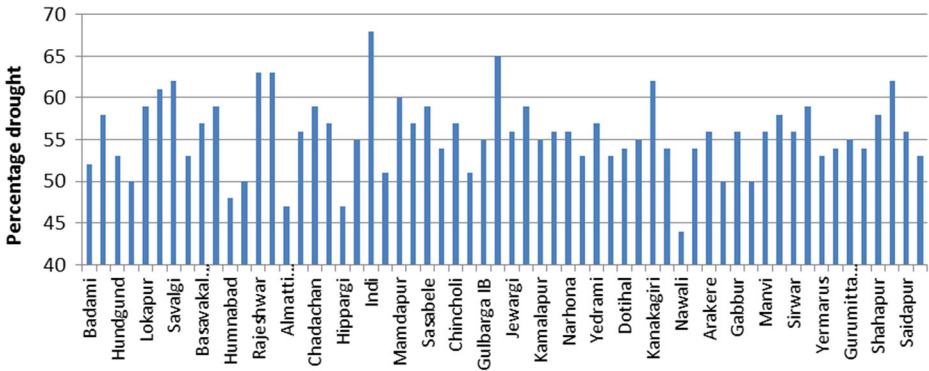
Fig. 4 Percentage of drought occurrences at selected locations

Gulbarga had an average drought intensity of 0.7 varying between 1.9 and 1.24 among stations with duration 2.58 years with longest duration 4.0 years. Yadgir, with average intensity of 0.77 which had similar pattern as Gulbarga showed variations between 0.47 and 1.21 with average duration of 2.94 years and longest duration of 4.25 years. Raichur and Koppal districts showed more or less similar patterns. In Koppal, average drought intensity was 0.56 with variations between 0.35 and 0.9 and average duration is 2.26 years. Maximum duration observed was 2.75. For Raichur district average drought
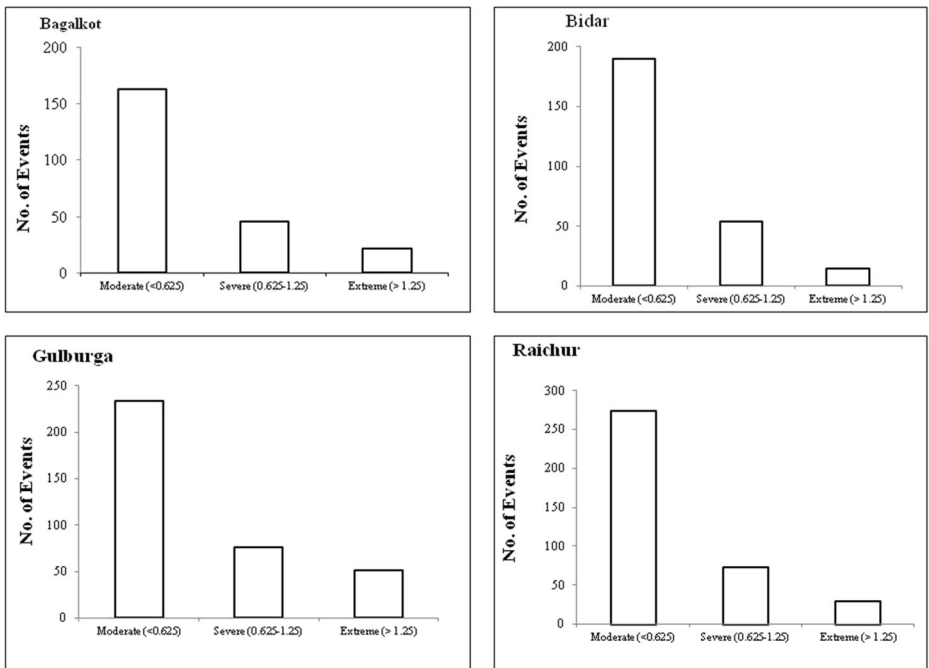
Fig. 5 Histogram showing the occurrences of different intensities of droughts during the study period

intensity was 0.59 which varied between 0.32 and 0.77. The district recorded average of 2.19 years, longest being 3.36 years.

For all the stations, the intensities were ordered and divided into the categories based on average duration of 2.5 years as 1. Moderate (less than 0.625) 2. Severe (0.625–1.25) and 3. Extreme (greater than 1.25). A histogram was drawn for these events and is presented in the Fig. 3

From the histograms (Fig. 5- Histogram showing the occurrences of different intensities of drought during the study period), it is evident that the occurrences of drought intensities under of moderate category are the highest followed by severe and extreme intensities. In Bagalkot, the district observed 231 drought events of which 70.5 % were moderate, 19.9 % were severe and 9.6 % were extreme. In Bidar, out of the 259 drought events, 73.4 % occasions experienced moderate, 20.8 % were severe and 5.8 % were extreme droughts. From the histogram above, it is seen that in Bijapur, out of 458 drought events, the study area has experienced the extreme droughts events only 58 times. In Raichur and Koppal district, 72 % of the times, drought were moderate intensity, 19.4 % were severe and 7.6 % were extreme conditions. In Gulbarga and Yadgir districts, out of the 361 events, 64.8 % times were moderate, 21.1 % time were severe and rest were extreme drought events. Thus, it was evident that most of the time, the study area was under moderate drought conditions.

Further, a relationship was established between the drought intensities and the probability of eir occurrences presented in Fig. 6. (Fig. 6 Relationship between
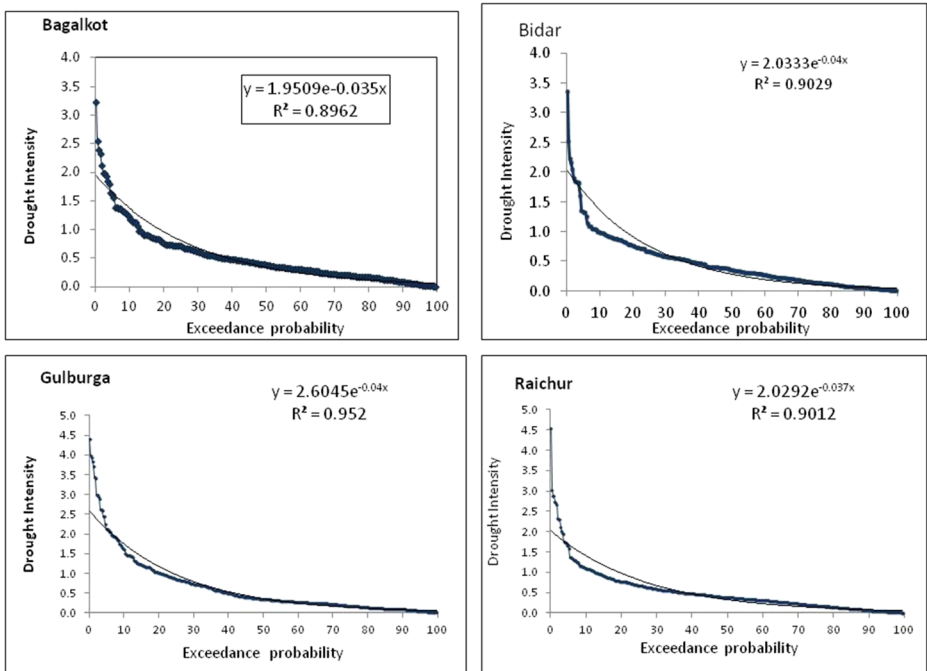

Fig. 6 Relationship between probabilities of exceedance and drought intensity for the study area

probabilies of exceedance and drought intensity for the study area) which would help us to predict and know the average duration of future drought and its intensity based on the annual rainfall values. From the above figures it could be seen that there are very few higher intensive drought events have occurred which were about 10–15 % of time during the study period. However, the events having drought intensity less than 1 have occurred most of the time

3.6 Spatial Distribution of Droguht Severity

After computing the severity for all the stations, the drought severity map was generated using GIS platform. A number of interpolation methods exist for mapping. To name a few are the Thiessen polygons, inverse distance weighing and geo-statistical methods like Krigging and co-Krigging. Some studies have compared and indicated that inverse distance weighing – the IDW (Tonkaz 2006) whereas some others proved Krigging (Sanaei and Ghahraman 2006) as a superior method. In this study, few methods were tried out and found that Krigging proved to be a better method for the study area. Map showing drought severity has been presented in the Fig. 7 (Fig. 7 Drought severity map of the study area).

Overall categories of drought show that the most frequent and severe droughts occur in the northern regions. Northern and western portions of the study area are under severe drought conditions. Extreme drought conditions persists in the central region. Moderate drought severity occurred only in very few locations. Out of the total area, about 50.4 % area were under extreme drought, 41.1 % under extreme drought and 8.5 % under moderate drought.
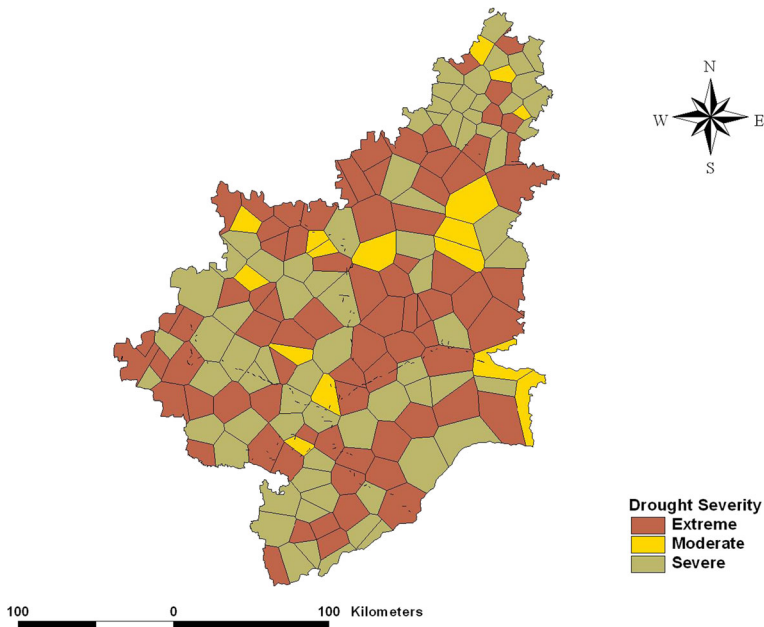

Fig. 7 Drought severity map of study area

4 Conclusion

Drought analysis for North interior Karnataka region consisting of seven districts has been performed using the methodology developed by Ponce et al. (2000). Climatic data for 178 stations with record varying 30–58 years were analyzed for drought intensity, duration and frequency. From the analysis following points were noted;

1. The study region experienced drought conditions on more than 50 % of the occasions during the study period
2. The region has undergone highly intense drought condition for a period of 10–15 % of total period of the study
3. Incidences of moderate drought events were more, where as severe droughts, though occur on less occasions have average drought durations of more than 2 years.
4. The decadal average rainfall index shows that the drought would continue even in the coming decades.
5. Rainfall trends estimated for selected stations spread across the study region showed a declining trend indicating increasing drought severity in the coming years

Further it is suggested to study the effect of rainfall deficiency on the water resources using the suitable drought index.

References

Abdulrahim MA, Ifabiyi IP, Islamaila A (2013) Time series analyses of mean monthly rainfall for drought management in Sokoto, Nigeria. Ethipial J Environ Studies Manag 6(5):461–470

Alam ATMJ, Rahman MS, Saadat AHM (2013) Monitoring meteorological and agricultural drought dynamics in Barind region Bangladesh using standard precipitation index and markov chain model. Int J Geomatics Geosci 3(3):511–524

Asati SR (2012) Analysis of rainfall data for drought investigation at Brahmapuri (MS). Int J Life Sci Biotech Pharma Res I(4):1–8

Bhakar SR, Bansal AK, Chhajed N, Singh RV (2006) Rainfall analysis for Drought estimation in Udaipur region. J Agric Eng 43(6):40–43

De Martonne E (1926) Arèisme et indice artidite. C R L'Acad Sci Paris 182:2395–1398

Gommes R, Petrassi F (1994) Rainfall variability and drought in Sub-Saharan Africa since 1960. Agrometeorology series. Working paper. 9. Rome. Food and Agriculture Organisation

Hayes MJ (2007) Drought indices. Intermountain west climate summary. pp. 2–6

Jain SK, Agarwal PK, Singh VP (2007) Hydrology and water resources in India. Springer. 1303 pages

Kinninmonth WR, Voice ME, Beard GS, de Hoedt GC, Mullen CE: 2000, Australian climate services for drought management. Drought: a global assessment. In Wilhite DA (Ed) Routledte, 210–222.

Liu WT, Kogan FN (1996) Monitoring regional drought using the vegetation condition index. Int J Remote Sens 17:2761–2782

Manual for drought management 2009. National Institute of Disaster Management. Ministry of Agriculture.

McKee TB, Doesken NJ, Kliest J (1993) The relationship of drought frequency and duration to time scales.Proceedings of the Eighth conference on applied climatology. Amaheim. C.A. American meteorological Society, Boston MA, pp 179–184

McKee TB, Doesken NJ, Kliest J (1995) Drought monitoring with multiple time scales. Proc. of nineth conference on applied climatology. Am Meteol Soc Boston. pp: 233–236

Mishra AK, Singh VP (2010) A review of drought concepts. J Hydrol 391(1–2):202–216

Nagaraja BC, Somasekhar RK, Kavitha A (2011) Impact of drought on agriculture. Challenges facing poor farmers of karnataka. South India. Paper presented at conference on climate change and security. Trondhiem. Norway. 21–24 June 2011

Palmer WC (1965) Meteorological drought. US Department of commerce weather Bureau, Washington

Paulo AA, Rosa RD, Pereria LS (2012) Climate trends and behavior of drought indices based on precipitation and evapotranspiration in Portugal. Nat Hazards Earth Syst Sci 12(5):1481–1491

Ponce VM, Pandey RP (2000) Drought characterization in arid and semi arid climatic regions of India. Technical report.No. 10. NIH. Roorkee

Ponce VM, Pandey RP, Ercan S (2000) Characterization of drought across the climatic spectrum. J Hydrol Eng ASCE 5(2):222–224

Richard R, Heim J (2002) A review of twentieth century drought indices used in the United States. Am Meteorol Soc 1149–1166

Sanaei SHN, Ghahraman B (2006) Spatial modeling of soil erosion using GIS (A case study in Kermanshah, Iran), Agro- Environment, 2006

Sen Z (2008) Wadi hydrology. CRC Press. 368p

Tonkaz T (2006) Spatio-temporal assessment of Historical droughts using SPI with GIS in GAP regions of Turkey. J Appl Sci 6(12):2565–2571

Tsakiris G, Pangalou D, Tigkas D, Vangelis H (2007) Assessing the areal extent of droughts. Water res. Manage. New approaches and Technologies. European water resources association, Chania. Greece. June 14–16, 2007

World Meteorological Organization (WMO)-1975. Drought and Agriculture WMO.TN138. Geneva