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Assessment of Historical Spatio-temporal Variability in Rainfall and Drought of Kalyan-karnataka Region, Karnataka, India

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ABSTRACT

The evaluation of meteorological droughts mainly relies on rainfall data to identify patterns in the climate and water availability, which in turn helps evaluate the risk of drought as well as its severity . There is a drought when the amount of precipitation is below average. When this event lasts for a long time, precipitation is unable to satisfy human demands. By using the Standardised Precipitation Index (SPI), the present study examines the long-term geographical and temporal variability of rainfall, its trend, and the degree of climatic dryness in the study area using SPI. Rainfall data from 31 meteorological stations for the years 1960 to 2014 were assessed using non-parametric techniques such as the Mann-Kendall test, Sen's slope estimator, and the Standardised Precipitation Index. The maps of the variation in rainfall were produced using ArcGIS V.xx, The trend analysis of the study reveals both a positive and a negative tendency. The study also provides information on the total annual rainfall that was recorded over the study area for the previous 55 years. This rainfall total was regionally distributed between 656.25 ermillimeters and 842.60 millimeters. The severity of the issue and the extreme dryness were shown by the analysis of taluk-wise precipitation data for meteorological drought. In the Kalyan Karnataka region, the state of Karnataka's agricultural productivity is highly dependent on rainfall and the frequency of meteorological droughts.

Keywords: *Climate change, Meteorological drought, Mann-Kendall test, SPI, Sen's slope estimator, Water resources, Weather parameters*

INTRODUCTION

Rainfall distribution patterns have altered across the globe because of climate variability and climate change resulting in an increase in the concentration of greenhouse gases (GHGs) in the atmosphere due to anthropogenic activities [6]. The climatic condition of India varies from one part or region to another [29]. The southern part of the country has climatic conditions different from the northern parts on different meteorological parameters [5]. Drought is defined as the water deficit phenomenon for a prolonged time period, which can continue for several days, months, and years, affecting water resources, agriculture, the environment, and human lives [7],[13]. The deficiency of precipitation, soil moisture, runoff, and increased evapotranspiration is linked to the drought phenomenon [9] and [28]. The variability in rainfall and hydro-meteorological drought has been analyzed at diverse spatial and temporal scales by various researchers to identify, evaluate, and provide solutions for drought conditions across the world [32] and [12]. Several drought indices were used for a comprehensive assessment of drought severity, intensity, and magnitude [2]. Water resources planning and management greatly includes identifying periods of scarcity and drought as key considerations [29]. Understanding and estimating these droughts would help to solve problems like low agricultural crop yields, restored groundwater supplies, lake/reservoir shrinks, drinking water shortages, and reduced feed availability, which could have a severe influence on the local people [30]. Therefore, forecasting and predicting drought features, such as frequency, monitoring, and severity is critical for water resource management, as well as agricultural production [27].

Several methods are available in the literature for monitoring drought and Deciles, Standardized Precipitation Index (SPI) and Effective Drought Index (EDI) are three frequently used drought indexes that use rainfall as the sole variable for drought calculation [32] and [4]. Because of its simplicity and flexibility to reflect dryness at different time periods, the SPI drought index can be used to evaluate the drought situation [31]. The main advantage of these indices is that standardization is based on simple methodologies which can be used to draw conclusions on the drought severity from the observed anomalies and allows comparison across different sites and scales [10]. For temporal analysis, the Mann–Kendall test and Sen's slope estimator are greatly used for determining long-term signals in the rainfall data [1]. The SPI makes drought assessment easier and has a wide range of meteorological, hydrological, and agricultural applications [25]. Many researchers used the SPI across the country viz [22] for Andra Pradesh, [6] for Haryana, [21] and [17] for Rajastan, [18]for Tamilnadu, [17] for Himalayan Region,[28] for Karnataka, [14] for Indian continent for study on spatiotemporal rainfall

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variability and reported that SPI can be widely used in because of its computational simplicity and reliable interpretation of annual and seasonal rainfall. However, while tackling the issue of changes in rainfall extremes locally, the knowledge of regional trends in rainfall is crucial as regional trends are mostly averaged out in the rainfall trend analysis throughout India [23]. Kalyan-Karnataka region is comprised of six districts (Bidar, Kalaburgi, Yadgir, Raichur, Koppal, and Bellary) and agriculture is the major source of income for more than 60 % of small and marginal farmers in the region. Cotton, pigeon pea, and paddy are the major crops and these crops are affected by prolonged dry spells during the crop season, which leads to low crop productivity [20]. The temporal and spatial variability of rainfall patterns in the region played a major role in their agricultural production and farm income and people were forced to migrate for their sustenance [8]. As rainfall is an unpredictable natural phenomenon, statistical analysis of its distribution patterns and quantum of rainfall plays an important role particularly in backward areas like the Kalyan-Karnataka region [24]. The statistical analysis of rainfall paves the way for help the government in agricultural planning and policymaking and for farmers in adopting farm production practices, crop contingency planning, etc. [23]. The authors learned that there was no such significant study on spatial and temporal variability of rainfall in the Kalyan-Karnataka area of Karnataka for suggesting suitable measures to cope with changing climate. An attempt was made to understand the spatial and temporal variability of rainfall and meteorological drought through the M-K test and SPI indices using long-term weather data to develop appropriate drought management strategies through adopting soil and water conservation measures for farmers, policymakers, and other stakeholders in the study area.

STUDY AREA

Kalyan Karnataka region is the northern part of Karnataka state covering an area of 44,145 sq. km which is 23 % of the state's total geographical area. The region includes six districts namely Bidar, Kalaburgi, Yadgir, Raichur, Koppal, and Bellary. The climate in this region is dry most of the year, with particularly scorching summers. The geographical location of the study area is presented in Figure 1. The region receives 60 % of rainfall during both southwest and northeast monsoons with an average annual rainfall of 692 millimetres. The air temperatures range from 8°C (December) to 45°C (May) with an average annual temperature of 26.5°C.

Weather data collection: Daily rainfall (mm) data of the study area for a period of 55 years (1960 to 2014) was collected from twenty-four weather stations established by Karnataka State Natural Disaster Monitoring Centre, Bengaluru in collaboration with National Aeronautics and Space Administration's (NASA) POWER project with a grid at 0.5 degrees latitude and 5 degrees longitude and which made publicly available for different stakeholders.

Statistical analysis*:* Long-term daily rainfall data was statistically analyzed using the Microsoft Excel spreadsheet program. Spatio-temporal variability and wetness and dryness in the study region were determined using the Mann-Kendall Test, Sen's slope estimator, Standardized Precipitation Index (SPI), and Indian Meteorological Classification for Drought (IMC) as per standard procedure [21].

Trend Analysis: The Mann-Kendall test and Sen's slope estimator were used to determine the long-term variability and trend slope of daily rainfall data to study the trend of spatio-temporal rainfall variability in the study area.

Mann-Kendall test and Sen's slope estimator: When examining climatic and hydrologic time series data, one common tool is the Mann-Kendall test (non-parametric test). Rather than focusing on individual population parameters, non-parametric approaches look at where the probability distribution of the sampled population is located. Although the aggregate magnitude of the data points determines the test's outcome, the ranking of the individual data points also matters. In order to find a pattern in a set of data, the Mann-Kendall test is frequently utilized This statistic (S) uses the Mann-Kendall formula to determine the general direction of the data. Negative values show a decline in the concentration of constituents over time whereas positive values show an increase. As the magnitude of the Mann-Kendall statistics increases, so too does the strength of the trend (i.e., large magnitudes indicate a strong trend). Linear time series trends may be evaluated with the help of a simple non-parametric approach. Consequently, non-parametric analysis is required. For estimating the value and confidence interval for the slope of a current trend, Sen's method is a linear model that calculates the trend's slope (measured in units of change over time). Detailed procedure of Mann-Kendall and Sen's Slope statistics can be found in [26].

Standardized Precipitation Index (SPI): In order to calculate the SPI, a probability density function is fitted to historical precipitation data for a certain time period and region. The gamma distribution is frequently used. It is then necessary to convert the gamma distribution's cumulative distribution function into a normal distribution, which has the same mean and standard deviation as the original distribution. The SPI's negative numbers indicate a high level of dryness, whereas the SPI's positive values indicate a high level of moisture. Its most notable feature is that it may be used to track droughts over a variety of time frames (1, 3, 6, 9, 12, 24, and 48 months), depending on the amount of viable water resources available. SPI could be utilized for agricultural drought detection in the short term, and for water supply management in the long run. SPI's positive number denotes wet weather, whereas its negative value denotes aridity. Standardized numbers ranging from 0 to 1 indicate the severity of a drought (-2 and less). The percentage of meteorological drought that can above the limitations of the most generally recognized meteorological drought index ever, namely the SPI, has undergone extensive research. The standard deviation is a measurement of the difference between a data value and the mean in standard units. Using this measure, we can see how much rainfall varies from year to year and how many standard deviations there are from the average [33].

Spatial analysis: A Spatial Analysis Tool in the ArcGIS V. xx software used for investigating spatial patterns of daily rainfall data in the study area.

Spatial Interpolation: For all-natural and atmospheric sciences, spatial interpolation, or estimating a variable at an unsampled site using data from nearby samples, is critical. The ArcGIS V. xx spatial analyst tool was used to interpolate and analyze long-term annual rainfall data on a map.

The study area's rainfall map was generated using the Inverse Distance Weighting (IDW) interpolation technique. The method of IDW is used because it provides more accurate results than kriging and/or spline interpolation. IDW's spatial interpolation was based on the notion of distance weighting [7].

RESULT AND DISCUSSION

Drought years according to SPI

The Kalyan-Karnataka Region's (Number of stations: 31) drought severity years have been classified by SPI value as Extremely wet (EW), Very wet (VW), Moderately Wet (MW), Normal, Moderately Dry (MD), Very Dry (VD), and Extremely Dry (ED). The results of the draught analysis are presented in Table 1. The seasonal rainfall patterns and drought years for the Kalyan-Karnataka Region of Karnataka, as well as the severity of the drought in each month, are presented in Fig 02. The information was examined for Z values, Q values, and the Standardised Precipitation Index (SPI) spanning 55 years for 31 stations. This Z value ranges from -1.83 to 2.82. Shorapur recorded the lowest Z score (-1.83), suggesting an exceptionally dry year. Basavakalyan has the highest Z score (2.82) suggesting a very wet year. The Q values in this dataset vary from -3.243 to 4.609. Shorapur recorded the lowest Q score (-3.243) which denotes a year that was exceptionally dry and far from the long-term average. The highest Q score (4.609) is found in Basavakalyan and denotes a year with exceptionally high rainfall and a sharp deviation from the long-term average. Extremely wet to extremely dry are the two extremes of the SPI values. Extremely wet circumstances have been present in Yadgir, Shahapur, and Shorapur throughout 2, 1, and 3 years, respectively. Extremely wet rainfall affected Devadurga for four years while extreme wet rainfall affected Kalaburgi for two years. For a sizable period (between 33 and 46 years), the majority of rainfall stations have seen typical circumstances. Several rain gauges have recorded periods of moderate dryness and extreme dryness in various years, indicating sporadic drought episodes. Overall, the data offers insightful information on the wet and dry circumstances that various rainfall stations during the 55 years have encountered. A similar study was also reported by [19] and expressed that, it can be applied to the regional management of water resources, agricultural planning, and drought monitoring [11] and [25] reported draught analysis through the Standardised Precipitation Index (SPI) could be helpful to reduce the damage resulting from drought, it is necessary to assess the drought risk that can identify the impacts, causes, and vulnerability of drought.

Spatial variability of meteorological drought:

The spatial variability of meteorological drought occurrences between the years 1960 and 2014 are presented in Figure 3 and are categorized into three levels: (a) Moderate, (b) Normal, and (c) Severe. In the study area, multiple rainfall stations have recorded spatial variability of metrological drought during 55 years, taking into account distinct drought years (normal, moderate, and severe). The study examined the variations and trends in the drought and drought years throughout the study area to better understand the geographical variability. Variation within typical years was seen in the range of 28 to 49 at several rainfall stations, demonstrating a significant variation even within a regular year. Some rainfall stations experience more severe drought years than others, although both types of stations experience more moderate or typical years. The considerably larger number of drought years in all categories at rainfall stations like Shorapur, Lingsugur, and Aland suggests greater drought sensitivity. In contrast, rainfall sites like Shahapur and Manavi have comparatively fewer dry years across all categories. The study suggests that variations in the feature being measured when we compare the quantity across various sorts of drought years. For instance, the Hagaribommanahalli has the lowest value of 28, while the Kalaburgi has the highest value of 49 during typical years. This shows that, the effects of the region's droughts vary according to location. The study shows the spatial variability may have altered over 55 years in the study area. Over the years, Yadgir noticed increases in normal years from 41 to 44. These adjustments imply that, the characteristic's spatial patterns exhibit temporal variability. The overall spatial patterns can also be influenced by the number of drought years in each group (normal, moderate, and severe). Concerning the aforementioned rainfall stations and various drought years, spatial analytic techniques can be used to visualize patterns, and spot trends or clusters of high and low values for the "overall" feature. This study can shed light on the regional dynamics of the "overall" feature and its connection to drought occurrences across the 55-year timeframe.

Spatial variability of rainfall:

Figure 3 illustrates spatial variability maps of average annual rainfall for different periods: (a) 1960 to 2014 (b) 1960 to 1969 (c) 1970 to 1979 (d) 1980 to 1989 (e) 1990 to 1999 (f) 2000 to 2009 (g) 2010 to 2014. With 835.92 mm of rainfall recorded at Yadgir between 1960 and 1969, the station had a slightly higher average value than the others. Additionally, Shahapur, Shorapur, and Raichur have relatively high rainfall, indicating that their total rainfall was also substantial. Rainfall stations like Kalaburgi, Afzalpur, and Sedam have less precipitation than Yadgir, Shahapur, and Raichur, showing that there was comparatively less precipitation overall during that period. Rainfall in the Yadgir district ranged from 835.92 mm to 591.21 mm between 1960 and 1969. We may see changes in the rainfall when we compare it across the research area. For example, Kalaburgi had the highest rainfall throughout the 1960's and 1970's (894.69 mm), while Shorapur recorded the lowest (591.21 mm). This suggests that, the area has spatial variability in rainfall. We can see variances when comparing the rainfall across the research area. For instance, Kalaburgi had the highest rainfall between 1960 and 1969 (894.69 mm), while Shorapur had the lowest (591.21 mm). By comparing the rainfall from 1960 to 1969 and 1970 to 1979, we can see how the geographical variability may have altered over time. For instance, the value rose from 796.49 mm in 1960-1969 to 860.67 mm in 1970-1979 at Shahapur. These alterations show temporal variability in rainfall spatial patterns. Rainfall was recorded in the study area between 1980 and 1989 in the range of 955.69 mm to 533.96 mm. We can see changes in rainfall when we compare regions. For instance, between 1980 and 1989, Shorapur recorded the lowest value, 667.87 mm, and Shahapur recorded the highest value, 1090.10 mm. This implies that there are variations in the rainfall that is being recorded in the area. We can see how the regional variability may have evolved by comparing the rainfall values between the two time periods (1980-1989 and 1990-1999). The value of Yadgir falls from 955.69 mm in the years 1980–1989 to 845.55 mm in the years 1990–1999. These alterations show temporal variability in rainfall spatial patterns. When we look at variations over time and between different rainfall stations in the study region, patterns of spatial variability can start to appear. Rainfall in the studied area ranged from 510.12 mm to 906.08 mm between

2010 and 2014, demonstrating a significant difference between rainfall stations. When we compare rainfall figures for the study area as a whole, we can notice variations. With Kalaburgi having the highest (894.69 mm) and Chincholi receiving the least (583.9 mm) rainfall between 2000 and 2009, different locations experienced different amounts of precipitation. The changes in the cropping pattern, wetland cultivation, and other agronomical management could change the spatial and temporal rainfall and its distribution [3]. Spatial variability patterns can begin to emerge when studies examine the variances over time and between rainfall stations [16]. While some stations might change, others might experience high or low rainfall levels across both periods. Consequently, we may conclude that spatial analysis techniques can aid in the visualization of patterns and the identification of trends or clusters of high and low rainfall for the study region and periods.

CONCLUSIONS

The study's analysis of the long-term spatial and temporal variability of rainfall and meteorological drought in the Kalyan-Karnataka region of Karnataka, India, was its main focus. Six districts make up the study region, which has a dry environment for the majority of the year with hot summers and only 692 mm of annual rainfall on average. Sen's slope estimator and the Mann-Kendall test were two statistical analysis tools used in the study to evaluate the long-term variability and trend of rainfall data. The findings showed both yearly rises and declines in rainfall patterns, illuminating the intricate nature of precipitation fluctuations in the area. The severity of the drought was assessed using the Standardised Precipitation Index (SPI). The SPI values divided drought years into five categories: extremely, very, moderately, and slightly wet; normal; moderately, and slightly dry; and extremely, very, and slightly dry. Various rainfall stations (sub-districts) within the region experienced varying degrees of drought intensity, according to the analysis, with some places enduring more severe drought years than others. The management of water resources, the scheduling of agricultural activities, and the monitoring of droughts can all benefit from this knowledge. It was possible to see the spatial patterns in the rainfall data using spatial analysis utilizing the ArcGIS program and the Inverse Distance Weighting (IDW) interpolation method. The produced maps showed how rainfall was distributed throughout the study region and showed where there was more or less rainfall. In general, this study helps us understand the statistical traits of rainfall variability and meteorological dryness in the Kalyan-Karnataka region. The study findings can help in the creation of appropriate risk management methods as well as decision-making procedures managing water resources, managing food risks brought on by climate change, and other topics. Based on these results, future research can examine the effects of drought on the region's agriculture, ecology, and way of life for people.

Future scope of the study

The results of the present study would help to conduct further studies on impact of climate change on agriculture and allied sector in Kalyan Karnataka region and prepare contigency planning for cope up with adverse climate to help farming community the region.

Conflict of interest

No potential conflict of interest was reported by the authors.

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Table: 1 Taluka wise long term trend of Z, Q values and Standardized Precipitation Index.

TALUKA	LATI TUDE	LONGI TUDE	Z Value	Q Value	Standardized Precipitation Index (SPI)						
					EW	VW	MW	Normal	MD	VD	ED
Yadgir	16.7602	77.1428	-0.620	-1.426	2	4	2	36	10	1	0
Shahapur	16.6955	76.8432	-1.090	-2.828	1	4	4	36	10	0	0
Shorapur	16.5217	76.7611	-1.830	-3.243	3	3	3	40	6	0	0
Raichur	16.2120	77.3439	0.270	0.300	1	5	2	39	9	2	0
Devadurga	16.4235	76.9355	1.500	1.737	4	1	5	39	6	3	0
Lingsugur	16.1550	76.5199	-0.740	-0.874	0	4	4	43	6	1	0
Manvi	15.9951	77.0478	0.870	1.191	0	3	7	40	5	3	0
Sindhanur	15.7689	76.7545	0.980	1.494	4	1	3	43	6	1	0
Yelaburga	15.6142	76.0131	-0.360	-0.438	4	1	3	39	9	1	1
Kushtagi	15.7519	76.1929	1.400	2.111	2	3	4	40	6	3	0
Gangavathi	15.4319	76.5315	0.740	0.979	4	1	4	40	6	3	0
Koppala	15.3363	76.1585	1.550	2.583	2	2	5	43	6	1	0
Kalaburgi	17.3297	76.8343	-1.730	-3.214	2	3	3	46	2	2	0
Afzalpur	17.2026	76.3558	-0.200	-0.192	0	4	5	38	7	3	1
Aland	17.5676	76.5662	-1.060	-1.709	2	3	6	40	5	1	1
Chincholi	17.4610	77.4193	-1.000	-2.540	3	2	1	44	3	1	1
Chittapur	17.1174	77.0904	-0.460	-0.781	1	4	5	38	8	1	1
Jevargi	17.0114	76.7769	-1.420	-2.553	5	1	2	44	4	1	0
Sedam	17.1784	77.2873	-0.490	-0.681	1	4	6	37	5	2	2
Aurad	18.2527	77.4177	0.990	1.884	1	3	6	39	4	4	1
Basavkalyan	17.8721	76.9470	2.820	4.609	1	6	1	33	6	1	1
Bhalki	18.0504	77.2184	-0.750	-1.007	1	2	7	40	6	1	1
Bidar	17.9149	77.5046	0.110	0.196	1	2	6	38	9	2	0
Humnabad	17.7696	77.1267	0.130	0.262	2	1	6	39	5	4	1
Bellary	15.1293	76.9204	0.980	2.758	0	2	5	20	6	1	0
Hagari Bommanahalli	15.0559	76.2110	0.800	2.377	1	2	4	21	4	2	0

Hoovina Hadagali	15.0198	75.9330	1.010	3.110	0	3	3	22	3	3	0
Hospete	15.2667	76.4333	0.800	2.377	1	2	3	21	4	2	0
Sandur	15.0890	76.5455	0.980	2.758	1	2	2	23	4	2	0
Kudligi	14.9038	76.3853	1.550	4.389	0	2	5	20	6	1	0
Siruguppa	15.6206	76.8952	0.680	1.633	2	1	2	23	5	1	0

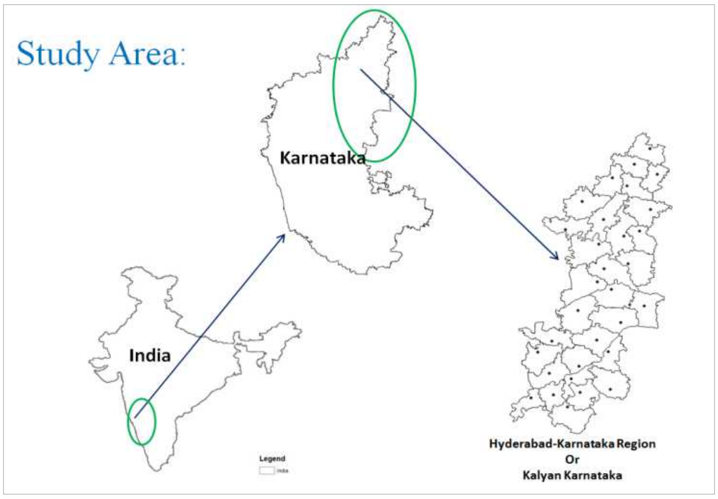

Fig.1 Location of the study area.

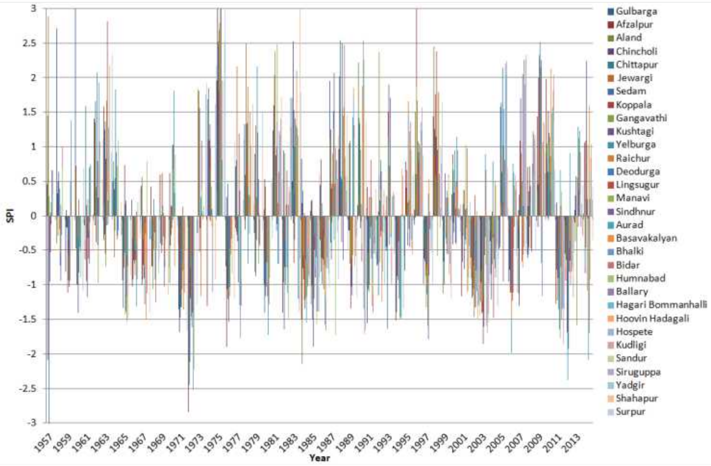

Figure. 2 Standardized precipitation index of various rainfall stations.

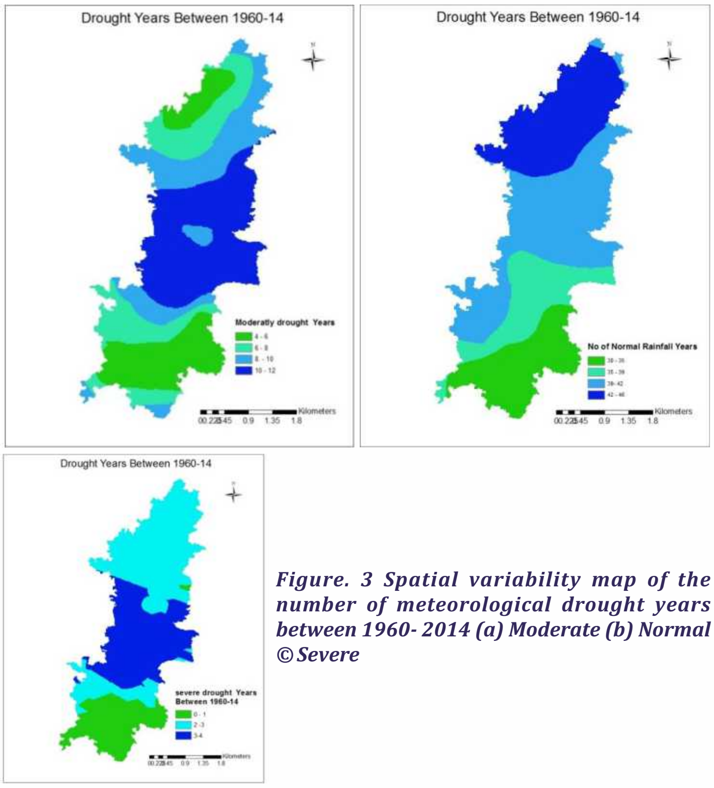

Figure. 3 Spatial variability map of the number of meteorological drought years between 1960- 2014 (a) Moderate (b) Normal © Severe

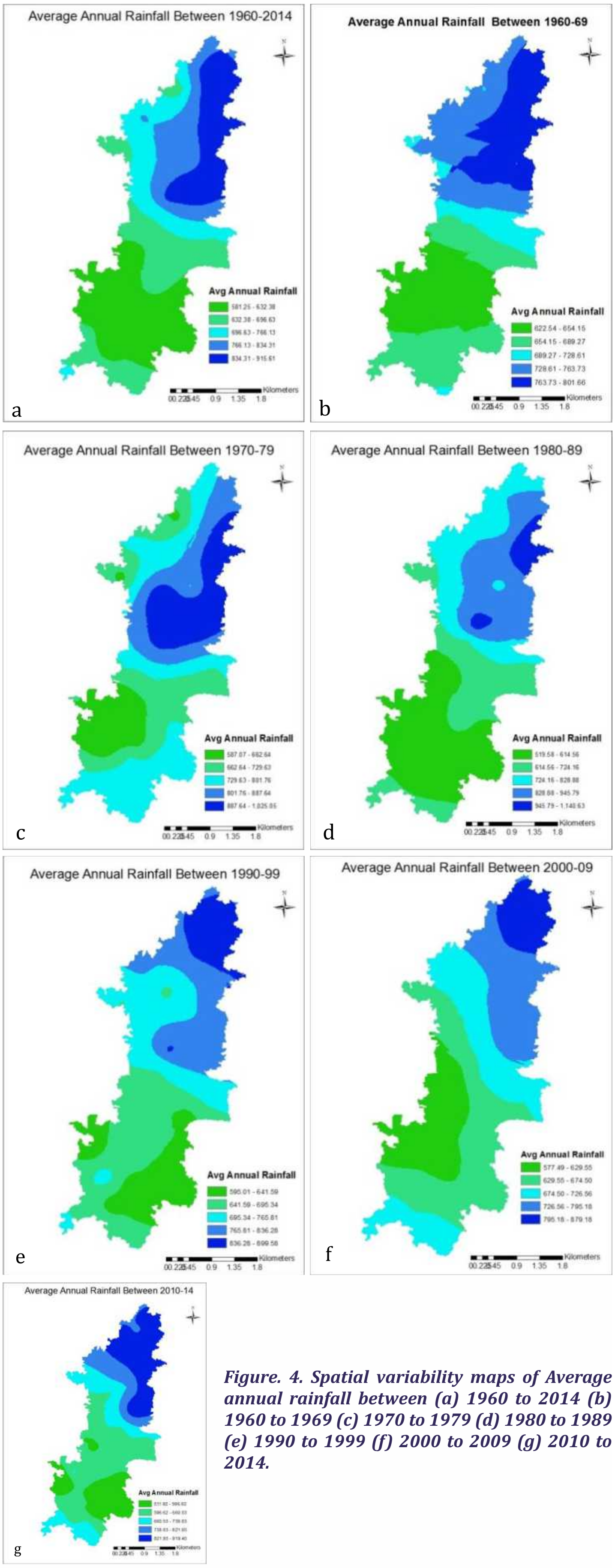

Figure. 4. Spatial variability maps of Average annual rainfall between (a) 1960 to 2014 (b) 1960 to 1969 (c) 1970 to 1979 (d) 1980 to 1989 (e) 1990 to 1999 (f) 2000 to 2009 (g) 2010 to 2014.

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