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Rainfall characteristics under changing climate in Sundergarh district of Odisha

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सार– दुनिया भर में चरम घटनाओं की तीव्रता और आवृत्ति में वृद्धि दुनिया के ऊष्ण होने का सबसे स्पष्ट संकेत है। कई शोधकर्ताओं ने ओडिशा के तटीय जिले में इन घटनाओं की प्रकृति की सूचना दी है, लेकिन उत्तर-पश्चिमी पठार कृषि-जलवायु क्षेत्र के अंतर्गत आने वाले सुंदरगढ़ जिले के संबंध में अभी भी अध्ययन करने की आवश्यकता है। इस अध्ययन का उद्देश्य 34 वर्षों के दैनिक वर्षा डेटा (1988-2022) का उपयोग करके ब्लॉक स्तर पर ओडिशा के सुंदरगढ़ जिले में वर्षा की विशेषताओं - वर्षा जलवायु विज्ञान, वर्षा के दिनों, प्रवृत्ति - उनके विचलन और परिणामस्वरूप मौसम संबंधी सूखे का अध्ययन करना था। विभिन्न श्रेणियों में वर्षा के दिनों की आवृत्ति निर्धारित करने के लिए वर्षा के दिनों के लिए आईएमडी वर्गीकरण को अपनाया गया । मौसम संबंधी सूखे की घटना और प्रचंडता को निर्धारित करने और प्रत्येक ब्लॉक के लिए अध्ययन अवधि के दौरान सूखे और गीले की घटनाओं के प्रकरणों की पहचान करने के लिए क्लाइम्पैक्ट का उपयोग करके एसपीआई की गणना की गई। वर्षा (वार्षिक और मौसमी) की प्रवृत्ति और 95% सार्थक स्तर पर वर्षा के दिनों का पता लगाने के लिए एम.के.टेस्ट और सेन के ढलान अनुमानक का उपयोग किया गया। दीर्घकालिक वर्षा विश्लेषण से पता चलता है कि जिले की औसत वार्षिक वर्षा 1290 ± 314 मिमी है, जिसमें से अधिकांश वर्षा दक्षिण-पश्चिमी मॉनसून (86%) के दौरान होती है, उससे कम मॉनसूनोत्तर (6.2%), उससे कम मॉनसून पूर्व (5.7%), और सबसे कम सर्दियों के दौरान (2.1%) होती है। जुलाई और अगस्त के महीनों में हुई वर्षा कुलवर्षा का 50% से अधिक है। वर्षा के स्थानिक वितरण ने संकेत दिया कि औसत वार्षिक वर्षा 1071 मिमी (सुबडेगा) से 1578 मिमी (बोनई) तक भिन्न होती है। वार्षिक रूप से, अधिकांश ब्लॉकों में वर्षा भरोसेमंद है। हालांकि, मॉनसून पूर्व, मॉनसूनोत्तर और सर्दियों के दौरान, सीवी बहुत अधिक होता है, इसलिए वर्षा भरोसेमंद नहीं है। जिले में प्राप्त वार्षिक वर्षा का बड़ा हिस्सा हल्की से मध्यम श्रेणी की वर्षा की घटनाओं से होता है पूरे जिले के लिए गणना किए गए एसपीआई मानों से पता चलता है कि इन सूखे की घटनाओं की आवृत्ति इस प्रकार थी: मंद (34% महीने); मध्यम (महीनों का 7.6%); प्रचंड (महीनों का 3.3%); और चरम (महीनों का 3.2%)। वर्तमान अध्ययन ओडिशा के सुंदरगढ़ जिले में वर्षा जलवायु विज्ञान और जलवायु परिवर्तन के तहत इसकी प्रवृत्ति पर प्रासंगिक जानकारी प्रदान करता है। अध्ययन के निष्कर्ष बताते हैं कि जलवायु लचीले समाज के बारे में जागरूकता बढ़ाने, कर्मियों को सतत विकास दृष्टिकोणों के बारे में प्रशिक्षित करने और सामुदायिक स्तर पर जल संचयन तकनीकों की आवश्यकता को उजागर करने की तत्काल आवश्यकता है।

ABSTRACT. Most pronounced signal of warming world is the increase in intensity and frequency of extreme events worldwide. Many researchers have reported the nature of these events in coastal district of Odisha, but for Sundergarh district which comes under North-western Plateau Agro-Climatic Zone, it still needed to be studied. The present study was conducted with an objective to study rainfall characteristics - rainfall climatology, rainy days, trend - their deviation and resulting meteorological drought in Sundergarh district of Odisha at block level using 34 years of daily rainfall data (1988-2022). IMD classification for rainy days was adopted to determine the frequency of rainy days in different categories. SPI was computed using Climpact to determine the occurrence and severity of meteorological drought and identify episodes of dry and wet events during the study period for each block. MK test and Sen's slope estimator was used for detecting trend in rainfall (annual and seasonal) and rainy days at 95% significance level. Long term rainfall analysis reveals that the mean annual rainfall of the district is 1290 ± 314 mm, most of which is received during SW monsoon (86%) followed by post-monsoon (6.2%), pre-monsoon (5.7%) and least during winter (2.1%). Rainfall received in the months of July and August together accounts for more than 50% of the total. Spatial distribution of rainfall indicated that mean annual rainfall varies from 1071 mm (Subdega) to 1578 mm (Bonai). Annually, rainfall is dependable in most of the blocks. However, during pre-monsoon, post-monsoon and winter, CV is very high, so the rainfall is not dependable. Bulk of annual rainfall received in the district is contributed by rain events of light to moderate category. Direction and magnitude of the trend of rainfall amount and rainy days varies a lot in different blocks. SPI values calculated for the district as a whole shows that frequency of occurrence of these drought events were: mild (34% of months); moderate (7.6% of months); severe (3.3% of months) and extreme (3.2% of months). The present study provides pertinent information on the rainfall climatology and its trend under climate change over the Sundergarh district of Odisha. Finding of the study suggests that there is an urgent need to raise awareness about the climate resilient society, train personnels about sustainable development approaches and highlight the necessity of water harvesting techniques at community level.

Key words - Rainfall climatology, Rainy days, Variability, Standard precipitation index, Mann Kendall test.

1. Introduction

The frequency and intensity of extreme heat and heavy rainfall events since the late 1980s, especially in mid-latitude regions, have been observed to increase (Fischer *et al*., 2015; Lehmann *et al.*, 2015). Arctic near-surface temperature is rising at a pace two to three times greater than that observed in the tropics, termed Arctic amplification (Cohen *et al.*, 2014), becoming even positive in recent years. Issues mentioned in Arctic Report 2018, like record low sea-ice extent in Barents and Kara Sea (BKS); decreased old ice-cover in the Arctic, which has reduced from 16% to less than 1% in 33 years; Atlantification of fresh Arctic water; heat waves across central Arctic, have raised questions like how these changes are going to affect the weather in middle and low latitudes. Does the influence bring sufferings to the entire globe or will it be restricted only to Polar Regions? What effect will these have on the marine and land carbon cycle, *etc*.? In recent years, rising ocean temperature in the tropics has led to increased frequency and intensity of cyclones as observed globally. Simultaneously, marked decrease in precipitation levels since 1994 in many regions of Australia, increased weather variability, untimely rains, rainy days with heavy downpours and prolonged dry spells otherwise, have become normal in many parts of India in the last decade. This has forced the scientific community to think about the future of Earth.

The Indian subcontinent receives most of its rain during the south-west monsoon period, *i.e*., from June to September. The geography of this region makes it unique but also susceptible to the above-mentioned changes. Atmospheric teleconnection existing between the Indian Ocean, Pacific Ocean & adjoining landmasses translates a lot of weather-related changes occurring in one part of the globe to the others. In meteorology, we call it the butterfly effect. Variation in insolation, movement of air masses, pressure gradient, flow direction of atmospheric rivers & a multitude of other meteorological factors, they all act simultaneously and determine the spatial & temporal distribution of rainfall in the country. India is such a diverse country that it is not uncommon to see floods in one part & water scarcity in another part. In the past decade, the country has witnessed several flooding events caused by intense rain spells, also called cloudbursts in different parts of the country. Simultaneously, the country has also faced water shortages in megacities, especially during the summer season.

For the sustenance of a developing country like India with billions of inhabitants to feed and to ensure a quality life for all, there is a need to reconsider our approach to development. The recent report of IPCC titled "Climate Change 2021: The Physical Science Basis" highlights that continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events. Also, monsoon precipitation is projected to increase over South and Southeast Asia. Rainfall characterization at the block level the lowest administrative level will help the decision-making bodies and policy planners to identify the gaps and opportunities available. Adoption and implementation of any approach with a view of sustainability at this level will give the most effective results. Both soil and water are valuable natural resources which need to be conserved for future generations. In earlier days, each locality used to have fallow lowland or small pond-like structure (*e.g*., Dobha) where runoff flows, gets stored and subsequently keeps on recharging the groundwater table. However, in the present day due to increased population pressure in and near the cities land is filled and covered with impervious materials to erect multistory apartments, roads and other buildings. Even though the rainfall pattern has not changed in a region, the inhabitants are facing a shortage of water during summers. This is mainly because in the race of development, cities have constructed big buildings, roads, supermarkets, *etc*., people on the outskirts filled lands to grow vegetables, and left very little space for water to get stored and subsequently infiltrate and percolate into the soil. It would be wise to go for a bottom to top approach to raise awareness among households about sustainability and climate resilience. Odisha, an eastern Indian province, is mainly an agrarian state where about 70% of the population is engaged in agricultural activities and 50% of the state's economy comes from the agricultural sector (Panigrahi *et al*., 2010). In Odisha, the current stage of ground water extraction is 42.18 % as of 2017 (CWC Abstract on water sector, 2020). The depth of ground water level varies between 5-10 m during pre-monsoon and between 2-5 m during the post-monsoon season (Central Ground Water Board) in Sundergarh district. In the coastal districts however, depth of water table is relatively shallow *i.e*., it varies between 2-5 m during pre-monsoon and < 2 m during post-monsoon. In the last two or three decades, frequency of extreme weather events such as intense rainfall has increased in many parts of Odisha (Pasupalak *et al.*, 2017).

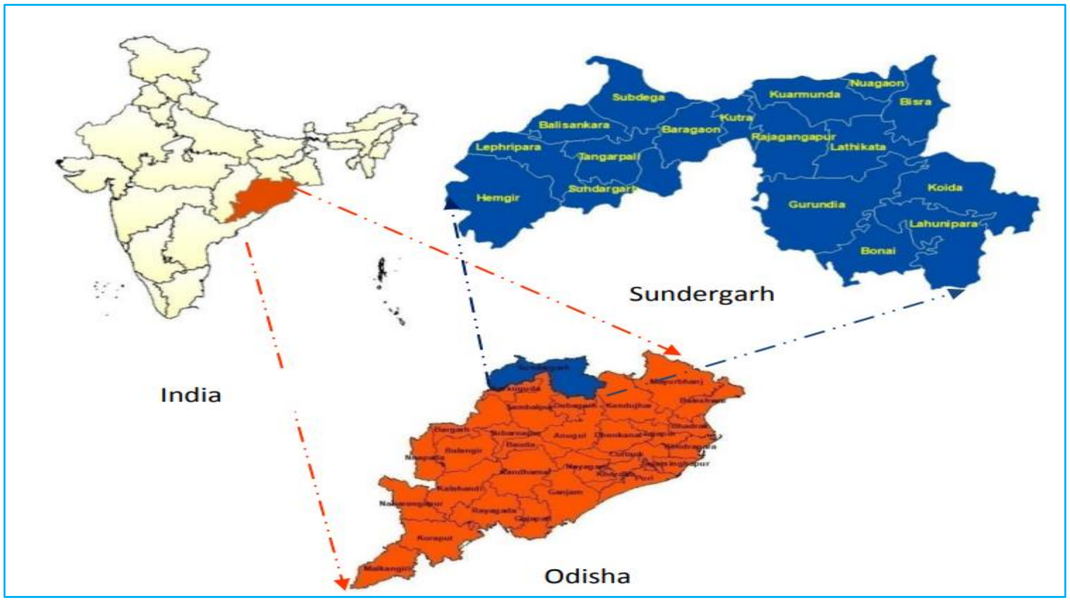


Fig. 1. Location map of study area.

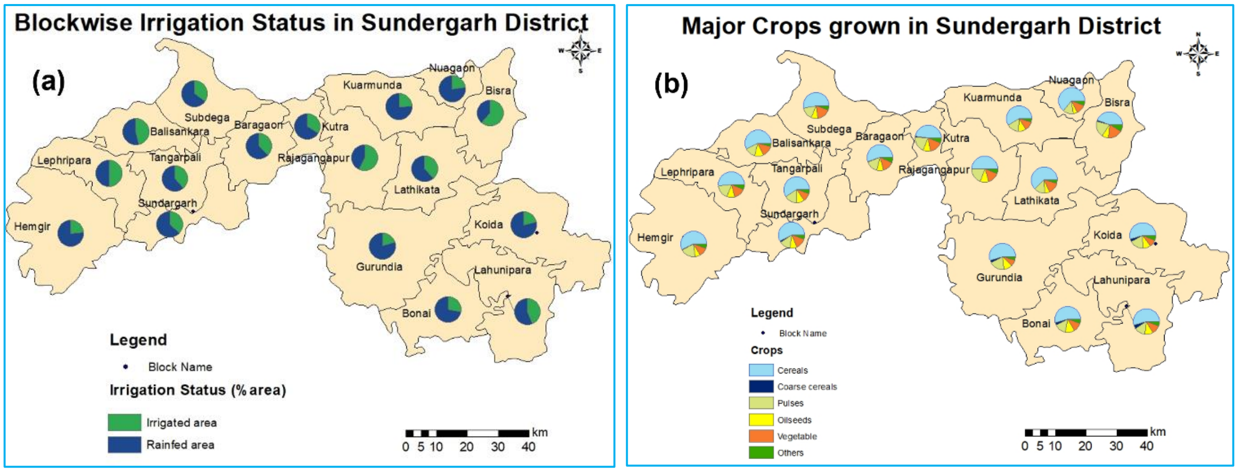
A significantly increasing (decreasing) trend in the frequency of high-intensity (low-intensity and wet days) rainfall events over most parts of Odisha is observed for all the seasons (Nageswararao *et al.*, 2019). Most of these rainfalls are associated with the low-pressure systems developing over north and adjoining central Bay of Bengal. Higher intensity of rainfall breaks the soil structure, creates temporary surface crust, thus running water has less retention time over any surface, resulting in more runoff and diminished groundwater recharge. A long-term imbalance between the abstraction and recharge of groundwater results in hydrological drought sooner or later depending on the soil moisture holding characteristics and the amount of water present in the aquifer.

Selection of crops, cropping system and associated agricultural activities depends a lot on the soil moisture availability and rainfall characteristics. In order to plan different adaptation and mitigation strategies against the changing climate, policy maker or agricultural official must have a good understanding of the rainfall characteristics of the area apart from the edaphic, hydrological and socio-economic characteristics. In view of the changing climate, extreme rainfall events were studied by several researchers (Swain *et al*., 2018; Naika *et al*., 2019; Swain *et al*., 2020) for different districts of Odisha, especially the coastal districts. Similar study is needed for the North-western Plateau Agro-Climatic Zone of Odisha which shows more continental type of climate. Block wise irrigation status (PMKSY, 2016) indicates that the blocks are still under rainfed agriculture. Therefore, it is a dire need to identify the potentials and constraints associated with rainfall in the district. This enables the end user (farmer) as well as policy maker to identify potential regions and time when challenges associated with any unforeseen event can be avoided and the community can be made resilient and adapted to such circumstances, if possible. In this study, an attempt was made to study the spatial and temporal variability of rainfall and rainy days, their trend during the study period, frequency of rainfall events in different categories and their deviation resulting in different types of meteorological drought. This analysis provides information at block level which is assumed homogeneous with respect to weather and thus can be a great tool for decision makers who can give advisory, recommend farm operations, choice of crops and cropping pattern based on the results.

2. Materials and methods

2.1. *Study area description*

Sundergarh district forms the North-Western border of Odisha (Fig. 1). Geographically, it extends between 21° 35′ N and 22° 32′ N latitudes and 83° 32′ E and 85° 22′ E longitudes, spanning over an area of 9712 sq.km, out of which 3130 sq.km area is net sown. Sundergarh comes under North-western Plateau Agro-climatic zone of the state (Nayak *et al.*, 2020), one of the unexplored regions of Odisha, which experience Hot & Moist Sub-humid climate. The district comprises of 17 blocks and is second largest in the state in terms of area, accounting for 6.23 % of the total area. Cropping intensity in the district is very low (126.8%) compared to that of the state average (156%). A greater proportion of available land in the district is still rainfed and only a few blocks have irrigated



Figs. 2 (a & b). (a) Block wise irrigation status and (b) major crops grown in the district (data source: PMKSY, 2016).

area more than 50% (Fig. 2). Rainfall characterization is therefore needed to identify potential and limitations of the district in terms of weather and use the same for necessary decision making.

TABLE 1

Description of rain-gauge stations in the district including their geographic position

Block Name	Block_ID*	Latitude	Longitude
Balisankara	1	22.3505	84.0351
Baragaon	2	21.9064	84.6824
Bisra	3	22.2479	84.9981
Bonai	4	21.8256	84.9495
Gurundia	5	21.8468	84.7848
Hemgir	6	21.9495	83.7026
Koida	7	21.9017	85.2464
Kuarmunda	8	22.3029	84.7776
Kutra	9	22.2328	84.456
Lahunipara	10	21.9031	84.9331
Lathikata	11	22.1406	84.8919
Lephripara	12	22.1456	83.8063
Nuagaon	13	22.0221	85.0979
Rajagangapur	14	22.1902	84.5799
Subdega	15	22.2866	84.1058
Sundargarh	16	22.124	84.0432
Tangarpali	17	22.0984	83.9937

***** Block id: number corresponding to each block in maps

2.2. *Data*

Daily rainfall series of 34 years (1988-2022) recorded at 17 rain-gauge station, one in each block (administrative unit) were used. The database has been collected from the Department of Revenue and Disaster management, Special Relief Commissioner, Government of Odisha. Table 1 presents the characteristics of rain-gauge stations, including the geographic position in map (Block id).

2.3. *Methodology*

Daily series of rainfall data were used to compute climatological mean, Interannual variability (IAV) and Coefficient of variation (CV) at different time scales. The threshold levels for coefficient of variation (CV) were taken as <25 %, <50 %, <100 %, <150 % for annual, seasonal, monthly and weekly rainfall respectively during interpretation (Manorama *et al.*, 2007). If the CV is within the threshold limit of variability, it is considered that the rainfall is highly dependable and vice versa. In addition, rainfall events in different categories (mean ± standard deviation; IMD, 2021) and Standardized Precipitation Index (SPI) on a time scale of 3, 6, 12 and 24 months (Balram and Fanai, 2020) were also calculated. Based on the intensity of 24-hour accumulated rainfall, IMD categorized rainfall events into seven different categories: very light; light; moderate; heavy; very heavy; extreme heavy and exceptionally heavy rainfall (Table 2). Recently, threshold values of rainfall intensity for each category were modified and therefore have been presented in Table 2. In addition to the frequency of intense rainfall events, the frequency of rainy days in different categories (as per IMD classification); Standard Operation Procedure-Weather Forecasting and Warning (2021)) *i.e.*, dry days and wet days, were also calculated in R. Dry days are the number of days with “no rain”. Wet days are

TABLE 2

Different categories of rainfall events based on the intensity as classified by the IMD

S. No.	Terminology	Rainfall range (in mm/day)
01	Very light rainfall (VLR)	Trace – 2.4
02	Light rainfall (LR)	2.5 – 15.5
03	Moderate Rainfall (MR)	15.6 – 64.4
04	Heavy rainfall (HR)	64.5 – 115.4
05	Very heavy rainfall (VHR)	115.5 – 204.4
06	Extreme heavy rainfall (EHR)	≥ 204.5
07	Exceptionally heavy rainfall (Exc. HR)	When the amount is a value near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 24 cm.

Source : IMD

TABLE 3

SPI classification and their values

Category	SPI range
Extremely wet	2.00 or more
Severely wet	1.50 to 1.99
Moderately wet	1.00 to 1.49
Mildly wet	0 to 0.99
Mildly dry	0 to -0.99
Moderately dry	-1.00 to -1.49
Severely dry	-1.5 to -1.99
Extremely dry	-2.00 or less

(Source: World Meteorological Organization, 2012)

the number of days receiving a given amount of rainfall (equal to or more than 1 mm/day; Pal and Tabbaa, 2011; Sinha *et al.*, 2013).

SPI is calculated to identify the episodes of dry and wet periodsat various time scales (McKee *et al.*, 1993). Short term rainfall anomalies are computed in studies dealing with soil moisture, whereas long-term anomalies are used in studies on groundwater, reservoir storage *etc*. In order to compute SPI for any location, long term precipitation data is required (Edwards and McKee, 1997). In the present study, SPI was computed using Climpact (https://infoasis.shinyapps.io/climpact/) at 1, 3, 6, 12 and 24 months, over the period of 1988-2022 for different blocks of Sundergarh. Considering the length of the article, results were tabulated and presented for all time scales, however, graphical representation to show the variation of SPI, was done only for 12-month averaged SPI and 1-month SPI values during the monsoon months. Climpact is an *R* software package that calculates Expert Team on Sector-specific Climate Indices (ET-SCI) in which SPI is one of the indices. Positive SPI values indicate greater than median precipitation whereas negative values indicate less than median precipitation (Balram and Fanai, 2020). The identification of wet and dry periods and classification of drought severity can be done using the classification system adopted by McKee *et al.*, 1993 (Table 3).

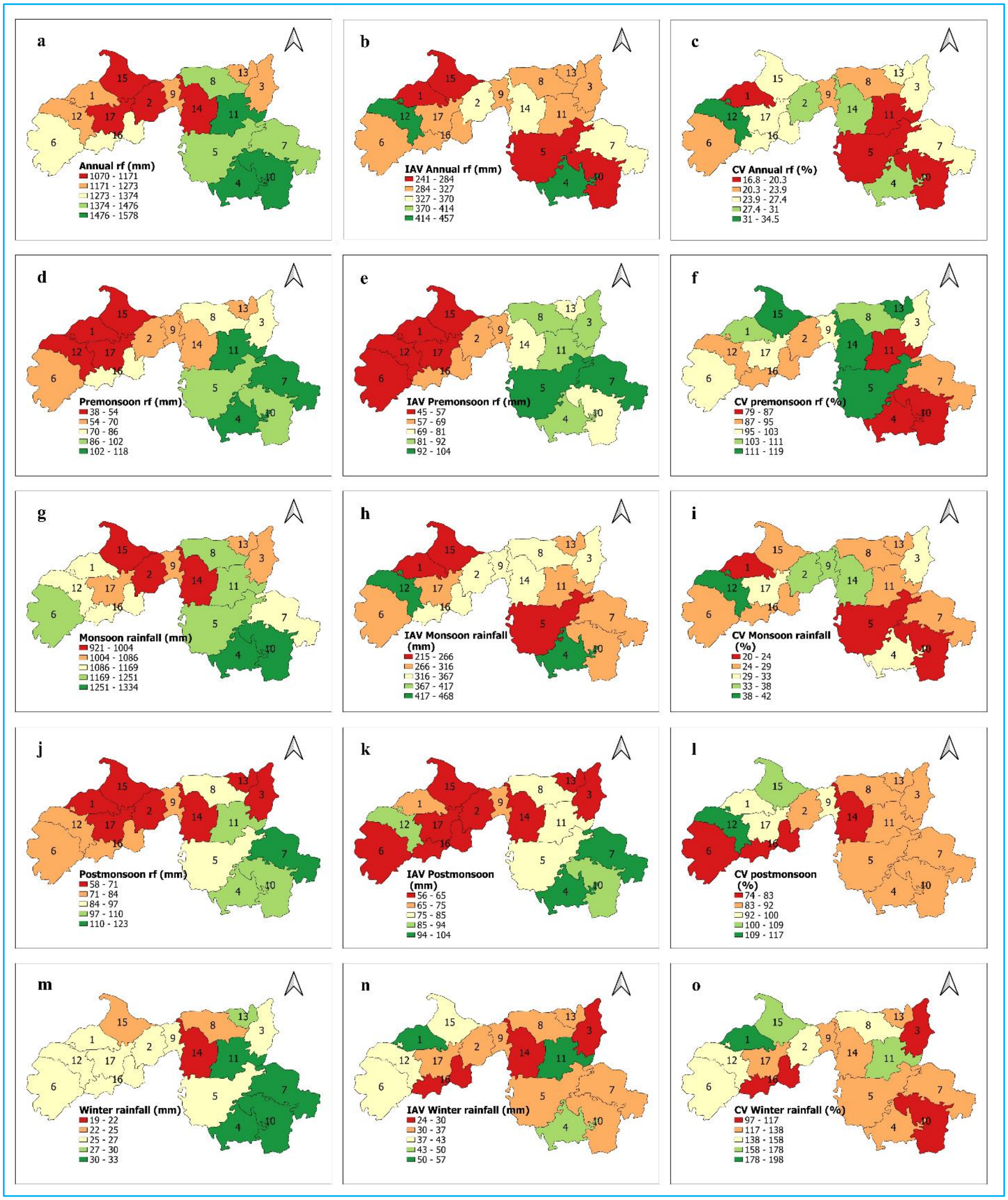
To identify the trends of rainfall, total number of rainy days and various rainfall events, non-parametric Mann-Kendall test at 95% significance level was used (Waghaye *et al*., 2018; Tiwari *et al*., 2019). MK test is not affected by gross data errors and outliers (Guhathakurta *et al*., 2011). Sen's slope estimator is then computed to capture the magnitude of the trend. MK test and Sen's slope was computed in *R* using "Trend" package (https://cran.r-project.org/web/packages/trend/trend.pdf).

3. Results & discussion

In this study, characteristics of rainfall at different temporal scales (annual, seasonal and monthly) for Sundergarh district of Odisha have been analyzed using the observed station dataset and results are presented in the following subsections.

3.1. *Spatial distribution of rainfall*

The mean, inter annual variability (IAV) and coefficient of variation (CV) of rainfall for the seventeen blocks of Sundergarh district were computed using daily rainfall data of 34 years (1988-2022). Block wise distribution of long-term mean rainfall at annual, seasonal, and monthly time scale are presented in Table 4. The mean annual rainfall for the district as a whole is 1290 ± 314 mm, which however exhibits great spatial and temporal heterogeneity at the block level. It varies from 1071 mm in Sub dega to 1578 mm in Bonai. Blocks in the eastern and north-eastern part of the district receive higher amount of rainfall. SW monsoon is the main rain bearing season in Sundergarh district, which alone accounts for about 86% of the total annual rainfall. The district receives highest rainfall in the month of August (27.5% contribution) followed by July (26.6%), September



Figs. 3(a-o). Spatial distribution of rainfall and its variability (expressed as Interannual variability and Coefficient of variation) in different blocks of Sundergarh district for the study period (1988-2022).

a-c: mean, Interannual variability (IAV in mm) and Coefficient of variation (CV in %) for annual rainfall;

d-f: same indicators for pre-monsoon rainfall;

g-i: same for SW Monsoon rainfall;

j-l: same indicators for post-monsoon rainfall; and

m-o: same for winter rainfall.

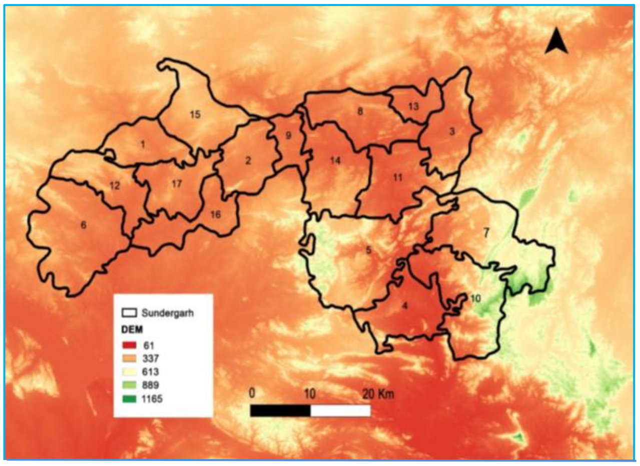


Fig 4. SRTM Digital Elevation Map of Sundergarh district & adjoining.

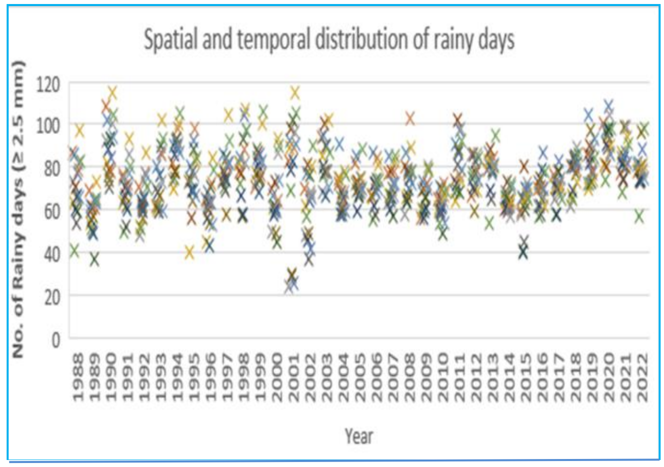


Fig. 5. Year-wise variation of the number of rain days at seventeen stations in the Sundergarh district.

(16.4%) and June (15.5%; Table 4). Rainfall received in the months of July and August together accounts for more than 50% of the total annual rainfall. Winter months are generally dry (receives 2.1% of annual rainfall). Pre-monsoon and Post-monsoon season receive a few of the rainfall events that contributes about 5.7 % and 6.2 % respectively to the annual rainfall. The long-term mean rainfall for all blocks at different time scale can be seen in Table 4.

Block wise distribution of mean, IAV and CV of annual and seasonal rainfall are shown in Fig. 3. CV for the annual rainfall ranges from 16.8% (Lahunipara block) to 34.5% (Lephripara). Rainfall is considered dependable when CV is less than 25% for the annual rainfall and less than 50% for the seasonal rainfall. Annually, rainfall can be considered dependable in most of the blocks. Although Bonai receives highest rainfall in the district, its coefficient of variation is high (29 %). Other blocks with high CV are: Bargaon; Bisra; Lephripara and Rajgangpur. The undulating topography of the district and adjoining areas (Fig. 4) is an important factor explaining the heterogeneity observed at block level. The presence of medium to higher hills in south-eastern part of district may be ascribed as one of the reasons of concentration of rainfall in these blocks and rain shadow effect in the remaining blocks.

The seasonal rainfall during pre-monsoon, post-monsoon and winter months is not dependable as the CV during these months is very high. During monsoon months (June-Sept), however, rainfall can be considered dependable (CV ranging between 19.6 - 42.1%). The coefficient of variation varies between 30-40% in Bargaon, Bisra, Bonai, Kutra, Lephripara and Rajgangpur. The lowest and highest variability is observed for Balisankara (19.6%) and Lephripara (42.1%) respectively. Elsewhere, rainfall variability was found to lie between 20 - 30%. Because rainfall received during monsoon months contributes about 86% to the annual rainfall, it is the main cropping season in the district. Rice is the major crop grown throughout the district. In years with poor SW monsoon, rainfed crops generally suffer significant loss. Despite the district receives good amount of annual rainfall, cropping intensity is only 126.7% (Pasupalak *et al*., 2019). This is mainly because: (*i*) about 40% of the rainfall received annually (45% during the monsoon season) is lost as runoff from the undulating topography of the district; (*ii*) high variability of rainfall during pre-monsoon, post-monsoon and winter season; and (*iii*) insufficient irrigation facility. This suggests a need of supple-mental irrigation facility if the farmer is growing a second crop during *rabi* or *zaid* cropping season. Also, it is to note that there is 75% probability of receiving at least 20 mm of weekly rainfall during SMW 25-38 (Supplementary Table 1), which again exhibits great spatial variability among the blocks.

3.2. *Spatial distribution of rainy days and intense rainfall events*

Number of rainy days (*i.e.*, a day receiving ≥2.5 mm of rainfall) varies from 64 (in Subdega) to 85 (in Lahunipara and Koida) annually (Table 4). Fig. 5 shows the spatial variation of number of rainy days representing 17 blocks in different years during the study period.

During first half of the study period (1988-2003), spatial variation was high compared to the later half (2004-2022). This indicates that in the last decade, number of rainy dayswas found to be relatively homogenous throughout the district compared to what was observed before 2003. Fig. 6 shows the contribution of different categories of rainfall events (based on 24-hours

TABLE 4

Mean monthly, seasonal, annual rainfall and rainy days based upon 1988-2022 data over different block of Sundargarh district

Block name	Balisankara	Bargaon	Bisra	Bonai	Gurundia	Hemgir	Lahunipara	Lathikata	Lephripara	Koida	Kuarmunda	Kutra	Nuagaon	Rajgangpur	Subdega	Sundergarh	Tangarpali	**District**
Jan	16	13	10	16	12	14	13	17	17	13	12	14	13	7	15	14	12	**13.4**
Feb	10	12	15	17	15	13	17	16	10	17	10	13	17	12	9	12	13	**13.4**
Mar	7	12	10	12	14	9	11	15	9	17	11	10	14	10	9	13	10	**11.4**
Apr	14	17	17	28	16	14	27	23	10	26	18	11	12	15	10	16	10	**16.7**
May	27	36	53	63	61	33	62	76	33	75	55	41	42	41	20	44	32	**46.7**
Jun	205	175	185	260	231	208	243	223	191	223	196	188	177	161	162	212	168	**200.5**
Jul	354	299	307	403	358	369	388	379	335	344	376	318	317	268	301	376	325	**342.2**
Aug	323	310	324	418	364	386	400	399	363	344	391	337	336	317	308	364	331	**353.8**
Sep	216	173	193	252	235	248	226	237	221	217	223	182	216	175	178	216	190	**211.6**
Oct	51	46	54	81	73	55	76	72	54	99	67	49	49	49	45	53	49	**60.1**
Nov	8	11	7	14	11	10	10	14	11	14	15	13	10	11	8	10	8	**10.9**
Dec	7	11	9	14	11	10	12	11	9	9	8	10	12	9	6	9	5	**9.5**
Winter	26	25	25	33	27	27	30	33	27	30	22	27	30	19	24	26	25	**26.8**
Pre-monsoon	48	65	80	103	91	56	100	114	52	118	84	62	68	66	39	73	52	**74.8**
Monsoon	1098	957	1009	1333	1188	1211	1257	1238	1110	1128	1186	1025	1046	921	949	1168	1014	**1108.1**
Post-monsoon	66	68	70	109	95	75	98	97	74	122	90	72	71	69	59	72	62	**80.5**
Annual	1238	1115	1184	1578	1401	1369	1485	1482	1263	1398	1382	1186	1215	1075	1071	1339	1153	**1290.2**
No. of Rainy day	67	76	76	79	75	75	85	71	65	85	78	68	73	70	64	81	69	**73.4**

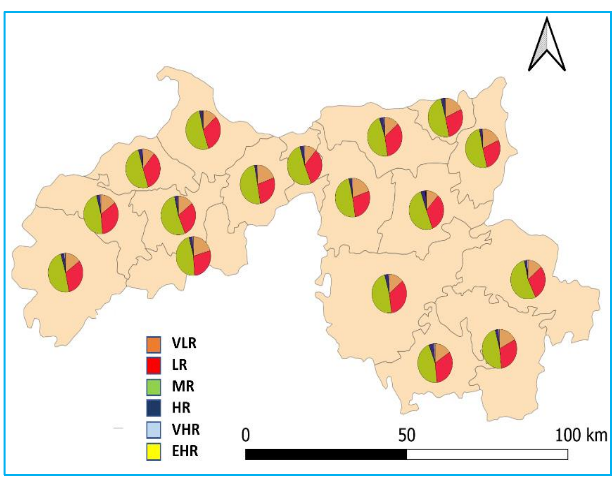


Fig. 6. Spatial distribution of the proportion of rainfall events (based on accumulated 24-hours rainfall) in a given categories to the total rainy days in Sundergarh.

accumulated rainfall) to the total rainy days in different blocks. A significant fraction of the rainfall is received as intense spells. Annually, about 49 ± 2 % rain spells received are of *Moderate* category followed by *Light* rain (31 ± 3 %) and *Very Light* (15 ± 3%) category (Table 5).

This suggests that a greater proportion of the rainfall is received as rainfall events of light to moderate category. It is apparent that bulk of the annual rainfall at different stations is contributed by few rainy days, most of which are associated with heavy downpours. Therefore, there is a high probability of getting floods after such events and experiencing prolonged dry spells otherwise. Soils in the district are coarse-textured and moderately shallow in depth. Even though the district is receiving good quantum of rainfall in monsoon months, majority of the farmers are practicing rainfed farming & they grow single crop. Only a small fraction of farmers is able to grow another crop

TABLE 5

Mean and Inter annual variability (IAV)of number of rainy days in various categories, dry days and wet days in different blocks of Sundergarh during the study period (1988-2022).

Block name	Categories of rainy days (Based on 24-hour accumulated rainfall)						Days with or without rainfall	
	Very LR	Light R	Mod. R	Heavy R	Very HR	Ext. HR	DD	WD
Balisankara	7 ± 4	34 ± 9	23 ± 4	3 ± 2	0 ± 1	0.0 ± 0.2	305 ± 9	60 ± 9
Bargaon	15 ± 7	38 ± 7	21 ± 6	2 ± 2	0 ± 1	0.0 ± 0.2	304 ± 9	61 ± 9
Bisra	14 ± 6	39 ± 10	21 ± 6	2 ± 2	0 ± 1	0.0 ± 0.4	301 ± 9	64 ± 9
Bonai	12 ± 6	36 ± 9	26 ± 7	3 ± 2	1 ± 1	0.1 ± 0.2	298 ± 10	67 ± 10
Gurundia	10 ± 6	36 ± 8	25 ± 5	3 ± 2	1 ± 1	0.0 ± 0.3	301 ± 8	64 ± 8
Hemgir	11 ± 7	37 ± 6	24 ± 5	3 ± 2	1 ± 1	0.1 ± 0.3	301 ± 11	64 ± 12
Koida	12 ± 5	46 ± 8	25 ± 7	2 ± 2	1 ± 1	0.1 ± 0.4	292 ± 10	74 ± 10
Kuarmunda	10 ± 5	34 ± 7	24 ± 5	3 ± 2	1 ± 1	0.1 ± 0.2	304 ± 10	61 ± 10
Kutra	7 ± 4	34 ± 8	21 ± 6	2 ± 2	0 ± 1	0.0 ± 0.2	305 ± 10	59 ± 10
Lahunipara	15 ± 6	41 ± 8	26 ± 5	3 ± 2	1 ± 1	0.1 ± 0.2	294 ± 9	71 ± 9
Lathikata	9 ± 6	39 ± 7	25 ± 5	4 ± 2	1 ± 1	0.1 ± 0.2	298 ± 9	69 ± 9
Lephripara	10 ± 6	32 ± 8	23 ± 8	2 ± 2	1 ± 1	0.1 ± 0.2	305 ± 12	60 ± 12
Nuagaon	13 ± 6	36 ± 9	21 ± 5	3 ± 2	0 ± 1	0.0 ± 0.2	305 ± 9	60 ± 9
Rajgangpur	14 ± 9	34 ± 7	19 ± 7	2 ± 1	0 ± 1	0.0 ± 0.2	309 ± 12	56 ± 10
Subdega	8 ± 5	33 ± 7	20 ± 6	2 ± 2	0 ± 1	0.0 ± 0.3	309 ± 8	55 ± 9
Sundergarh	16 ± 6	38 ± 7	23 ± 5	3 ± 2	1 ± 1	0.1 ± 0.3	301 ± 10	64 ± 10
Tangarpali	10 ± 5	36 ± 9	20 ± 6	2 ± 2	0 ± 1	0.1 ± 0.2	306 ± 10	59 ± 10

VLR = Very light rain, LR =Light rain, MR= Moderate rain, HR = Heavy rain, DD = days with no rainfall, WD =days with rainfall (>0 mm)

TABLE 6

Trend of rainfall (annual and seasonal) and rainy days in different blocks of Sundergarh (1988-2022).

Block name	Annualrainfall	Pre-monsoon	SW Monsoon	Post-monsoon	Winter	No. of Rainydays
Balisankara	-2.84	0.00	-5.30	0.91	0.05	0.10
Bargaon	14.47*	1.96*	10.00*	1.13	0.19	0.36*
Bisra	13.28*	3.10*	5.00	2.43*	0.30	0.32
Bonai	-11.04	-0.25	-10.57	0.42	0.00	0.00
Gurundia	9.50	1.92	4.24	1.69	0.00	0.21
Hemgir	12.95*	1.11	11.00	1.62	0.12	0.00
Koida	-1.42	1.00	-4.45	0.26	0.00	-0.15
Kuarmunda	7.25	2.94*	-1.17	1.25	0.47*	0.50*
Kutra	2.58	0.82	0.71	1.31	0.34	0.44*
Lahunipara	-5.02	-0.47	-7.49	0.82	0.00	-0.83*
Lathikata	-3.58	1.54	-7.57	0.98	0.00	0.00
Lephripara	1.15	0.41	1.95	0.66	0.00	0.00
Nuagaon	0.56	0.38	-3.11	1.00	0.00	0.08
Rajgangpur	17.02*	2.28*	11.18*	2.13*	0.30	0.81*
Subdega	16.40*	0.91*	15.51*	1.00	0.00	0.00
Sundergarh	-3.38	0.76	-7.37	0.93	0.00*	0.07
Tangarpali	14.49*	1.70*	9.88*	0.85	0.55	0.40*

* Indicates values at 95% significance level.

using the supplemental irrigation from various sources. Undulating and rolling terrains at downhill of the district can be utilized as a valuable and appropriate site for checkdams and similar structures to collect and store runoff from the villages.

3.3. *Trend of rainfall at different temporal scales and rainy days*

Mean annual rainfall (mm) in different blocks of Sundergarh showed great variation (Table 6) during the study period. Rainfall is showing significantly increasing trend in blocks like Bargaon (14.47 mm/year), Bisra (13.28 mm/year), Hemgir (12.95 mm/year), Rajgangpur (17.02 mm/year), Subdega (16.40 mm/year) and Tangarpali (14.49 mm/year). Increase in rainfall offers several kinds of opportunities, but, if not managed well, it can result in natural disasters. This therefore, demands preparedness against any unforeseen events, especially in the areas with poor drainage. Keeping in view the soil characteristics, vegetation & physiography of the region, runoff must be channelized & stored by adopting different Managed aquifer recharge (MAR) techniques. This way water requirement for household activities as well as agricultural purposes can be met out during prolonged dry spells. However, in Bonai & Lahunipara, annual rainfall is showing decreasing trend of magnitude greater than 5 mm/year (Table 6). The decreasing trend again demands attention. In Bonai, more than two-third of the cultivable area is rainfed, whereas, in Lahunipara more than half is rainfed (PMKSY, 2016). Other blocks such as Balisankara, Lathikata & Sundergarh are also witnessing reduction in annual rainfall. Therefore, reduction of rainfall can bring down crop yields & may impact food security in the region. Taking into consideration the irrigation status in different blocks, construction of appropriate water retention & storage structures should be encouraged at the individual as well as community level.

In the case of seasonal rainfall, magnitude as well as direction of trend was computed for all four seasons. Trend direction during the SW monsoon season followed the trend of annual rainfall in some of the blocks but with varying magnitude. Mann Kendall trend analysis for SW monsoon suggests that rainfall is decreasing in about 50% of the blocks (Table 6), with a magnitude greater than that observed in the case of annual rainfall. Unlike SW monsoon season, rainfall is increasing during the pre-monsoon season (except in Bonai and Lahunipara). Although magnitude of the Sen's slope is smaller, rainfall is showing an increasing trend in all blocks during post-monsoon season. In winter season, rainfall is showing a significant increase in Kuarmunda (0.47 mm/year) and no change in Sundergarh and other blocks.

With regard to the trend of the number of rainy days, it showed significant increase in some of the blocks, whereas, a decrease in others (Table 6). A significantly increasing trend was observed in Bargaon, Kuarmunda, Kutra, Rajgangpur and Tangarpali, with varying magnitudes. Opposite trend however, was observed in three blocks namely, Lahunipara, Koida and Lathikata. Although result indicated decreasing trend in these blocks, the trend was significant only in Lahunipara (-0.83 per year). Special consideration needs to be given to Hemgir and Subdega where annual rainfall is showing an increasing trend without any trend in rainy days. This suggests that frequency of extreme rainfall events has increased in these blocks without any change in the number of wet days (>1 mm/day). Interpretation of the result also suggests that there is rise in the number of intense rainfall events, thus, leading to (*i*) submergence of crops in the lowlands, (*ii*) increased removal of topsoil fertile soil (erosion) by the running water on the sloping surface, (*iii*) reduced infiltration of water into the soil, caused by sealing of macro as well as micropores, (*iv*) less recharge of groundwater and (*v*) more loss in the form of surface runoff.

Information of this kind is of utmost importance to agriculture officials. They can use it to minimize the damaging potential of any hazard - resulting from change in rainfall pattern and transform it into opportunity. It is necessary to be prepared for the changing climate and adopt strategies to make the farming climate resilient. Excess runoff during monsoon months can be stored in farm ponds, dugout ponds, reservoirs *etc*. which will simultaneously recharge the groundwater. MAR techniques - such as check dam, percolation tank, recharge well *etc*. which have been implemented across the country since 1970s (Dillon *et al*., 2020) can be advocated. Field channels can be constructed for smooth delivery of water into the fields when in need and safe removal of excess water during and after the rainfall events. Also, because the district is comprised of uneven terrains in many blocks, check dams can be constructed across the course of river (or deep gullies created by running water) at regular intervals. Checkdams have traditionally been built to (*i*) slow down the velocity of running water, (*ii*) impeding waterflow increases the retention period and thus facilitate ground water storage, and (*iii*) conserve soil. Implementation of different MAR techniques ensures the availability of water for longer period and second crop can be grown without any risk of failure. Fisheries are another important source of livelihood which can be promoted in the region when community is made aware of *in-situ* and *ex-situ* water harvesting techniques. High water requiring crops can also be grown during monsoon season.

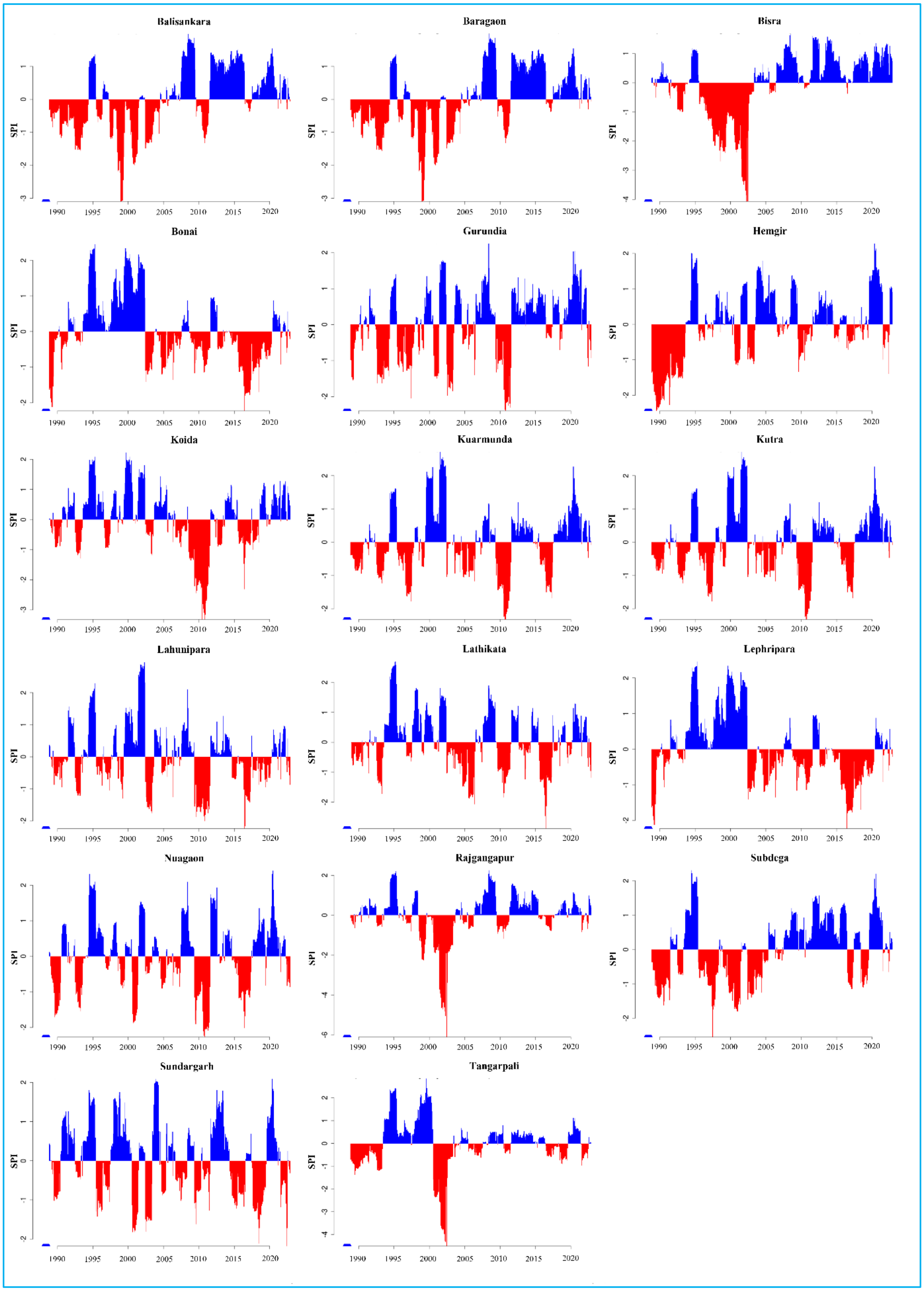


Fig. 7. Variation of SPI (12-month) during the study period for seventeen blocks of Sundergarh.

Fig. 8. Variation of SPI (1-month) values in the seventeen blocks of Sundergarh district during the monsoon months.

3.4. *Meteorological drought assessment using SPI*

Fig. 7 shows the long-term variability of rainfall and episodes of dry and wet periods during the study period using 12 month averaged SPI values. Graphical representation of SPI values (Fig. 7) shows a cyclic pattern of wet and dry periods, although duration of each period varies in different blocks. This illustrates the long-term variability of rainfall in the district over the seventeen blocks. Result also indicates that the district experienced almost equal number of dry and wet events in the past. In most of the blocks, dry periods alternated with wet periods. Majority of the drought events fall under mild drought category (68.7 %) followed by Moderate (17.8 %), severe (8%), and extreme (5.5%) category. 24 month averaged SPI values indicate the occurrence of *Extreme drought* conditions during 1990-93 in Hemgir, during 1998-99 in Balisankara, Bargaon and and Bisra and during 2009-11 in several blocks (namely, Gurundia, Koida, Kuarmunda, Kutra, Lahunipara and Nuagaon). Balisankara, Bonai, Lephripara and Subdega have never experienced drought in extreme category during the study period.

Drought of various categories are recurring features in different blocks of Sundergarh district, which shows great variation across time and space. In addition to identifying the episodes of wet and dry periods, another attempt was made to find out the number of drought years and its frequency of occurrence. Table 7 shows that the

TABLE 7

Frequency (percentage) of occurrence of droughts in SPI series of 3, 6, 12 and 24 months in different blocks of Sundergarh district.

Blocks	3 month				6 month				12 month				24 month			
	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext
Balisankara	32.1	6.9	1.9	1.7	35.7	8.0	2.2	3.2	34.7	9.8	4.6	2.0	29.8	13.1	4.0	0.5
Bargaon	32.1	6.9	1.9	1.7	35.7	8.0	2.2	3.2	34.7	9.8	4.6	2.0	29.8	13.1	4.0	0.5
Bisra	31.1	3.1	3.8	1.2	24.5	8.0	3.2	3.9	20.5	5.6	3.4	8.3	14.6	1.0	10.6	7.1
Bonai	35.9	5.7	2.6	0.7	38.8	6.8	3.6	1.5	43.5	9.3	4.2	0.7	46.5	6.3	5.1	0.0
Gurundia	33.3	6.7	2.6	0.7	31.1	10.2	3.9	1.5	24.2	13.9	4.2	2.7	26.3	5.8	3.5	5.6
Hemgir	33.3	6.5	2.4	0.7	32.3	7.8	6.3	1.5	32.3	9.0	3.7	3.7	28.8	2.0	1.0	9.6
Koida	30.1	9.1	3.3	1.4	34.2	6.3	3.6	3.6	35.0	5.4	1.0	5.6	36.1	5.6	0.8	6.1
Kuarmunda	35.9	6.0	1.7	0.7	36.4	9.2	2.7	1.5	35.0	8.8	3.9	1.5	38.9	9.1	1.8	2.0
Kutra	35.9	6.0	1.7	0.7	36.4	9.2	2.7	1.5	35.0	8.8	3.9	1.5	38.9	9.1	1.8	2.0
Lahunipara	31.3	9.3	1.7	0.5	34.7	10.4	4.1	1.5	38.6	7.3	6.6	0.7	40.4	7.6	0.8	3.0
Lathikata	35.9	5.5	2.4	1.4	34.0	10.2	3.4	1.5	38.1	11.5	3.4	1.0	31.6	9.3	4.5	2.3
Lephripara	35.9	5.7	2.6	0.7	38.8	6.8	3.6	1.5	43.5	9.3	4.2	0.7	46.5	6.3	5.1	0.0
Nuagaon	35.2	5.3	3.1	0.7	34.5	8.5	4.4	1.9	33.0	8.3	5.6	2.4	31.6	10.1	3.5	3.0
Rajgangpur	33.5	4.5	2.6	1.2	34.7	3.4	3.9	2.7	33.5	2.0	4.9	4.2	34.8	4.3	0.3	6.3
Subdega	35.2	7.2	1.9	0.5	35.0	9.7	3.9	0.5	29.1	14.2	3.9	0.2	27.3	14.1	5.1	0.0
Sundergarh	32.8	5.5	2.4	0.7	35.4	8.7	5.1	0.7	32.5	12.2	3.9	0.5	39.6	7.1	4.5	1.0
Tangarpali	33.0	4.8	1.7	1.0	35.4	4.6	2.7	2.4	37.2	4.6	1.0	5.1	36.6	4.8	0.3	5.6
District	**33.7**	**6.2**	**2.4**	**1.0**	**34.6**	**8.0**	**3.6**	**2.0**	**34.1**	**8.8**	**3.9**	**2.5**	**34.0**	**7.6**	**3.3**	**3.2**

Mild = Mild drought, Mod = Moderate drought, Sev = Severe drought, Ext = Extreme drought

requency of the occurrence of droughts of various categories varies in different blocks. For different time scales under analysis, the blocks experienced maximum number of *mild* drought events (For example, ranging from 29.8 to 35.7% for Balisankara) followed by *moderate* drought (ranging from 6.9 to 13.1%), *severe* drought (ranging from 1.9 to 4.6%) and *extreme* drought (0.5 to 3.2%). The frequency of occurrence of severe and extreme drought is relatively smaller as compared to the mild and moderate droughts.

SPI values for 24-months analysis period showed that Bonai and Lephripara have experienced the highest number of *mild* drought years (46.5% frequency) followed by Lahunipara (40.4% frequency), and least in Bisra. Result also revealed that in addition to the *mild* droughts, Bisra has experienced several drought events of *severe* to extreme category. Year 1998 - 2002 were largely deficit years for Bisra. Year 1889-93 were the deficit years for Hemgir. Other periods of rainfall deficit in different blocks can be seen in Fig. 7 for 12-months analysis period. Deficit periods under different categories identified using 24-month averaged SPI suggests that most of the discrepancies in receipt of rainfall were observed during first half of the study period, suggesting below-normal recharge of groundwater and aquifers and resulting water shortage for household and agricultural needs. SPI values for 3-month analysis period indicates the drought of *mild* and *moderate* category is a persisting feature in the district. This suggests that soil moisture might not be at the optimal level during rainless periods and so there is a need of improving irrigation facility in all blocks to ensure availability of supplemental irrigation. Fig. 8 presents the SPI values at 1-month analysis period focused on monsoon months (June-September). There is again a cyclic pattern in the excess or deficit in any given month

Supplementary TABLE 1

Expected weekly rainfall at 75% probability levels in different blocks of Sundargarh district during the monsoon season.

Block	SMW 22	SMW 23	SMW 24	SMW 25	SMW 26	SMW 27	SMW 28	SMW 29	SMW 30	SMW 31	SMW 32	SMW 33	SMW 34	SMW 35	SMW 36	SMW 37	SMW 38	SMW 39
	Expected rainfall at 75% probability level corresponding to SMW																	
Balisankara	5.6	8	16.9	30.3	31	40.1	53.7	54.7	45.1	47.4	48.9	52.8	39.4	34.5	33.9	25.4	17.9	7.6
Baramunda	6.6	10.4	21.4	33.7	31.6	38.6	53.3	53	46.1	48.6	47.7	52.9	39.3	35.6	35.3	27.8	21.1	9.4
Bisra	7.7	11	20.6	35.4	35.4	40.3	52.8	50.1	46.5	52.1	49.7	55.1	38.7	34.6	31.7	29.1	23.2	9.9
Bonai	7.6	12.2	24.1	36.3	34.7	39	52.3	51.7	47.8	51.6	49.5	55.2	40.4	36.3	36.4	30.6	23.7	10.9
Gurundia	7.6	12.2	24.1	36.3	34.7	39	52.3	51.7	47.8	51.6	49.5	55.2	40.4	36.3	36.4	30.6	23.7	10.9
Hemgir	5.2	7.8	16.8	28.5	28.4	37	53.5	54.5	44.9	42.6	45.8	51.1	38.7	34.8	34.7	25.6	16.9	7.5
Koida	7.6	12.2	24.1	36.3	34.7	39	52.3	51.7	47.8	51.6	49.5	55.2	40.4	36.3	36.4	30.6	23.7	10.9
Kuarmunda	7.7	11	20.6	35.4	35.4	40.3	52.8	50.1	46.5	52.1	49.7	55.1	38.7	34.6	31.7	29.1	23.2	9.9
Kutra	6.6	10.4	21.4	33.7	31.6	38.6	53.3	53.0	46.1	48.6	47.7	52.9	39.3	35.6	35.3	27.8	21.1	9.4
Lahunipara	7.6	12.2	24.1	36.3	34.7	39	52.3	51.7	47.8	51.6	49.5	55.2	40.4	36.3	36.4	30.6	23.7	10.9
Lathikata	7.6	12.2	24.1	36.3	34.7	39	52.3	51.7	47.8	51.6	49.5	55.2	40.4	36.3	36.4	30.6	23.7	10.9
Lephripara	5.2	7.8	16.8	28.5	28.4	37	53.5	54.5	44.9	42.6	45.8	51.1	38.7	34.8	34.7	25.6	16.9	7.5
Nuagaon	7.7	11	20.6	35.4	35.4	40.3	52.8	50.1	46.5	52.1	49.7	55.1	38.7	34.6	31.7	29.1	23.2	9.9
Rajgangpur	6.6	10.4	21.4	33.7	31.6	38.6	53.3	53	46.1	48.6	47.7	52.9	39.3	35.6	35.3	27.8	21.1	9.4
Subdega	7	9.9	19.3	33.4	33.1	40	54.1	52.1	45.5	50.5	49.2	53.2	38.7	34.4	31.7	26.8	21.2	9
Sundargarh	5.2	7.8	16.8	28.5	28.4	37	53.5	54.5	44.9	42.6	45.8	51.1	38.7	34.8	34.7	25.6	16.9	7.5
Tangarpali	5.2	7.8	16.8	28.5	28.4	37	53.5	54.5	44.9	42.6	45.8	51.1	38.7	34.8	34.7	25.6	16.9	7.5
District	**6.72**	**10.25**	**20.58**	**33.32**	**32.48**	**38.81**	**53.04**	**52.51**	**46.29**	**48.73**	**48.29**	**53.55**	**39.35**	**35.31**	**34.55**	**28.14**	**21.06**	**9.35**

in a given block, however, the interval between two similar cases and their magnitude varied in different years. This was the case for all blocks.

4. Conclusion

In the present study, long-term mean, variability, trend of rainfall and rainy days in different categories for seventeen blocks of Sundergarh district of Odisha have been analyzed using observed station dataset of 34 years (1988-2022). Statistics (mean, IAV and CV) of rainfall distribution at different temporal scales are important aspects of rainfall climatology. This is especially of interest to the local governing bodies which can be used as a tool in planning and designing runoff harvesting structures, improving irrigation potential of the small farmers, prepare contingency crop plans for respective block and raising cropping intensity of the district.

The main conclusions of the present study are as follows:

(i) Great spatial variability was observed at the block level: mean annual rainfall varied from 1087 mm (Subdega) to 1529 mm (Bonai).

(ii) Annually, rainfall can be considered dependable for most of the blocks. However, during pre-monsoon, post-monsoon and winter, CV is very high, so the rainfall is not dependable. This suggests a need of supplemental irrigation facility when the farmer plans to grow a second crop.

(iii) Bulk of annual rainfall received in the district is contributed by rain events of *light* to *moderate* category. The number of rainy days is showing a significant increasing trend (in Bargaon, Kuarmunda, Kutra, Rajgangapur and Tangarpali) and decreasing (in Lahunipara) trend.

(iv) During the study period, annual rainfall is showing an increasing as well as decreasing trend in different blocks. Significantly increasing trend was observed in Bargaon (14.47 mm/year), Bisra (13.28 mm/year), Hemgir (12.95 mm/year), Rajgangpur (17.02 mm/year), Subdega (16.40 mm/year) and Tangarpali. Decreasing and non-significant trend was observed in Bonai, Lahunipara, Lathikata, and Sundergarh. Because most of the high rainfall events are received during SW monsoon, we need to prepare ourselves with appropriate drainage systems to redirect runoffs towards reservoir and rivers. Simultaneously, in blocks where rainfall is showing a decreasing trend, there is a need to promote water harvesting at household and community levels to increase resilience of the society.

(v) Computation of SPI allowed us to establish the sequence of dry and wet periods during the study period for the seventeen blocks of Sundergarh. Results indicated a clear cyclic pattern of dry and wet periods, especially at lower time scales (3, 6 and 12 months), alternating with each other. For the district as a whole, SPI values at different time scales show that drought events were generally of mild, moderate, severe to extreme intensity. For 24-months analysis period, frequency of occurrence of these events were: mild (34% of months); moderate (7.6% of months); severe (3.3% of months) and extreme (3.2% of months). Remaining months showed positive SPI values, and thus corresponded to the wet events.

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