MAUSAM, **72**, 4 (October 2021), 865-878

631 : 551.577.62 (540.29)

Drought severity assessment in south Bihar Agro-Climatic zone

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(*Received 11 March 2021, Accepted 26 July 2021*)

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सार – वर्तमान अध्ययन में बिहार कृषि-जलवायु क्षेत्र- III, जो बिहार के सूखाग्रस्त क्षेत्र में पड़ता है, में सूखे की स्थिति को पहचानने और इसकी मात्रा निर्धारित करने पर ध्यान केंद्रित किया गया है। यह क्षेत्र पूरे दक्षिण बिहार क्षेत्र को शामिल करता है, जिसमें सत्रह जिले शामिल हैं। अध्ययन क्षेत्र में सूखे की गंभीरता का आकलन दो तरीकों से किया गया है, अर्थात्, वर्षा प्रस्थान विश्लेषण और संभाव्यता विश्लेषण। शोध कार्य ग्रिड स्तर पर किया गया है जिसमें पचास-पचास ग्रिड शामिल हैं। कार्य के विश्लेषण का जिलेवार मूल्यांकन किया गया है और इसके अलावा परिणाम दो कृषि-जलवायु क्षेत्रों (क्षेत्र-iii) (क) और क्षेत्र-iii (ख) के लिए व्याख्या की गई है। दशकों से, बारिश की असमान शुरुआत के कारण क्षेत्र लगातार सूखे की घटना के प्रभाव में है। भागलपुर जिले का ग्रिड सैंतालीस वर्ष में एक बार कम से कम सूखे की आवृत्ति होती है और 116 वर्ष की अवधि में अधिकतम बासठ सूखा वर्ष का सामना करना पड़ता है, परिणामस्वरूप वर्षा प्रस्थान विश्लेषण। वर्ष 1978-79 के दौरान, बांका जिले के ग्रिड -32 (जी -32) के लिए -82.99% की अधिकतम वार्षिक वर्षा 2.7 वर्षों में एक बार की वापसी अवधि के साथ देखी गई थी। संभाव्यता विश्लेषण से निष्कर्ष निकलता है कि ग्रिड 37, 42, 45 और 47 से प्रभावित क्षेत्र सूखाग्रस्त हैं (75% औसत वर्षा की संभावना 80% से कम है)। प्रस्थान के साथ-साथ संभाव्यता विश्लेषण से संकेत मिलता है कि ग्रिड सैंतालीस सूखा-प्रवण है। यह सामान्य तौर पर मौसम संबंधी सूखे के आकलन में दो तरीकों की अनुकूलता और विशेष रूप से ग्रिड -47 की सबसे गंभीर स्थिति और आस-पास के इलाकों को प्रभावित करने वाली स्थिति को दर्शाता है।

ABSTRACT. The present study has been focused to recognize and quantify the drought condition in Bihar Agro-climatic Zone-III, which falls in the drought-prone region of Bihar. The zone covers the whole South Bihar region, comprising of seventeen districts. The drought severity assessment in the study area has been carried out by two methods *i.e*., the rainfall departure analysis and the probability analysis. The research work has been carried out at a grid level consisting of fifty-five grids. The analysis of work has been further evaluated district-wise and in addition the result has been interpreted for the two agro-climatic zones {zone-iii (a) and zone-iii (b)}. For decades, the area is under the influence of frequent droughts due to uneven distribution of rainfall. The grid forty-seven of Bhagalpur district having maximum drought frequency of once in 1.87 years and also faces a maximum number of sixty-two drought years in the period of 116 years, as resulted from rainfall departure method. The maximum annual rainfall departure of -82.99% was observed for the grid-32 (G-32) of Banka district, during the year 1978-79, with a return period of once in 2.7 years. The probability analysis concludes that the areas influenced by grids 37,42,45, and 47 are drought-prone (probability of 75% mean rainfall being less than 80%). The departure as well as the probability analysis indicates that the grid-47 as drought-prone. This shows the compatibility of the two methods in meteorological drought assessment in general and particularly the most drought severe condition of the grid-47.

Key words – Drought area, Drought years, Weibull's plotting position formula, Departure analysis.

1. Introduction

In the world, India has also its position in the top list of most drought vulnerable countries with a drought frequency of at least once every three years during the last decades (FAO 2002, World Bank, 2003). Drought is a complex hazard and one of the major challenges to life affecting social as well as economic progress. The damage contribution in percentage to agriculture with respect to others by natural hazard was around 22% (FAO, 2015). The drought impact, as compared to different natural calamities is more severe. The drought categorization can be expressed as its regional extent, severity condition and period of persistence. The severity indicates, how

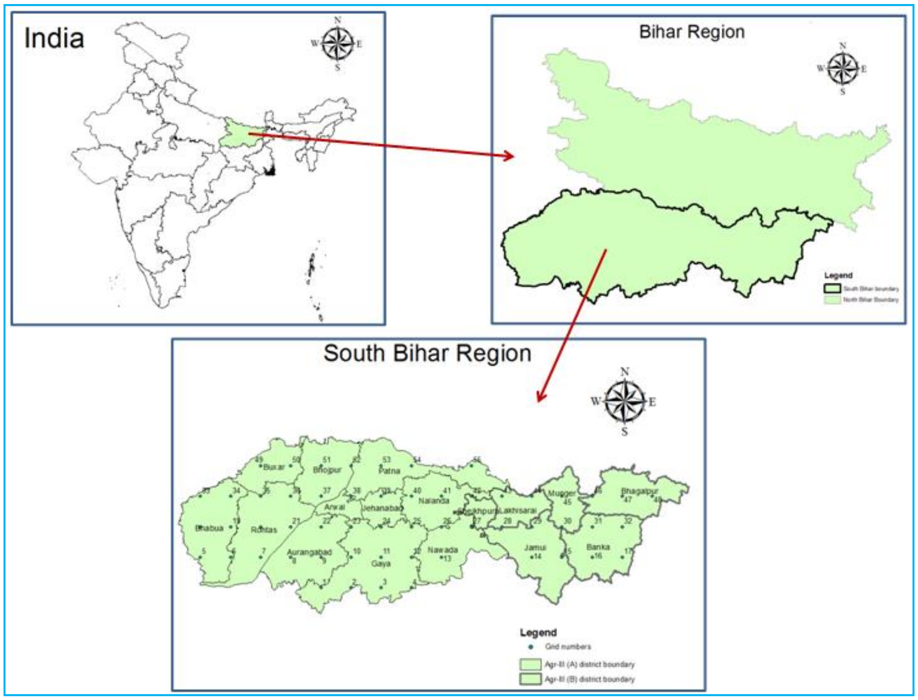

Fig. 1. Location map of study area

intensely the area is hit by the hazard, the persistence shows the continuous existence of drought (WMO, 2016 and GWP, 2016). The attributes, indicating impacts of drought, comprises of soil water depletion, stream flow reduction, storage in reservoir and level of groundwater as well as lake (Dracup *et al*., 1980). The various spatio temporal drought factors were integrated for drought vulnerability assessment in the drought-prone region of Bundelkhand, Madhya Pradesh (Kar *et al*., 2018). The spatial and temporal drought analysis using 3-m SPI is very helpful to detect the onset and withdrawal of the drought events and the drought prone areas and additionally the expansion pattern (Kar *et al*., 2018). The amount of rainfall in arid mainly depends on few events of rainfall so their proneness to drought is relatively high (Sun *et al*., 2006). The severity of drought and maximum intensified areas, changes gradually and seasonally respectively (Wilhite, 2000).The drought severity is taken as an important factor for the drought propagation analysis as compared other indexes, which help in advance, policy makers to detect this phenomenon (Kar *et al*., 2016). Identification of drought persistence and drought area is useful for monitoring drought events and acts as an early warning system. The southern part of river Ganga is facing severe drought every year during kharif season. The pre-monsoon drought is more severe as compared to the post-monsoon season (T. Ghosh *et al*., 2014). This study has been carried out in south Bihar Agro-Climatic Zone-III which falls in the drought-prone region of Bihar. The zone is highly rainfed and the south-west monsoon is the only big contributor of rainfall. The deficit monsoon rainfall is responsible for the regular occurrence of drought and subsequent water stress in the zone. The present study will help in understanding and quantifying the drought scenario of the region consisting of a total of 55 grids in the area.

2. Data and methodology

2.1. Study *area*

Bihar is a land-locked state situated on the eastern part of India, between 83° 30' to 88° 00' longitude and 21° 58' to 27° 03' latitude. The state is roughly quadrilateral in shape situated on the north east side of India. The Bihar State with a geographical area of 94.2 thousands square kilometer is divided by river Ganges into two parts, the north Bihar having an area of 53.3 thousands square kilometer, and the south Bihar having an area of 40.9 thousands square kilometer. The present research has been carried out in South Bihar region. Based on soil characterization, rainfall, temperature and terrain, three main agro-climatic zones in Bihar have been identified by Food and Agriculture Organization. These are : Zone - I (North West Alluvial Plain), Zone - II (North East Alluvial Plain), and Zone - III (A, B) (South Bihar, Alluvial Plain), each with its own potential and prospects.

TABLE 1

Drought severity classification based on percentage of departure

Drought severity Classes	Rainfall departure (%)
Mild Drought	-10 to -20
Moderate Drought	-20 to -25
Severe Drought	-25 to -50
Extreme Drought	Less than -50

The whole south Bihar comes under Agro-Climatic zone –III, located in the south of the river Ganga and has been further sub-classified as Agro-climatic zone III (A) and Agro-climatic zone III (B). The districts of Agro-climatic zone III (A) are Sheikhpura, Munger, Jamui, Lakhisarai, Bhagalpur and Banka and the districts that comprises Agro-climatic zone III (B) are Rohtas, Bhojpur, Buxar, Bhabhua, Arwal, Patna, Nalanda, Nawada, Jehanabad, Aurangabad and Gaya. The total geographical area of south Bihar is 40,875.5 square kilometer, which represents 25.75% of the total area of the State. The location map of the study are has been shown in Fig. 1.

2.2. *Climate*

The average annual rainfall in the zone is 1102.1 mm. The land's slope is towards north east with gentle slope gradient and moderate to low gradient. South Bihar is drained by six rivers namely (*i*) Karmnasa, (*ii*) Sone, (*iii*) Punpun, (*iv*) Kiul-harhar, (*v*) Badua and (*vi*) Chandan. All these rivers drain into the main Ganga stem (Report of the special task force on Bihar, 2008, G.O.I).

2.3. *Soil type and geology*

The soil is mostly medium to heavy textured throughout the depth of the profile. There are no marshy lands in this zone. The main broad soil association groups recognized in this zone are (*i*) Recent alluvial calcareous soils, (*ii*) Tal land soils, light grey, dark grey medium to heavy textured soils, (*iii*) Old alluvial reddish yellow, yellowish-grey centenary soils, (*iv*) Old alluvial grey, grayish-yellow, heavy texture soils with cracking nature, (*v*) Recent alluvial yellowish to reddish-yellow non-calcareous non-saline soils, (*vi*) Old alluvial yellowish to red-yellow soils of foothills, and (*vii*) Old alluvial saline and saline-alkali soils (Report of the special task force on Bihar, 2008, G.O.I).

2.4. *Data availability*

The shape-file of Bihar is collected from the Survey of India and the seventeen districts comprising of South Bihar Agro-climatic Zone-III as per the Food and Agriculture Organization of the United Nations, are extracted in the ARC GIS platform. The freely available daily gridded rainfall data at grid level of 0.25* 0.25 degree spatial resolution is downloaded for all fifty-five grids of the study area from the India Meteorological Department (Pai *et al.*, 2014) and is processed and converted in monthly gridded data for all grids in excel, using pivot table, from 1901 to 2016.

2.5. *Identification of drought years*

Rainfall departure is a good indicator for the identification of wet or dry grids for a given time period (Kar *et al.*, 2016). In the research, IMD method has been employed for meteorological drought assessment (Report of Irrigation Commission, 1972). A grid is considered to be affected by drought, in case, the annual rainfall received that year, is less than 75% of its normal value, as per Indian Meteorological Department (Appa Rao, 1986). The drought years in a given study area are identified by using the departure analysis as done by various researchers (Kar *et al.*, 2016). The drought years have been identified based on the departure analysis of annual rainfall for the period of study. The annual rainfall departure was computed by subtracting the normal annual rainfall (R_m) from the mean annual rainfall (R_i) for that year. The percentage departure (D_i) is subsequently computed by dividing the rainfall departure by the normal annual rainfall for various grids as given by Equation 1.

$$D_i\,(\%) = \{(R_i - R_m) / R_m\} * 100 \quad (1)$$

Where,

Di = Annual rainfall departure for the i^{th} year,

Ri = Annual rain fall for i^{th} year,

Rm = Normal annual rainfall for the years of research

The year having annual rainfall departure more than or equal to 25% is considered to be a drought year. The severity of drought has been classified according to percentage deviations from the normal rainfall and grouped into four severity classes as given in Table 1, (Kar *et al.*, 2016). The departure analysis of annual rainfall has been computed for all the fifty-five grids of the agro-climatic zone-III and consequently the drought years have been detected.

2.6. *Identification of drought prone grids*

To detect the drought-prone zone, the probability analysis of rainfall was done in the area, which was facing

TABLE 2

Summary of annual rainfall departure analysis

AGR Zone	Districts Names	Grid No.	Data Available	Drought Frequency	Drought Years	Maximum Departure	Departure Year	Drought Condition
A	Arwal	G-38	116	2.37	49	-68.62	1965-66	Extreme
A	Aurangabad	G-8	116	2.97	39	-61.34	1965-66	Extreme
A	Aurangabad	G-9	116	3.05	38	-49.44	2004-05	Severe
A	Aurangabad	G-22	116	2.64	44	-49.27	1965-66	Severe
B	Banka	G-16	116	2.9	40	-45.37	1965-66	Severe
B	Banka	G-17	116	2.76	42	-44.52	1964-65	Severe
B	Banka	G-31	116	3.05	38	-51.22	1965-66	Extreme
B	Banka	G-32	116	2.7	43	-82.99	1978-79	Extreme
A	Bhabhua	G-5	116	3.14	37	-74.96	1950-51	Extreme
A	Bhabhua	G-6	116	2.9	40	-51.13	1978-79	Extreme
A	Bhabhua	G-18	116	2.47	47	-66.06	1965-66	Extreme
A	Bhabhua	G-19	116	2.76	42	-45.98	1979-80	Severe
A	Bhabhua	G-33	116	3.05	38	-49.13	1965-66	Severe
A	Bhabhua	G-34	116	2.64	44	-59.96	1965-67	Extreme
B	Bhagalpur	G-46	116	2.97	39	-59.70	1922-23	Extreme
B	Bhagalpur	G-47	116	1.87	62	-56.89	1922-24	Extreme
B	Bhagalpur	G-48	116	2.69	43	-50.85	1965-66	Extreme
A	Bhojpur	G-37	116	2.42	48	-67.57	1982-83	Extreme
A	Bhojpur	G-51	116	2.9	40	-68.62	1971-72	Extreme
A	Buxar	G-49	116	3.23	36	-59.15	2003-04	Extreme
A	Buxar	G-50	116	3.14	37	-69.79	1971-72	Extreme
A	Gaya	G-1	116	3.05	38	-68.76	2008-09	Extreme
A	Gaya	G-2	116	2.23	52	-50.85	2013-14	Extreme
A	Gaya	G-3	116	2.58	45	-52.08	2009-10	Extreme
A	Gaya	G-4	116	2.83	41	-44.07	1965-66	Severe
A	Gaya	G-10	116	2.9	40	-45.47	2004-05	Severe
A	Gaya	G-11	116	3.32	35	-49.62	1978-79	Severe
A	Gaya	G-12	116	3.14	37	-45.77	1965-66	Severe
A	Gaya	G-23	116	2.47	47	-52.60	1965-66	Extreme
A	Gaya	G-24	116	3.32	35	-50.79	2004-05	Extreme
A	Gaya	G-25	116	2.52	46	-58.10	2010-11	Extreme
B	Jamui	G-14	116	2.83	41	-47.99	1965-66	Severe
B	Jamui	G-15	116	2.97	39	-56.07	1965-66	Extreme
B	Jamui	G-29	116	3.05	38	-48.77	1965-66	Severe
A	Jehanabad	G-39	116	2.9	40	-57.34	2004-05	Extreme
B	Lakhisarai	G-28	116	2.83	41	-39.76	1953-54	Severe
B	Lakhisarai	G-43	116	2.64	44	-58.19	1971-72	Extreme
B	Lakhisarai	G-44	116	2.9	40	-65.08	1976-77	Extreme
B	Munger	G-30	116	2.76	42	-62.48	1965-66	Extreme
B	Munger	G-45	116	2.76	42	-56.28	1965-66	Extreme
A	Nalanda	G-40	116	3.14	37	-52.31	2004-05	Extreme
A	Nalanda	G-41	116	2.64	44	-48.38	2003-04	Severe
A	Nawada	G-13	116	2.83	41	-68.16	1974-75	Extreme
A	Nawada	G-26	116	2.7	43	-60.92	1922-23	Extreme
A	Patna	G-52	116	2.37	49	-80.35	1948-49	Extreme
A	Patna	G-53	116	2.47	47	-71.01	1965-66	Extreme
A	Patna	G-54	116	2.97	39	-58.73	1965-66	Extreme
A	Patna	G-55	116	2.64	44	-62.50	1965-66	Extreme
A	Rohtas	G-7	116	2.83	41	-57.71	1965-66	Extreme
A	Rohtas	G-20	116	2.58	45	-54.11	1965-66	Extreme
A	Rohtas	G-21	116	2.64	44	-49.24	1965-66	Severe
A	Rohtas	G-35	116	2.9	40	-62.09	2008-09	Extreme
A	Rohtas	G-36	116	2.52	46	-51.35	1965-66	Extreme
B	Sheikhpura	G-27	116	2.97	39	-75.31	1976-77	Extreme
B	Sheikhpura	G-42	116	2.76	42	-56.93	1945-46	Extreme

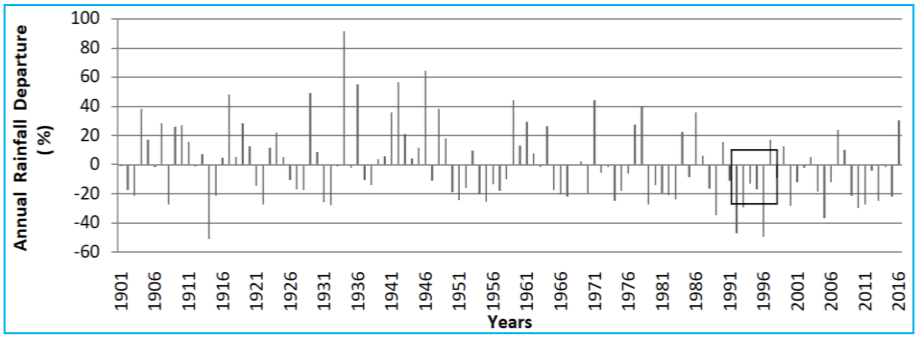

Fig. 2. Annual rainfall departure at grid 2

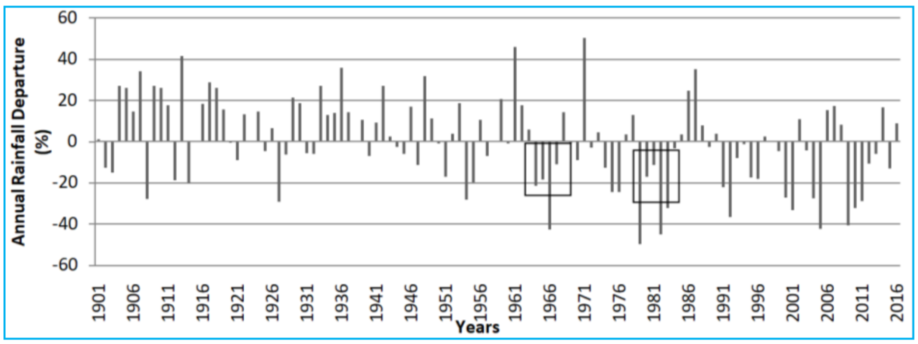

Fig. 3. Annual rainfall departure at grid 11

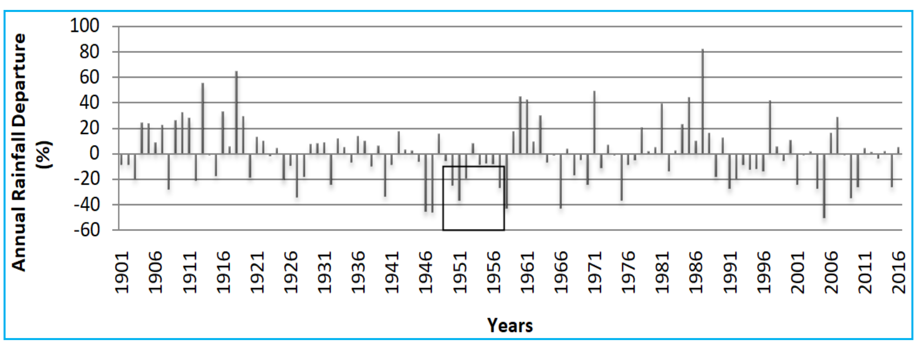

Fig. 4. Annual rainfall departure at grid 24

frequent drought events (Kar *et al.*, 2016). The result of this study will help in drought mitigation plans to be implemented on a priority basis. Weibull's plotting position formula has been used for performing the probability distribution analysis of annual rainfall. The analysis method was done by arranging the magnitude of annual rainfall in the decreasing order and ordering it. The first entry takes order of 1 and the last entry as N, and finally the plotting position formula was fitted to the ordered data. Consequently, the plots between the probability of exceedance and the corresponding magnitude of annual rainfall were prepared. By using the Equation 2, the probability of exceedance is estimated.

$$P = \{m / (n+1)\} * 100 \tag{2}$$

Where;

P = Probability of exceedence (%)

m = Order of rainfall in the series

N = Total number of rainfall events in the series.

The probability of occurrence for rainfall equivalent to 75% of mean annual rainfall as well as the 75% dependable annual rainfall was computed and analyzed for

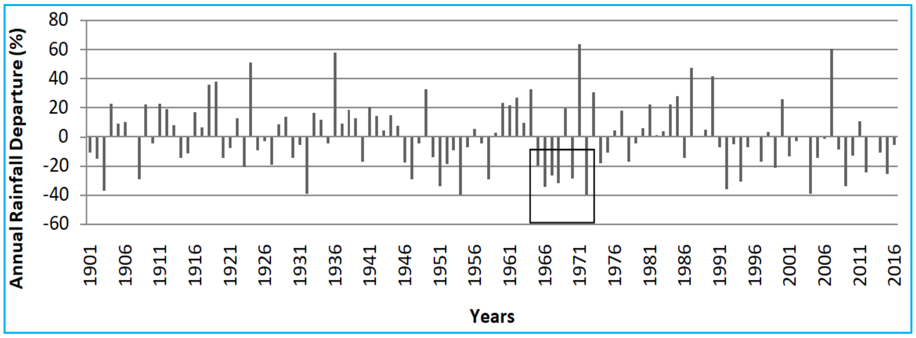

Fig. 5. Annual rainfall departure at grid 28

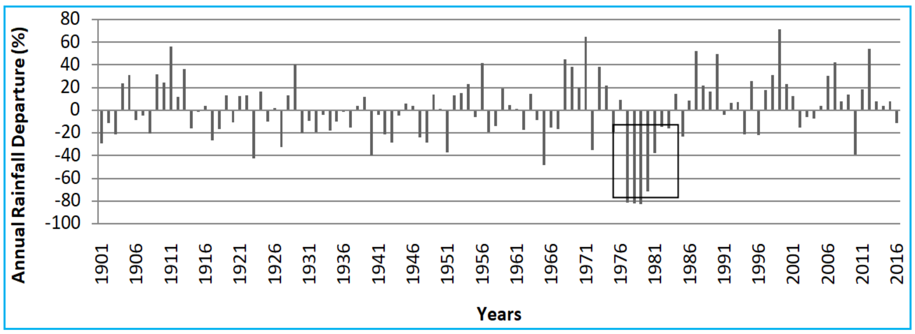

Fig. 6. Annual rainfall departure at grid 32

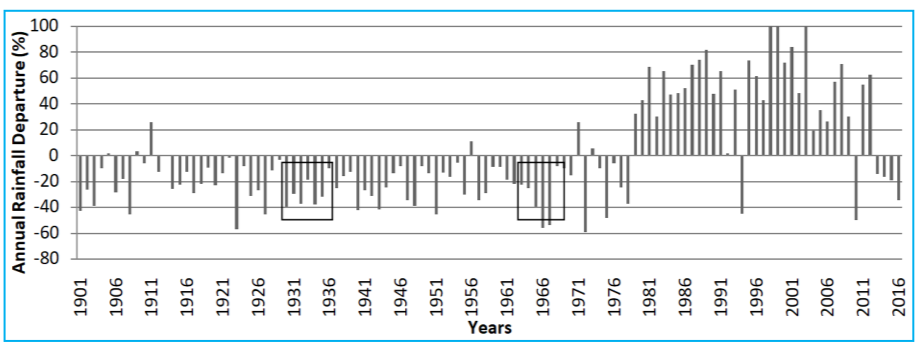

Fig. 7. Annual rainfall departure at grid 47

drought conditions. A grid was considered to be drought prone if the probability of occurrence of 75% mean annual rainfall was less than 80% otherwise the area was not considered as drought prone (CWC, 1982).

3. Results and discussion

3.1. *Identification of drought years at grid level*

The percentage departure of rainfall from normal annual rainfall has been carried out to identify the drought years based on the data for the period from 1901-02 to 2015-16 at grid level in the study area. The departure of rainfall in the positive direction indicates wet conditions whereas the departure in a negative direction indicates the condition of drought. The result shows that maximum annual rainfall departure of -82.99% was observed during the year 1978-79 (mean annual rainfall, 1137.74 mm) for the grid-32 (G-32) of Banka district with a maximum return period of once in 2.7 years and second most rainfall departure of -80.35% observed during the year 1948-49 (mean annual rainfall, 932.53 mm) for the grid 52 of Patna district with a maximum return period of once in 2.4 years.

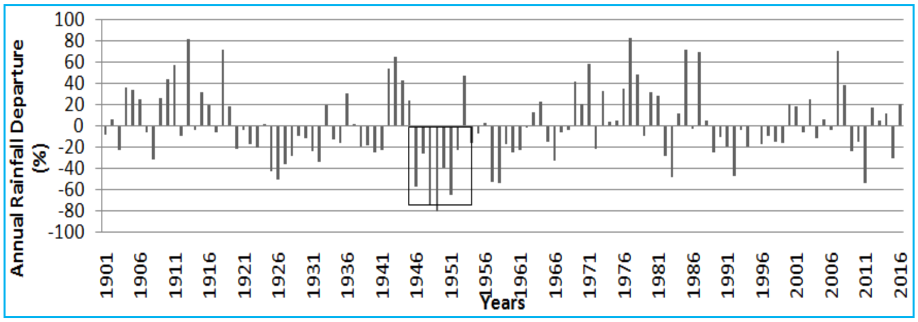

Fig. 8. Annual rainfall departure at grid 52

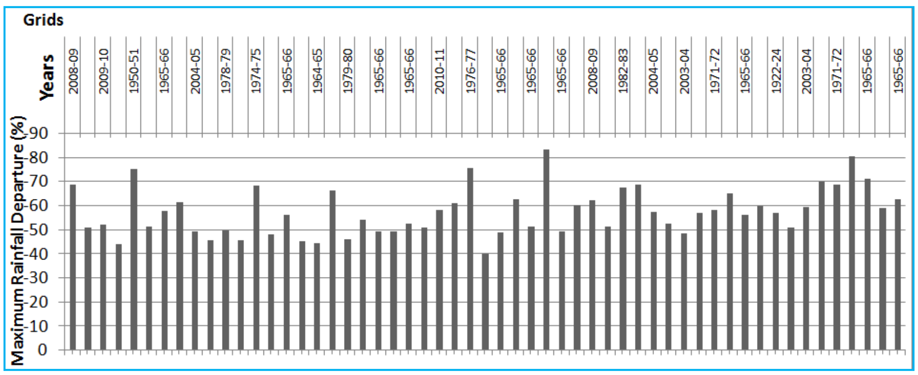

Fig. 9. Maximum rainfall departure at grids from 1901-2016

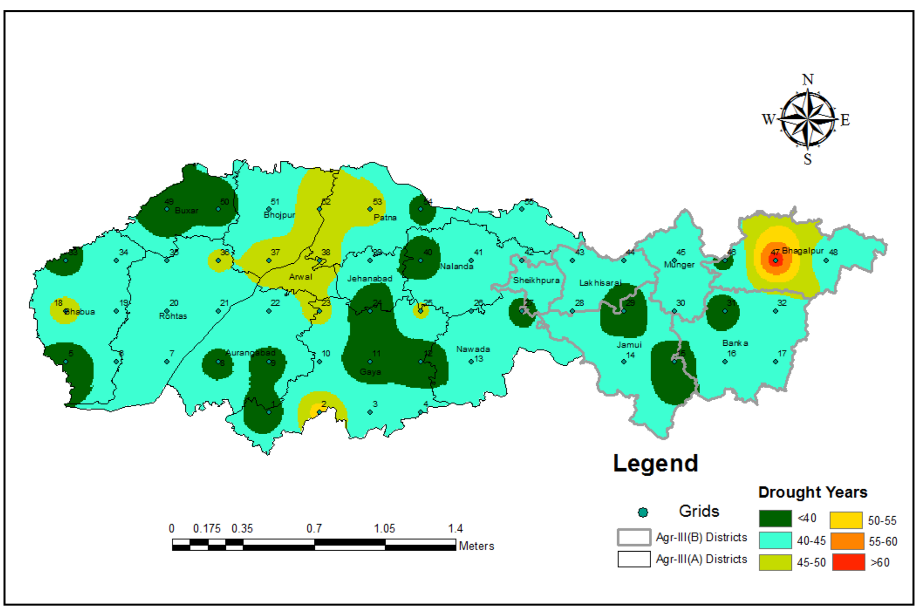

Fig. 10. Spatial variation map of south Bihar for drought years

However, the minimum rainfall departure -39.76 % has been observed for the grid 28 of Lakhisarai district during 1953-54 (mean annual rainfall, 1096.31 mm), with a maximum return period of once in 2.8 years. The bar diagram indicating maximum rainfall departure in the period of 116 years from 1901 to 2016 was shown in Fig. 9. The complete summary of rainfall departure for all the fifty-five grids consisting of all seventeen districts was

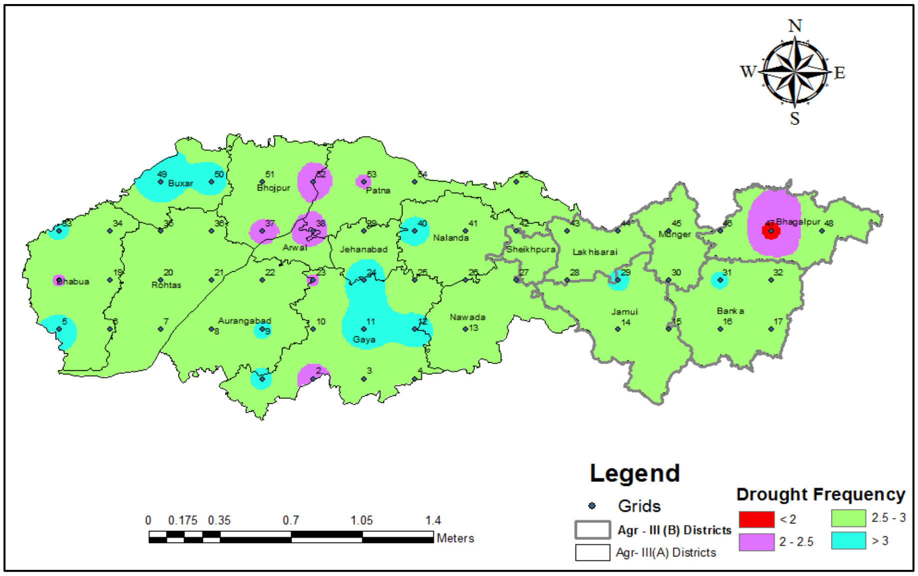

Fig. 11. Spatial variation map of south Bihar for drought frequency

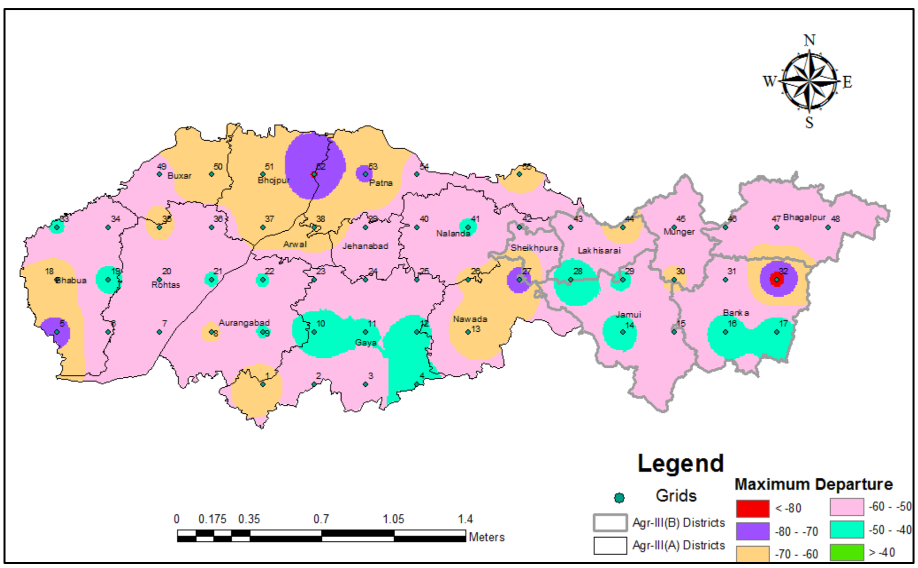

Fig. 12. Spatial variation map of south Bihar for maximum departure

tabulated in Table 2. It can be concluded from Table 2, that grid -74 (G-47) of Bhagalpur district faces a maximum number of sixty-two events with the most severe drought frequency of once in 1.9 years and the grid two (G-2) of Gaya district faces second most twelve (52) drought events during the study period, while grid 11 (G-11) and grid 24 (G-24) is at lowest position with only 35 drought events.

If we talk at the district level, then on an average, Arwal was the one that faces a maximum number of forty-nine (49) drought events and Bhagalpur was at second position with forty-eight (48) drought events, while Buxar was at the lowest position with only thirty-six to thirty-seven (36.5) drought events in the line. The bar graph of annual rainfall departure at grids 2, 11, 24, 28, 32, 47, and 52 are given in Figs. 2, 3, 4, 5, 6, 7 and Fig. 8 respectively. As the south-west monsoon was the only big contributor of rainfall, the deficit south-west monsoon was primarily responsible for the regular occurrence of drought and subsequent water stress in the study area, there by adversely affecting the major agricultural

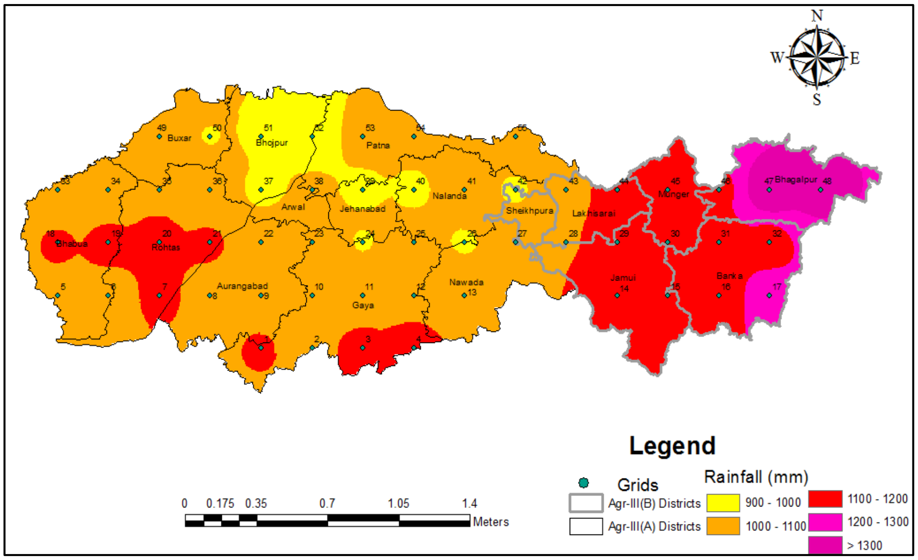

Fig. 13. Spatial variation map of south Bihar for normal annual rainfall (mm)

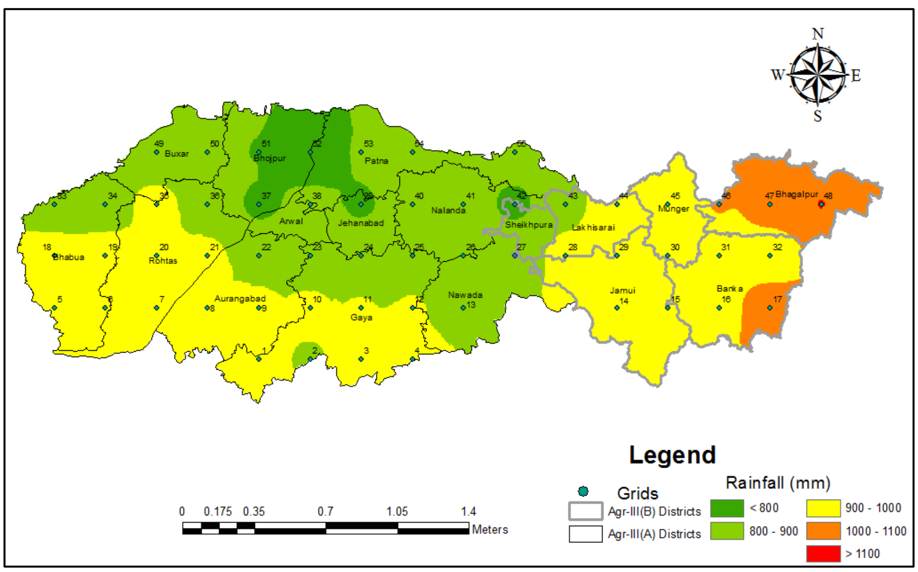

Fig. 14. Spatial variation map of south Bihar for 75% dependable rainfall (mm)

operations. The rainfall departure analysis also resulted that the drought occurs once every two to three years in the agro-climatic zone.

3.2. *Spatial analysis of drought parameters*

The spatial variation map of drought attributes (drought years, drought frequency and maximum departure) and rainfall attributes (normal annual rainfall and 75% dependable rainfall) has been prepared to visualize and analyze the results more effectively. The inverse distance weighed (IDW) interpolation technique has been used to interpolate the grid result of all the above discussed parameters, up-to the extent of the area of interest, on ARC GIS (10.1) platform. Fig. 10 shows the spatial variation of drought years in the districts of South Bihar agro-climatic zone III (A) and III (B). It indicates that more than fifty percent of the area faces drought years in the range of 40-45 in the study period of 116 years. The Drought years greater than sixty are mainly concentrated in Bhagalpur district of zone-iii (b), no patches of zone-iii (a) faces drought years in this category, this indicates the severity of the Bhagalpur district and nearby area.

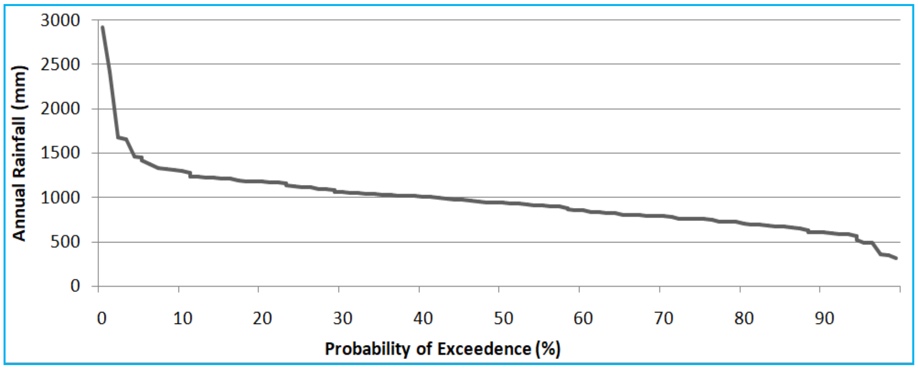

Fig. 15. Probability distribution of annual rainfall (mm) at grid 37

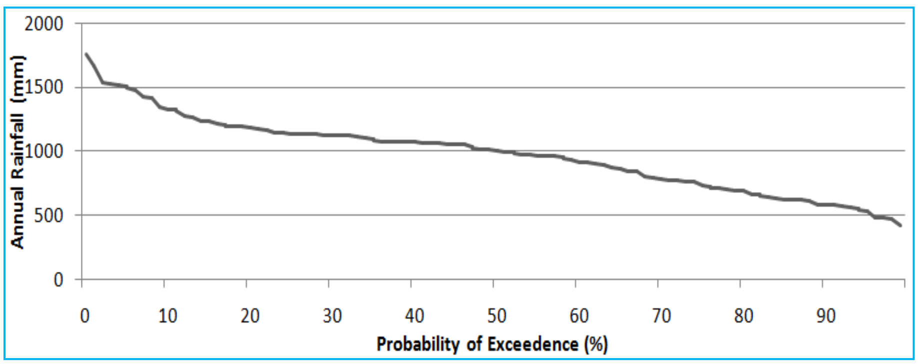

Fig. 16. Probability distribution of annual rainfall (mm) at grid 42

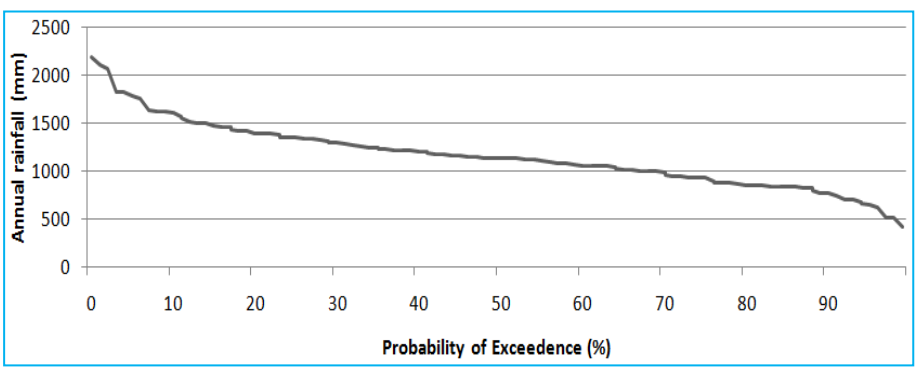

Fig. 17. Probability distribution of annual rainfall (mm) at grid 45

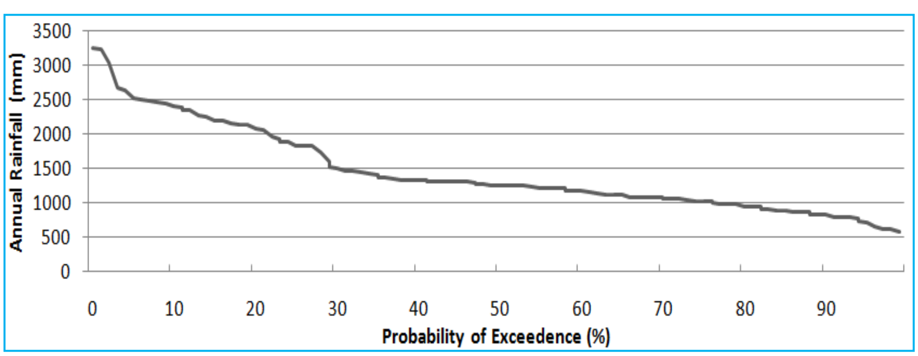

Fig. 18. Probability distribution of annual rainfall (mm) at grid 47

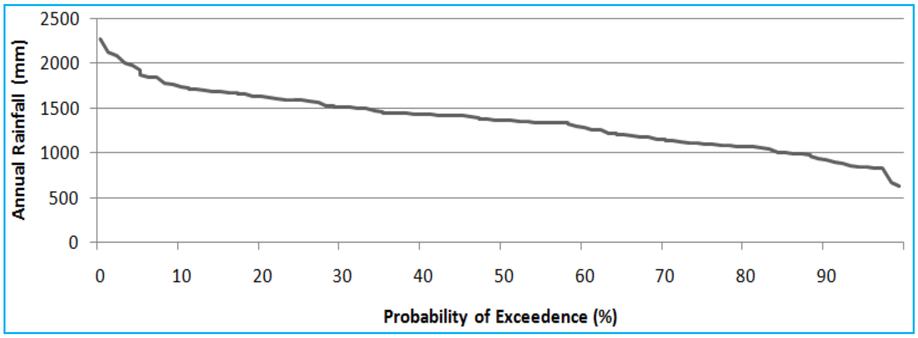

Fig. 19. Probability distribution of annual rainfall (mm) at grid 48

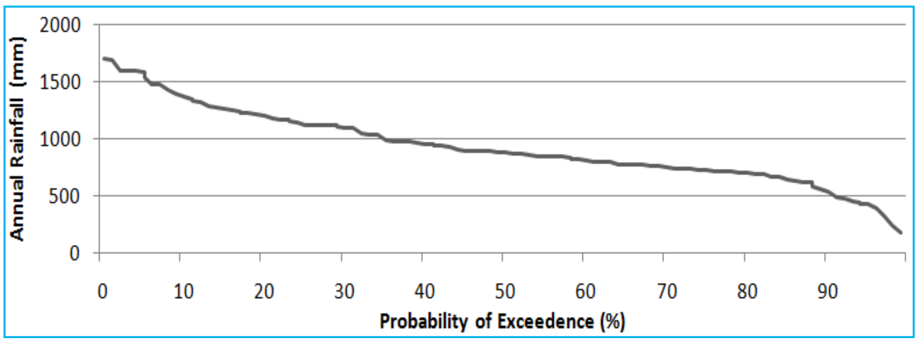

Fig. 20. Probability distribution of annual rainfall (mm) at grid 52

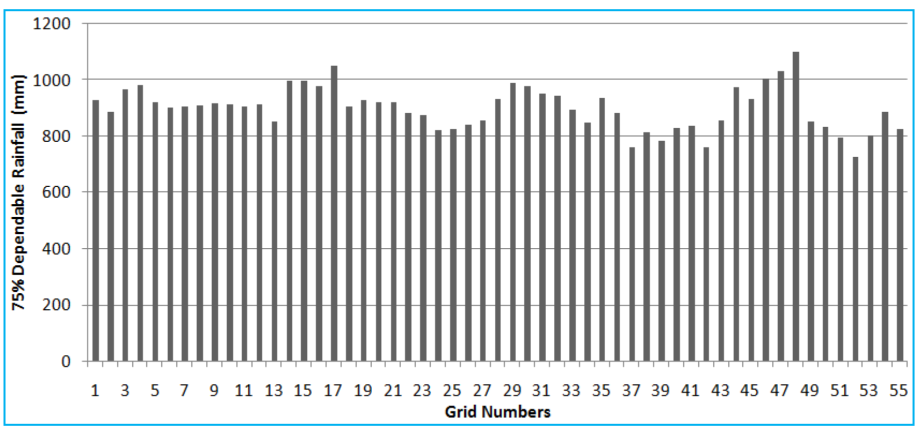

Fig. 21. Variation of 75 % dependable rainfall (mm) at grids

The spatial variation of drought frequency in the study area has been shown in Fig. 11. Drought frequency is inversely proportional to the number of drought years and the same can be seen by comparing Fig. 10 and Fig. 11. The grid 47 of Bhagalpur district with drought return of once in less than two years, put the adjoining area of the grid in severe drought frequency zone with a return period of once in 2-2.5 years. The visual interpretation indicates that more than 70% areas were under drought frequency of 2.5 to 3 years. The Fig. 12 depicts the spatial variation of maximum annual rainfall departure percentage throughout the period of 1901-2016 years. Most area faces departure in the range of -60 to -50 (%).

The Fig. 13 shows the spatial variation of normal mean rainfall in the districts of South Bihar agro-climatic zone. Most part of the agro-climatic zone-iii (b) has

TABLE 3

Probability distribution of annual rainfall at grids

Grid No.	Normal Annual Rainfall (mm)	75% of Normal Annual Rainfall (mm)	75% Dependable Rainfall (mm)	Probability of Occurrence of Rainfall equivalent to 75% of Normal (mm)	Drought Condition
1	1106.69	830.02	928.18	> 80%	Normal
2	1086.63	814.97	884.76	> 80%	Normal
3	1133.85	850.39	965.34	> 80%	Normal
4	1165.52	874.14	981.31	> 80%	Normal
5	1098.71	824.03	922.65	> 80%	Normal
6	1069.47	802.10	903.47	> 80%	Normal
7	1109.38	832.03	906.39	> 80%	Normal
8	1079.11	809.33	910.65	> 80%	Normal
9	1084.75	813.56	918.35	> 80%	Normal
10	1094.18	820.63	914.48	> 80%	Normal
11	1037.19	777.90	905.92	> 80%	Normal
12	1079.47	809.60	912.56	> 80%	Normal
13	1043.38	782.53	850.68	> 80%	Normal
14	1186.21	889.66	997.54	> 80%	Normal
15	1184.41	888.31	997.04	> 80%	Normal
16	1162.47	871.85	978.42	> 80%	Normal
17	1249.56	937.17	1052.09	> 80%	Normal
18	1108.87	831.65	904.07	> 80%	Normal
19	1125.17	843.88	928.33	> 80%	Normal
20	1138.95	854.21	919.37	> 80%	Normal
21	1119.11	839.33	921.16	> 80%	Normal
22	1047.13	785.35	884.12	> 80%	Normal
23	1054.91	791.18	875.56	> 80%	Normal
24	991.70	743.77	823.12	> 80%	Normal
25	1024.20	768.15	826.03	> 80%	Normal
26	987.36	740.52	841.45	> 80%	Normal
27	1028.46	771.35	856.17	> 80%	Normal
28	1096.30	822.23	934.00	> 80%	Normal
29	1134.07	850.56	989.78	> 80%	Normal
30	1150.61	862.96	979.87	> 80%	Normal
31	1135.56	851.67	952.56	> 80%	Normal
32	1137.74	853.31	945.67	> 80%	Normal
33	1039.17	779.38	892.96	> 80%	Normal
34	1028.19	771.15	848.40	> 80%	Normal
35	1098.53	823.90	935.09	> 80%	Normal
36	1063.19	797.39	884.48	> 80%	Normal
37	965.68	724.26	761.26	< 80%	Drought Prone
38	1013.68	760.26	812.60	> 80%	Normal
39	986.06	739.55	784.97	> 80%	Normal
40	980.50	735.37	827.73	> 80%	Normal
41	1046.45	784.83	838.73	> 80%	Normal
42	978.15	733.61	759.75	< 80%	Drought Prone
43	1063.79	797.84	855.91	> 80%	Normal
44	1132.96	849.72	973.17	> 80%	Normal
45	1163.42	872.56	932.56	< 80%	Drought Prone
46	1163.70	872.78	1003.74	> 80%	Normal
47	1454.24	1090.68	1032.70	< 80%	Drought Prone
48	1357.41	1018.05	1101.67	> 80%	Normal
49	1009.49	757.12	850.63	> 80%	Normal
50	995.72	746.79	833.03	> 80%	Normal
51	986.50	739.88	795.51	> 80%	Normal
52	932.52	699.39	726.14	> 80%	Normal
53	1033.74	775.31	801.90	> 80%	Normal
54	1038.24	778.68	884.83	> 80%	Normal
55	1069.82	802.37	825.84	> 80%	Normal

normal rainfall of 1100-1200 (mm) while in the zone-iii (a) the normal rainfall varies in between 1000 - 1100 (mm). The most eastern part of the study area shows the normal annual rainfall greater than 1200 mm and so on.

The Fig. 14 shows the spatial variation of 75% of dependable rainfall in the study period. Most part of the zone-iii (b) shows the dependable rainfall in the range of 900-1000 mm while most part of zone-iii (a) shows the dependable rainfall to vary from 800-900 mm.

3.3. *Identification of drought prone grids*

To detect the drought-prone zones at fifty-five grids in the study area, the probability analysis of rainfall was carried out using weibull's formula. The statistics so concluded based on the probability distribution of annual rainfall for the grids was tabulated in Table 3. It were observed that there was considerable variation in the 75% dependable rainfall values from a maximum of 1101.67 mm at grid 48 (G-48) to a minimum of 726.14 mm at grid 52 (G-52). The bar graph showing the variation in the 75% dependable rainfall from the grid to the grid was shown in Fig. 21. This indicates that rainfall distribution at neighbouring grids have a wide variation, where one station receiving more than its normal rainfall and at the same time other station may experience rainfall deficiency. The probability of occurrence of rainfall equivalent to 75% of normal was obtained from the probability distribution chart, which varies from the grid to grid. From the probability analysis, it was indicative of the fact that the areas influenced by grids 37,42,45, and 47 are drought-prone (probability of 75% mean rainfall being less than 80%) and faced water scarcity and droughts. So efforts should be focused on the four grids for drought preparedness, mitigation, and management measures. The graph depicting the probability distribution of the annual rainfall at grids 37, 42, 45, 47, 48, and 52 have been given in Figs. 15, 16, 17, 18, 19 and 20 respectively.

4. Conclusions

The analysis of annual rainfall departure concluded that the Arwal district of South Bihar, faces a maximum number of drought years (49) with an average return period of at least once in 2.4 years, while Buxar district faces the least number of drought events of 36 to 37 (36.5) on an average, with a return period of once in 3.2 years. From the Probability analysis, we concluded that grids 37, 42, 45, and 47 of Bhojpur, Sheikhpura, Munger, and Bhagalpur districts are drought-prone. Finally, when we compare both the drought assessment techniques, grid 47 of Bhagalpur district indicated as extreme drought zone with a maximum of sixty-two drought events of all fifty-five grids with drought frequency of at least once in 1.9 years (most severe condition of all grids). This concludes that the South Bihar faces most frequent drought events and particularly, the most eastern area is the most droughts vulnerable. Thus in general, both of the methods, probability analysis, and departure analysis are compatible with each other and can be used effectively for drought monitoring.

Disclaimer : The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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