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DROUGHT FREQUENCY ANALYSIS USING STANDARDIZED PRECIPITATION INDEX IN DIFFERENT DISTRICTS OVER CHHATTISGARH STATE, INDIA

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ABSTRACT

Drought is one of India's most commonly occurring national catastrophes. In this study, drought and non-drought analyses have been done in different districts over Chhattisgarh State. The Spatio-temporal analysis of drought/wet events in the state has been examined using a monthly time series of 118 years (1901-2018) from 27 stations. Standardized Precipitation Index (SPI) has been used for drought/wet identification. In this analysis, Gamma distribution has been utilized for SPI estimation. SPI has been calculated based on yearly time scales concerning the hydrological drought. The findings reveal that most of the years (about 70%) had followed the near normal condition for all stations. The extreme drought impact occurred in Kondagaon District, while the extreme wet impact occurred in Bastar and Kanker District during the 118 years events.

INTRODUCTION

Drought can be defined as, a lack of precipitation over aprolonged period, usually a season or more. Drought is a natural part of the climate and can happen almost anywhere on the planet. Drought characteristics and effects differ from place to place due to differences in geography and culture, which influence how people use water. Droughts are classified as meteorological, agricultural, or hydrological droughts in India, according to the National Commission on Agriculture, 1976(Mahesh, 2018). Hydrological drought refers to low levels of water in rivers, reservoirs and lakes, it has a significant impact on the water resource system. Human activities, such as reservoir drawdown, can exacerbate hydrological droughts. Droughts come in many forms and are caused by a variety of factors, but they are all interconnected by the water cycle (Bandopadhyay, 1988; Mahesh, 2018).

Droughts in the weather precede droughts in the hydrological and agricultural systems. As a result, a meteorological drought can be directly linked to the occurrence of prolonged and severe hydrological and agricultural droughts. Drought events in arid and semi-arid climate regions may cause greater ecological and economic losses due to the high variability of rainfall. (Ilgar, 2010; Cuhadarand Ela, 2019).Droughts are classified in a variety of ways. Drought severity, duration, frequency, magnitude, and spatial distribution are some of the drought elements (Chouhan et al., 2017).

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Climate change has aroused serious concerns among human beings as it has a strong impact on different weather parameters. The global rainfall trait has been affected by climate change. However, for all countries, the adjustments are not the same. Food security and the economy in a developing country like India, which is an agriculture-based economy, rely on water availability. Rainfall instability causes significant problems for the preparation of crops as well as water supplies. In addition, due to different factors such as urbanization, land use cover, weather parameters, climate change, etc, the rainfall pattern has changed over the years. Under changing climate conditions, hydrological modelling is crucial for studying potential changes in a watershed's hydrology and projecting the potential impacts on water resources due to climate change (Singh and Woolhiser 2002; Praskievicz and Chang 2009).

According to the Central Water Commission (2005), the annual per capita availability of water in India has decreased from 5177 m^3 in 1951 to approximately 1508 m^3 in 2014 and is expected to decrease to approximately 1465 m^3 in 2025.ICAR has already declared that if the annual availability per capita of water goes below 1000 m^3 then India will be a stressed country. This situation necessitates immediate action to plan and implement various management programmes to maximize the use of available water resources (Murty et al., 2014). Because of the complexity of hydrologic processes, various models have been developed in recent years to aid in the understanding of the hydrologic system (Arnold and Allen, 1996).

Drought cannot be avoided, but it can be prepared for and the effects of drought can be managed. The success of both is dependent on how clearly and accurately droughts are defined and drought characteristics are quantified, among other factors (Smakhtin and Hughes, 2004; Afrin et al., 2018).Drought situations require a proactive approach to lessen the impacts of drought when it occurs (Bordi et al. 2009; Meshram et al., 2018). One of the crucial aspects of drought management is the conservation of water and its efficient use, which can be achieved through on-farm water harvesting. This will help to improve surface and groundwater resources in a specific area, as well as promote concurrent use planning. Monsoon conservation and the development of additional water resources may help to supplement groundwater in the surrounding area. Moreover, the resources generated may aid in the development of more effective and long-term plans (Meshram et al., 2018).

Numerous drought indices have been used to detect and monitor droughts for many years. The standardized precipitation index (SPI) (McKee et al., 1993), Palmer drought severity index (PDSI) (Palmer, 1965), effective drought index (EDI) (Byun and Wilhite, 1999), and standardized precipitation evapotranspiration index (SPEI) (Vicente-Serrano et al., 2010) have all been used in drought analyses over the years (Kambombe et al., 2021).

SPI is a commonly used method besides drought identification. The SPI has an advantage over others because it is based solely on rainfall data and has a variable time scale to represent drought conditions. It is calculated for 3, 6, 12, 24, and 48th-month scales to reveal the impact's temporal behaviour (Bhaskar et al., 2018).The SPI was created to reflect the effects of drought on various types of water resources by quantifying the precipitation deficit over multiple timescales, so choosing the right timescale for the drought assessment is crucial.According to the World Meteorological Organization (2012), meteorological and soil moisture conditions (agriculture) react to precipitation irregularities on relatively short timescales (e.g., 1 to 6 months), while reservoirs, streamflow and groundwater react to longer-term precipitation irregularities (e.g., 6 to 24 months or longer). For instance, one might want to look at 1 or 2 months SPI for meteorological drought, 1 to 6 months for agricultural droughts, and hydrological drought analyses and applications for something like 6 months to 24 months or longer.

The cropping pattern of Chhattisgarh is dependent on rainfall. Despite having relatively good rainfall, Chhattisgarh has experienced frequent droughts in recent years.The average rainfall of Chhattisgarh State is around 1400 mm and about 80 % of the total rainfall is confined to the Monsoon season (i.e. from June to September). The state's rainfall has an irregular temporal and spatial distribution, due to this variation in rainfall the agriculture production of the state is affected. Every third year, there is always a threat of drought resulting due to the uneven occurrence of rainfall rather than deficient rain (Chhattisgarh Water Resources Department).

The main aim of this study was to analyze water surplus and deficit using the Standardized Precipitation Index in different districts over Chhattisgarh State, India.

STUDY AREA AND DATA USED

Chhattisgarh state is situated between 17° 46' and 24° 5'N, of northern latitudes and 80° 15' and 84° 20'E, of the eastern longitudes. The state has 28 administrative districts out of them, 27 districts are considered for the entire analysis. The average annual rainfall of the state ranges between 1149 and 1562 mm. The geographical area of Chhattisgarh is approximately 135,192 km^2 and has contributed approximately 12% of the forest to the Indian subcontinent, with Chhattisgarh contributing 44 % forest. The climate of Chhattisgarh is tropical. It is hot and humid as it is close to the Tropic of Cancer and dependent on monsoons for rain. Chhattisgarh has been divided into three agro-climatic zones namely Chhattisgarh plains, Bastar plateau and Northen hills zone(Patel et al., 2004).Chhattisgarh is a monocropped state, with rice (Oryza sativa) being the main crop grown on 3/5 of the total land area during the Kharif season. Rice, corn grains, wheat, sorghum, kodo millet and finger millet are the most popular foods consumed by tribes, which are produced during the monsoon. Chhattisgarh is a state, where agriculture is the primary source of income for more than 80 % of the population(Ramrao et al., 2006).The state's rainfall has an irregular temporal and spatial distribution, due to this variation in rainfall the agriculture production of the state is affected. Every third year, there is always a threat of drought resulting due to uneven occurrence of rainfall rather than deficient rain. The location map of the study area is shown in Fig. 1.

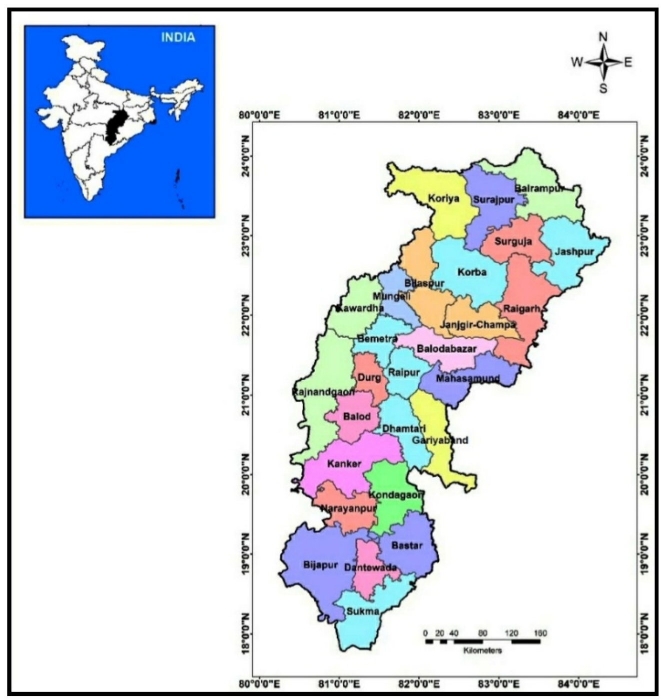


Fig 1: Location map of the study area as well as selected districts

METHODOLOGY

Firstly, daily rainfall data has been converted into monthly time series. In the present study, the monthly time series are used as input for drought and wet zone identification. The SPI-based drought analysis has been carried out for the entire Chhattisgarh state. For this purpose monthly long-term (1901-2018) time series has been considered. For the distributions, all data sets are ordered in descending order. Rainfall data of all districts have been arranged in the same manner and thereafter fitted the probability distributions using the Easy-fit (ver-5.4) software. All districts have followed the same distribution namely as gamma distribution with two parameters which is the best estimator for SPI estimation. In the present study, gamma distribution has been utilized for SPI estimation.

To investigate the drought/wet events of precipitation data, monthly precipitation data for 27 stations were obtained from the Indian Meteorological Department (IMD) website (http://www.imdpune.gov.in/Clim Pred LRF New/Grided Data Download.html). Drought analysis of precipitation has been performed for 27 districts of Chhattisgarh for 118 years (1901-2018) with a yearly time scale.

Further, the SPI values are categorized into seven classes: extremely wet, severely wet, moderately wet, near normal, moderately dry, severely dry, and extremely dry. In this study, SPI has been calculated based on yearly time scales concerning the hydrological drought. Further, the total number of the year has been evaluated as per different categories during 1901-2018.

Line of action adopted for SPI calculation

- Extraction of the IMD daily fine resolution (0.25deg × 0.25deg) database for the years 1901 to 2018.
- Preparation of GIS layers for the study area.
- Calculation of area-weighted average monthly rainfall for each districts using MATLAB code.
- Assessment of statistical results for long-term rainfall data sets for the study area.
- Conversion of data sets into annual and seasonal time series using data segregation and GIS techniques.
- Estimation of SPI values for identification of drought and non-drought conditions for different districts of Chhattisgarh state.
- Evaluation and representation of results in the form of tables, graphs and figures.
- Conclusion of the entire study.
- The suggestion of strategic planning for future work.

Further, brief methodology has been illustrated in Fig. 2.

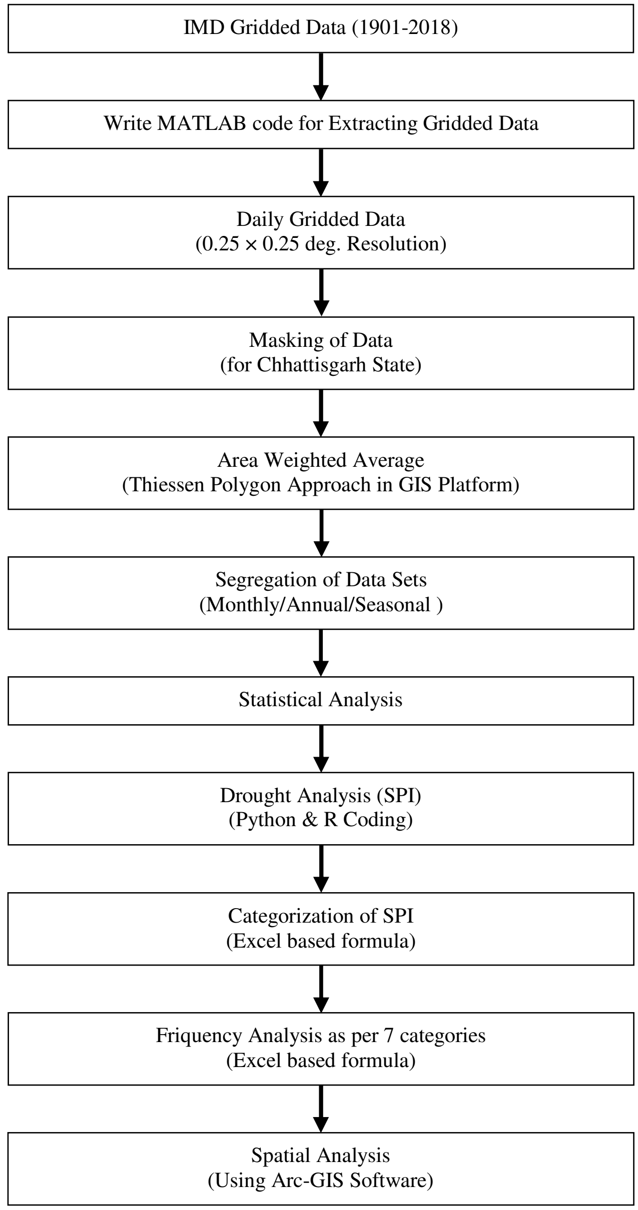


Fig 2: Flow chart of drought analysis for present study

Standardized Precipitation Index (SPI)

Standardized Precipitation Index was proposed by (McKee et al. 1993) to quantify the precipitation deficit or excess in terms of droughtiness or wetness respectively on multiple time scales (monthly, tri-monthly, six-monthly, yearly and two-yearly). To calculate the SPI, long-term precipitation data must be converted into different time scale data sets according to specifications. To test the goodness of fit (GoF) of two parametric gamma distributions, multiple long-term time-scaled data are fitted into a probability distribution before being transformed into a normal distribution with a mean SPI of zero. A value of zero indicates normal conditions, while positive and negative values indicate non-drought and drought conditions, respectively. The parameters of the gamma distribution are based on observed precipitation data, and they differ spatially. New fitted series for each timescale can be expressed in terms of rainfall amount, fitted series means, and fitted series standard deviation, for each timescale. (Guttman 1999; Komuscu 1999; McKee et al. 1993; Wu et al. 2007).SPI has been calculated as follows:

$$SPI = \frac{x_i - \bar{x}}{\sigma} \qquad (1)$$

Where, $x_i$is the individual fitted precipitation values; $\bar{x}$is the fitted series mean and σ is the fitted series standard deviation.

According to the SPI score, droughtiness and wetness have been classified into seven categories as shown in Table 1.

Table 1: Different categorization of drought and wet conditions as per SPI values

S. No.	Category	SPI Ranges
1.	Extremely wet	2.00 and above
2.	Severely wet	1.50 to 1.99
3.	Moderately wet	1.00 to 1.49
4.	Near normal	-0.99 to 0.99
5.	Moderately dry	-1.00 to -1.49
6.	Severely dry	-1.50 to -1.99
7.	Extremely dry	-2.00 and less

Probability Density Function Used in SPI

The main objective of fitting any distribution across different time scales is to determine the time series behavioral pattern or trend. Many researchers used the concept of SPI for drought identification in various locations around the world. Generally, three types of distributions, namely Gamma, Weibull and Log-normal, have been used to calculate SPI, with the Gamma distribution being considered the best for SPI estimation (Hayes et al. 1999; McKee et al. 1993; McKee et al. 1995; Shiau 2006).

The probability density function (PDF) and cumulative distribution function (CDF) are as follows:

$$f(x;\alpha,\beta)=x^{(\alpha-1)}\frac{e^{\frac{x}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)}\ for\ x>0 \tag{2}$$

$$f(x;\alpha,\beta)=\int_0^x f(u;\alpha,\beta)\,du=\frac{\gamma\left(\alpha,\frac{x}{\beta}\right)}{\Gamma(\alpha)} \tag{3}$$

$$for\ x>0\ and\ \alpha,\beta>0\ where,\Gamma(\alpha)=\int_0^\infty x^{\alpha-1}e^{-x}dx$$

$and\ \gamma(s,x)=\int_0^x t^{s-1}e^{-t}dt$ is the lower incomplete gamma function, α is the shape parameter and β is the scale parameter.

Shape and Scale Parameter Estimation

The SPI is calculated by applying a gamma probability density function to a time series frequency distribution.For each station, the alpha (shape) and beta (scale) parameters of the gamma probability density function are computed annually.The highest likelihood solutions (Stacy and Mihram, 1965) are used to estimate α and β optimally.

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

$$\hat{\beta}=\frac{\bar{x}}{\hat{\alpha}} \tag{5}$$

where,

$$A=\ln(\bar{x})-\frac{\sum\ln(x)}{n}$$

n = number of precipitation observations

Goodness-of-Fit Tests

A statistical goodness-of-fit (GoF) test is usually recommended for determining the compatibility of a model and data. GoF tests are used to describe the fitness of a distribution for a given set of observers and measures. GoF typically summarises the difference between observed and predicted levels in the model in question. The best-fitted distribution is selected based on the minimum error generated. The following techniques can be used to measure these errors.

The Kolmogorov-Smirnov (KS) test has been used to calculate the maximum difference between the hypothesized and empirical distributions. The statistics for the KS test are as follows:

$$D=\max_{1\le i\le N}\left(\left|F(x_i)-\frac{i-1}{N}\right|,\left|\frac{i}{N}-F(x_i)\right|\right) \tag{6}$$

where, x_i denotes the increasing order of the data, F denotes the theoretical cumulative distribution and N denotes the sample size. The model fitting between an observed CDF and an expected CDF was compared using Anderson-Darling (AD). The following is the definition of the AD test:

$$A^2=-n-\frac{1}{n}\sum_{i=1}^{n}(2i-1)\left[\ln F(X_i)+\ln(1-F(X_{n+1=i}))\right] \tag{7}$$

Where, F is the CDF of the specified distribution and X_i are the ordered data.

RESULTS AND DISCUSSION

Frequency analysis of drought/non-drought (7 categories) using SPI:

The present study emphasizes the drought/wet events of 27 stations of Chhattisgarh state for 118 years during 1901-2018. The number of events (in %) fall under extremely wet, severely wet, moderately wet, near normal, moderately dry, severely dryand extremely dry categories during annual time step are shown in Table 2. District wise summary of the wet and dry years followed by different categories has been illustrated in Fig. 3 (a-g).

In the Balod District, 13.56 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 5.08 %and 6.78 % respectively. On the other hand, 15.25 % of 118 years events comes under drought condition in which moderate drought and severe drought events are 5.93 % and extreme drought events are 3.39 %. And rest of the events (71.19 %) comes under near normal condition.

In the Baloda bazar District, 16.10 % of 118 years events comes under wet condition in which extreme wet events are 0.85 %, severe wet and moderate wet events are 7.63 %. On the other hand, 12.71 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 3.39 %, 6.78 %and 2.54 % respectively. And rest of the events (71.19 %) falls under near normal condition.

In the Balrampur District, 14.41 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 5.08 %and 7.63 % respectively. On the other hand, 18.64 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 9.32 %, 5.93 %and 3.39 % respectively. And rest of the events (66.95 %) comes under near normal condition.

In the Bastar District, 13.56 % of 118 years events comes under wet condition in which extreme wet events are 3.39 %, severe wet and moderate wet events are 5.08 %. On the other hand, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 8.47 %, 4.24 %and3.39 % respectively. And rest of the events (70.34 %) falls under near normal condition.

In the Bemetara District, 14.41 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 3.39 %and 9.32 % respectively. On the other hand, 17.80 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 10.17 %, 5.93 %and 1.69 % respectively. And rest of the events (67.80 %) comes under near normal condition.

In the Bijapur District, 14.41 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 5.08 %and 7.63 % respectively. On the other hand, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 8.47 %, 5.93 %and 1.69 % respectively. And rest of the events (69.49 %) comes under near normal condition.

In the Bilaspur District, 16.10 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 4.24 %and 10.17 % respectively. Similarly, 16.10 % of 118 years events comes under drought condition in which moderate drought events are 11.02 %, severe drought and extreme drought events are2.54%. And rest of the events (67.80 %) comes under near normal condition.

In the Dantewada District, 13.56 % of 118 years events comes under wet condition in which extreme wet and severe wet events are 2.54and moderate wet events are 8.47 %. On the other hand, 15.25 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 5.93 %, 5.08 %and4.24% respectively. And rest of the events (71.19 %) comes under near normal condition.

In the Dhamtari District, 15.25 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 4.24 %and 9.32 % respectively. On the other hand, 16.95 % of 118 years events comes under drought condition in which moderate drought events are 10.17 %, severe drought and extreme drought events are 3.39%. And rest of the events (67.80 %) comes under near normal condition.

In the Durg District, 15.25 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 7.63%and 5.93 % respectively. Similarly, 15.25 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 7.63 %, 5.08 %and2.54% respectively. And rest of the events (69.49 %) comes under near normal condition.

In the Gariyab and District, 16.95 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.85 %, 3.39%and 12.71 % respectively. On the other hand, 13.56 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 6.78 %, 2.54 %and 4.24 % respectively. And rest of the events (69.49 %) comes under near normal condition.

In the Janjgir-Champa District, 13.56 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 6.78% and5.08% respectively. On the other hand, 17.80 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 11.02 %, 5.08 %and1.69% respectively. And rest of the events (68.64%) comes under near normal condition.

In the Jashpur District, 16.10 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 2.54 %, 3.39%and10.17% respectively. Similarly, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 10.17 %, 4.24 %and 1.69 % respectively. And rest of the events (67.80 %) comes under near normal condition.

In the Kanker District, 12.71 % of 118 years events comes under wet condition in which extreme wet and severe wet events are 3.39and moderate wet events are 5.93 %. On the other hand, 17.80 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 11.86 %, 2.54

%and 3.39 % respectively. And rest of the events (69.49 %) comes under near normal condition.

In the Kawardha District, 16.10 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 2.54 %, 5.93%and 7.63 % respectively. Similarly, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 9.32 %, 5.93 %and 0.85% respectively. And rest of the events (67.80 %) comes under near normal condition.

In the Kondagaon District, 2.54 % of 118 years events comes under wet condition in which extreme wet and severe wet events are 0.00 %and moderate wet events are 2.54%. On the other hand, 8.47 % of 118 years events comes under drought condition in which moderate drought and severe drought events are 0.00 % and extreme drought events are 8.47 %. And rest of the events (88.98 %) comes under near normal condition.

In the Korba District, 13.56 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 2.54 %, 1.69 %and 9.32 % respectively. On the other hand, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 10.17 %, 5.08 %and 0.85 % respectively. And rest of the events (70.34 %) comes under near normal condition.

In the Koriya District, 16.10 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.00 %, 5.93 %and 10.17 % respectively. On the other hand, 13.56 % of 118 years events comes under drought condition in which moderate drought events are 6.78 %, severe drought and extreme drought events are 3.39%. And rest of the events (70.34 %) comes under near normal condition.

In the Mahasamund District, 12.71 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 5.93 % and5.08% respectively. On the other hand, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 8.47 %, 5.08 %and2.54% respectively. And rest of the events (71.19 %) comes under near normal condition.

Table 2: Frequencies (in %) of drought/wet events on 12 month or annual time scale using SPI for Chhattisgarh state during 1901-2018

Station name	EW	SW	MW	NN	MD	SD	ED
Balod	1.69	5.08	6.78	71.19	5.93	5.93	3.39
Balodabazar	0.85	7.63	7.63	71.19	3.39	6.78	2.54
Balrampur	1.69	5.08	7.63	66.95	9.32	5.93	3.39
Bastar	3.39	5.08	5.08	70.34	8.47	4.24	3.39
Bemetara	1.69	3.39	9.32	67.80	10.17	5.93	1.69
Bijapur	1.69	5.08	7.63	69.49	8.47	5.93	1.69
Bilaspur	1.69	4.24	10.17	67.80	11.02	2.54	2.54
Dantewada	2.54	2.54	8.47	71.19	5.93	5.08	4.24
Dhamtari	1.69	4.24	9.32	67.80	10.17	3.39	3.39
Durg	1.69	7.63	5.93	69.49	7.63	5.08	2.54
Gariyaband	0.85	3.39	12.71	69.49	6.78	2.54	4.24
Janjgir-Champa	1.69	6.78	5.08	68.64	11.02	5.08	1.69
Jashpur	2.54	3.39	10.17	67.80	10.17	4.24	1.69
Kanker	3.39	3.39	5.93	69.49	11.86	2.54	3.39
Kawardha	2.54	5.93	7.63	67.80	9.32	5.93	0.85
Kondagaon	0.00	0.00	2.54	88.98	0.00	0.00	8.47
Korba	2.54	1.69	9.32	70.34	10.17	5.08	0.85
Koriya	0.00	5.93	10.17	70.34	6.78	3.39	3.39
Mahasamund	1.69	5.93	5.08	71.19	8.47	5.08	2.54
Mungeli	0.85	3.39	11.86	65.25	12.71	3.39	2.54
Narayanpur	0.00	7.63	6.78	70.34	7.63	2.54	5.08
Raigarh	0.85	4.24	12.71	68.64	7.63	3.39	2.54
Raipur	0.00	7.63	8.47	66.95	10.17	2.54	4.24
Rajnandgaon	1.69	5.08	11.02	66.95	9.32	3.39	2.54
Sukma	1.69	4.24	11.02	67.80	10.17	3.39	1.69
Surajpur	0.85	4.24	5.93	74.58	8.47	2.54	3.39
Surguja	2.54	2.54	9.32	69.49	7.63	6.78	1.69

EW: Extremely Wet, SW:Severely Wet, MW:Moderately Wet, NN: Near Normal, MD: Moderately Dry, SD: Severely Dry, ED: Extremely Dry

In the Mungeli District, 16.10 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.85 %, 3.39 %and 11.86 % respectively. On the other hand, 18.64 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 12.71 %, 3.39 %and 2.54 % respectively. And rest of the events (65.25 %) comes under near normal condition.

In the Narayanpur District, 14.41 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.00 %, 7.63 % and 6.78 % respectively. On the other hand, 15.25 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 7.63 %, 2.54 %and 5.08 % respectively. And rest of the events (70.34 %) comes under near normal condition.

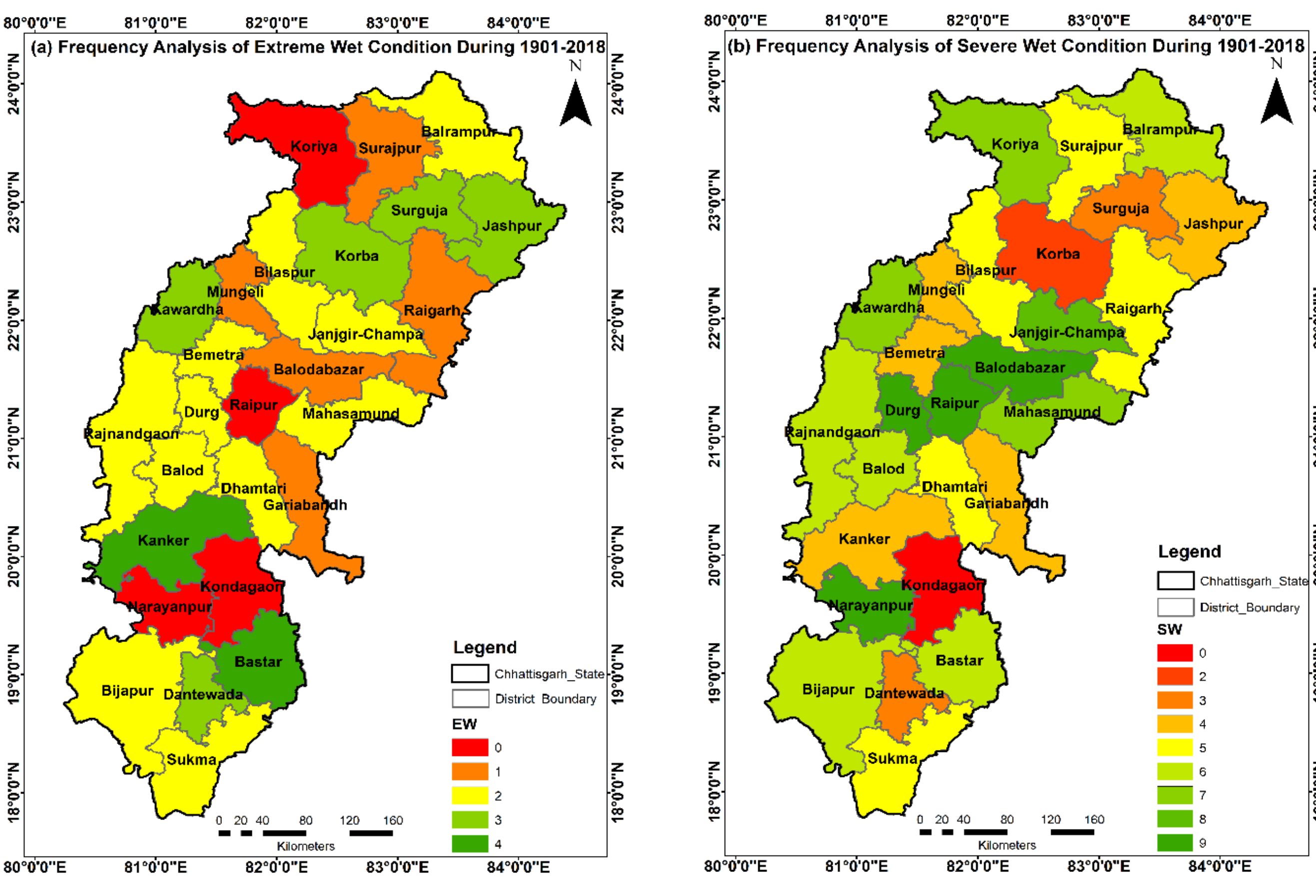
In the Raigarh District, 17.80 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.85 %, 4.24 %and 12.71 % respectively. On the other hand, 13.56 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 7.63 %, 3.39 %and 2.54 % respectively. And rest of the events (68.64 %) comes under near normal condition.

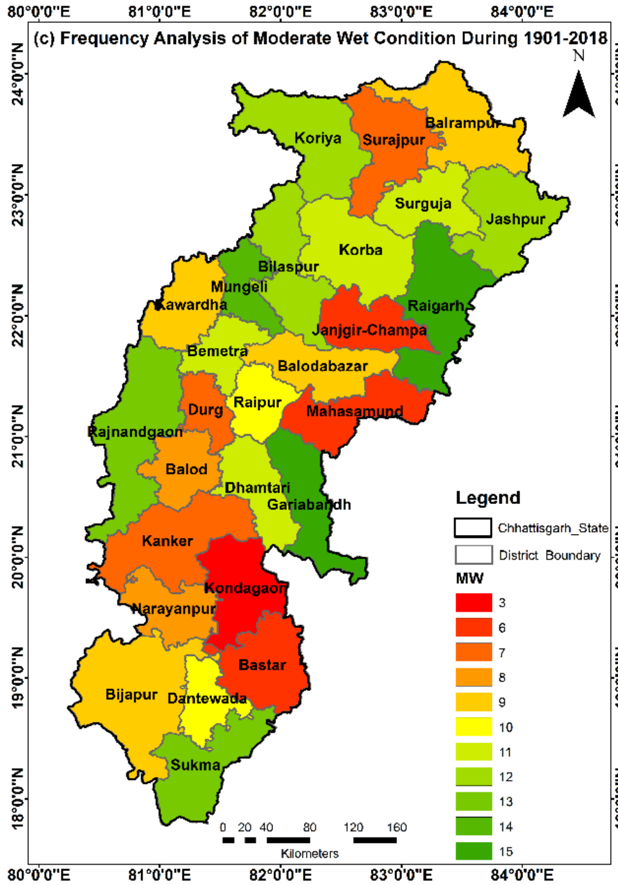
In the Raipur District, 16.10 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.00 %, 7.63 %and 8.47 % respectively. On the other hand, 16.95 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 10.17 %, 2.54 %and 4.24 % respectively. And rest of the events (66.95 %) comes under near normal condition.

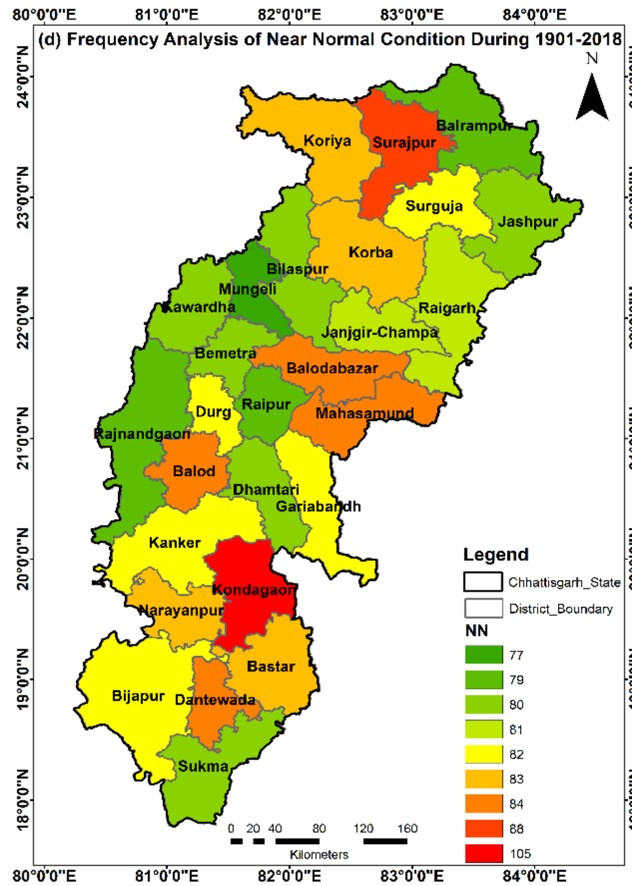
In the Rajn and gaon District, 17.80 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 5.08 % and 11.02 % respectively. On the other hand, 15.25 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 9.32 %, 3.39 % and 2.54 % respectively. And rest of the events (66.95 %) comes under near normal condition.

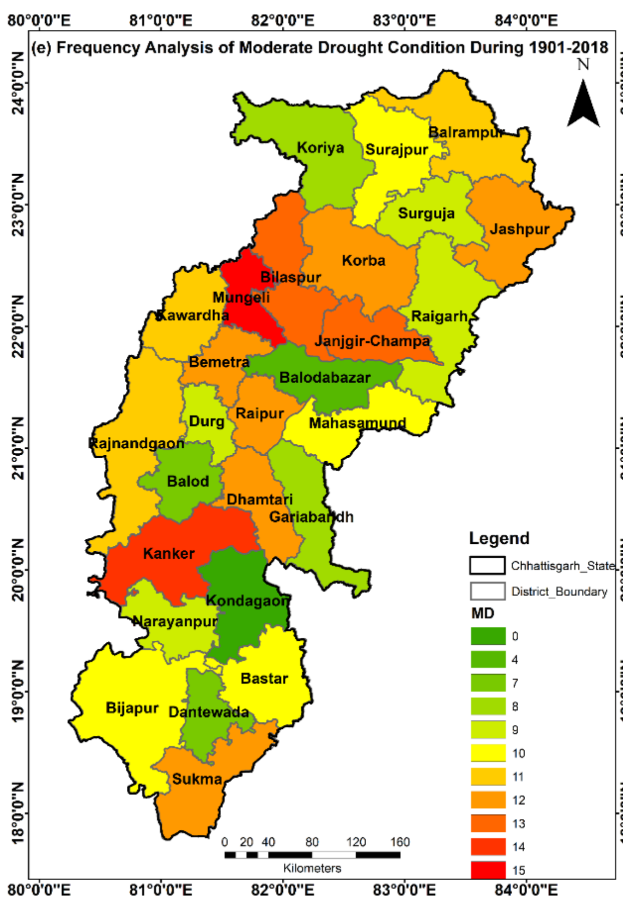
In the Sukma District, 16.95% of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 1.69 %, 4.24% and 11.02 % respectively. On the other hand, 15.25 % of 118 years events comes under drought condition in which moderate drought, severedrought and extreme drought events are 10.17 %, 3.39 % and1.69% respectively. And rest of the events (67.80 %) comes under near normal condition.

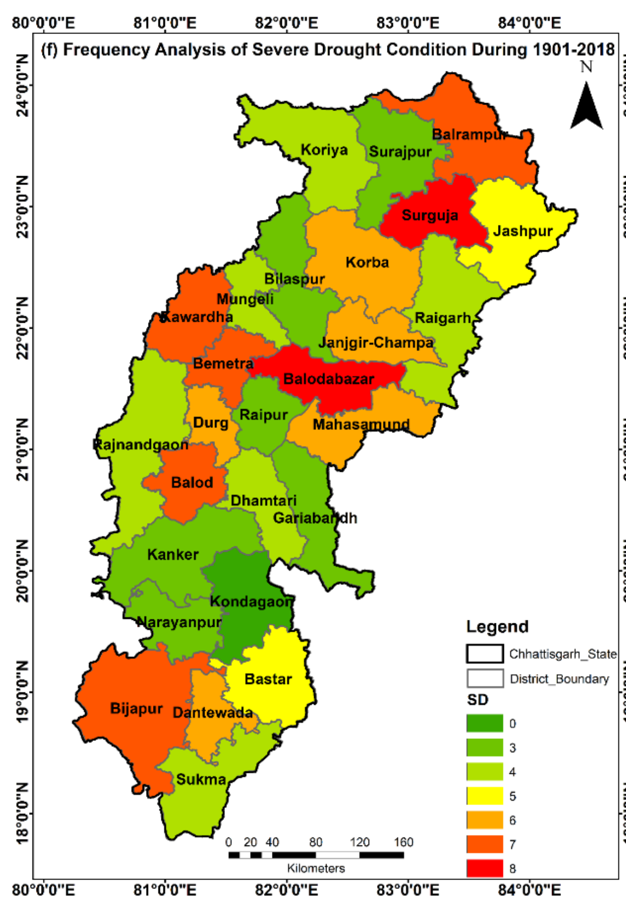
In the Surajpur District, 11.02 % of 118 years events comes under wet condition in which extreme wet, severe wet and moderate wet events are 0.85 %, 4.24 % and 5.93 % respectively. On the other hand, 14.41 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 8.47 %, 2.54 % and 3.39 % respectively. And rest of the events (74.58 %) comes under near normal condition.




(c) Frequency Analysis of Moderate Wet Condition During 1901-2018
Koriya
Surajpur
Balrampur
Surguja
Jashpur
Korba
Bilaspur
Mungeli
Kawardha
Raigarh
Janjgir-Champa
Bemetra
Balodabazar
Durg
Raipur
Mahasamund
Rajnandgaon
Balod
Dhamtari
Gariabandh
Kanker
Kondagaon
Narayanpur
Bastar
Bijapur
Dantewada
Sukma
Legend
Chhattisgarh_State
District_Boundary
MW
3
6
7
8
9
10
11
12
13
14
15
Kilometers


(d) Frequency Analysis of Near Normal Condition During 1901-2018
Koriya
Surajpur
Balrampur
Surguja
Jashpur
Korba
Bilaspur
Mungeli
Kawardha
Raigarh
Janjgir-Champa
Bemetra
Balodabazar
Durg
Raipur
Mahasamund
Rajnandgaon
Balod
Dhamtari
Gariabandh
Kanker
Kondagaon
Narayanpur
Bastar
Bijapur
Dantewada
Sukma
Legend
Chhattisgarh_State
District_Boundary
NN
77
79
80
81
82
83
84
88
105
Kilometers


(e) Frequency Analysis of Moderate Drought Condition During 1901-2018
Koriya
Surajpur
Balrampur
Surguja
Jashpur
Korba
Bilaspur
Mungeli
Kawardha
Raigarh
Janjgir-Champa
Bemetra
Balodabazar
Durg
Raipur
Mahasamund
Rajnandgaon
Balod
Dhamtari
Gariabandh
Kanker
Kondagaon
Narayanpur
Bastar
Bijapur
Dantewada
Sukma
Legend
Chhattisgarh_State
District_Boundary
MD
0
4
7
8
9
10
11
12
13
14
15
Kilometers


(f) Frequency Analysis of Severe Drought Condition During 1901-2018
Koriya
Surajpur
Balrampur
Surguja
Jashpur
Korba
Bilaspur
Mungeli
Kawardha
Raigarh
Janjgir-Champa
Bemetra
Balodabazar
Durg
Raipur
Mahasamund
Rajnandgaon
Balod
Dhamtari
Gariabandh
Kanker
Kondagaon
Narayanpur
Bastar
Bijapur
Dantewada
Sukma
Legend
Chhattisgarh_State
District_Boundary
SD
0
3
4
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6
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8
Kilometers

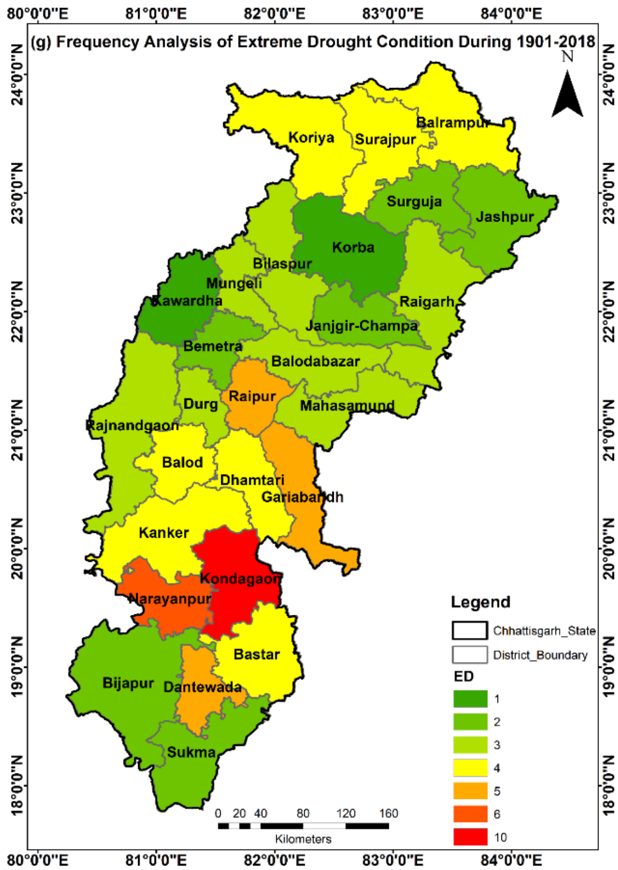

Fig. 5: Spatio-temporal variation of frequencies under annual time series during 1901-2018 for (a) extreme wet events, (b) severely wet events, (c) moderately wet events, (d) near normal events, (e) moderate drought events, (f) severe drought events and (g) extreme drought events.

In the Surguja District, 14.41 % of 118 years events comes under wet condition in which extreme wet and severe wet events are 2.54 % and moderate wet events are 9.32%. On the other hand, 16.10 % of 118 years events comes under drought condition in which moderate drought, severe drought and extreme drought events are 7.63 %, 6.78 % and 1.69 % respectively. And rest of the events (69.49 %) comes under near normal condition.

In summary, most of the events (about 70 %) fall under near normal conditions for all stations. The highest and lowest frequency of near normal conditions were observed at Kondagaon District (88.98 %) and Mungeli District (65.25 %) over 118 years of the event. Overall, the highest frequency of wet conditions was observed at Raigarh and Rajn and gaon District, while the lowest at Kondagaon District. On the other hand, the highest frequency of drought conditions was observed at Balrampur and Mungeli District, whereas the lowest at Kondagaon District. The highest frequency of extreme drought conditions has been observed at Kondagaon District and the lowest at Korba District, while the highest frequency of extreme wet conditions has been observed at Bastar and Kanker District and the lowest at Kondagaon, Koriya, Narayanpur and Raipur District during 118 years events.

CONCLUSION

The drought/wet events were analyzed for 27 districts of Chhattisgarh State for 118 years during 1901-2018. In this study, Standardized Precipitation Index (SPI) has been utilized based on a 12-month time scale for analyzing drought/wet events. The 12-month time scale SPI is used for assessing meteorological drought. The result reveals that most of the events (about 70 %) fall under near normal conditions for all stations.Among 27 districts, Balrampur and Mungeli Districts have been identified as drought area, and Kondagaon as wet area during the 118 years events. Among 27 districts, Balrampur and Mungeli Districts were drought areas and Kondagaon was wet area during the 118 years events.

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