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551.577 : 556.12 (540.47)

Extreme rainfall events over Odisha state, India

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सार – ओडिशा में जान-माल और आजीविका की क्षति का मुख्य कारण अति वृष्टि की घटनाएं है। इस शोध पत्र का मुख्य उददेश्य 1991-2014 के दौरान हुई अति वृष्टि की घटनाओं के ट्रेण्ड का निर्धारण और 1991 से पहले तथा बाद की अवधि के बीच की घटनाओं के साथ तुलना करना है। अति वृष्टि की घटनाओं की पहचान करने के लिए ब्लॉक स्तर पर दैनिक वर्षा आंकड़ों का उपयोग किया गया जबकि भारत मौसम विज्ञान विभाग (आई एम डी) के मानक के अनुसार तीन श्रेणियों जैसे: भारी वर्षा, बहुत भारी वर्षा और अत्यधिक भारी वर्षा के ट्रेण्ड का विश्लेषण करने के लिए जिला स्तर में इकठ्ठी हुई कुल वर्षा राशि का उपयोग किया गया है। पूरे राज्य में एक वर्ष में अत्यधिक वर्षा की एक बहुत भारी वर्षा की नौ और भारी वर्षा की चालीस घटनाएं हुई हैं। जब भिन्न - भिन्न जिलों में कुल अति वृष्टि की घटनाओं में प्रत्येक श्रेणी की वर्षा घटनाओं के प्रतिशत पर विचार किया गया तो अत्यधिक भारी वर्षा का अधिकतम प्रतिशत कालाहांडी में (5.8%), बहुत भारी वर्षा बोलांगीर में (23.8%) और भारी वर्षा क्योंझरगढ़ में (85.4%) पाया गया। इस ट्रेण्ड के विश्लेषण से पता चला हे कि कुछ जिलों नामत: बोलांगीर, नुआपाड़ा, क्योंझरगढ़, कोरापुट, मलकानगरी और नौरंगपुर में अत्यधिक वर्षा की घटनाओं में वृद्धि हुई है और अन्य जिलों में कोई परिवर्तन नहीं हुआ है। पुरी जिले में अत्यधिक भारी वर्षा की बारम्बारता कम रही है। वर्ष 1992 से 2014 के दौरान 20 जिलों में पूर्ववर्ती अभिलेखों से श्रेष्ठ एक दिन की अधिकतम वर्षा की घटनाओं से एक नया सर्वकालिक रिकार्ड प्रेक्षित किया गया जो भूमंडलीय उष्णन से प्रेरित जलवायु परिवर्तन को प्रभावित कर सकता है। दक्षिणी ओडिशा के अंदरूनी भाग को अतिवृष्टि के लिए तप्त स्थल के रूप में पाया गया है।

ABSTRACT. Extreme rainfall events are a significant cause of loss of life and livelihoods in Odisha. Objectives of the present study are to determine the trend of the extreme rainfall events during 1991-2014 and to compare the events between two periods before and after 1991. Block level daily rainfall data were used in identifying the extreme rainfall events, while district level aggregation was used in analysing the trend in three categories, *viz*., heavy, very heavy and extremely heavy rainfall as per criteria given by India Meteorological Department (IMD). The state as a whole received one extremely heavy, nine very heavy, and forty heavy rainfall events in a year. When percentage of occurrence of each category out of the total extreme events over different districts was considered, maximum % of extremely heavy rainfall occurred in Kalahandi (5.8%), very heavy rainfall in Bolangir (23.8%) and heavy rainfall in Keonjhargarh (85.4%). Trend analysis showed that number of extreme rainfall events increased in a few districts, namely, Bolangir, Nuapada, Keonjhargarh, Koraput, Malkangiri, and Nawarangapur and did not change in other districts. In Puri district, extremely heavy rainfall frequency decreased. New all-time record high one-day rainfall events were observed in twenty districts during 1992 to 2014, surpassing the earlier records, which could be attributed to climate change induced by global warming. Interior south Odisha was found as the hot spot for extreme rainfalls.

Key words – Extreme rainfall events, Block level, Odisha, Trend analysis, Climate change, All-time record high.

1. Introduction

Odisha state is frequently impacted by the weather hazards and extreme rainfall is one of them. Most of the extreme rainfalls are generally associated with the cyclonic circulation forming over the land or over the Bay of Bengal. Climate model simulations (Hennessey *et al*., 1997), reports of Intergovernmental Panel on Climate Change (IPCC, 2007) and empirical evidences confirm that warmer climates, owing to increased water vapor, lead to more intense precipitation events and therefore, increases risks of floods. As most of the people of Odisha depends upon agriculture, such changes on rainfall events is more important than the changes in mean pattern of rainfall for agriculture [Guhathakurta *et al.* (2010)]. Moreover, such changes in rainfall events warrant to

review and reorient the disaster management and mitigation practices. Secondly, northern parts of the state are greatly affected by flood as a result of extreme rainfall. General perception in the state is that extreme rainfall events are increasing with respect to intensity and frequency and such changes in rainfall would pose a great risk on crop production and productivity. Earlier, Rakhecha and Pisharoty (1996) studied the heavy rainfall events during the southwest monsoon season for some selected stations over the country. Stephenson *et al*. (1999), using the data for the period June to September 1986 to 89, have investigated extreme daily rainfall events and their impact on ensemble forecasts of the Indian Monsoon. Rajeevan *et al.* (2008) analysed the variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. Sen Roy and Balling (2004) studied the trends in extreme daily precipitation indices. Most of the studies on extreme rainfall were on macro-scale and all India basis. However, not much studies have been made on a micro-scale (block level) for the states in general and Odisha in particular. Hence, the present studies were carried out to determine the trend of the extreme rainfall events during 1991-2014 and to compare the intensity of events between two periods, before and after 1991.

2. Materials and method

The state of Odisha is located between 17.49′ and 22.34′ N latitudes and 81.27′ and 87.29′ E longitudes. The coastal state has 30 districts, which are further divided into 314 revenue Blocks Block wise daily rainfall data were collected from Special Relief Commissioner (SRC), Government of Odisha for the period from 1991 to 2014 and processed by using Statistical Analysis Software (SAS, 2014). The extreme rainfall events were categorized into three categories as per criteria of India Meteorological Department (website : IMD Monsoon Report 2014). These were (a) Heavy Rainfall (64.5-124.4 mm one-day rainfall), (b) Very Heavy Rainfall (124.5-244.5 mm one-day rainfall) and (c) Extremely Heavy Rainfall (≥244.5 mm one-day rainfall). Year wise total number of events under each category was calculated block wise and their aggregation using algebraic sum was done to get district wise events for all the 30 districts of Odisha (Pasupalak, 2015). Percent events under each category out of total of all the three categories in a year were calculated district wise. The time series data on number of category wise events were subjected to Mann-Kendall test (Kendall, 1970) for trend analysis. The trend analysis software, Weather Cock (Rao *et al*., 2015), based upon the algorithm used in RC LimDex V.1 (Zhang and Feng, 2004), was used to detect the trends of the occurrence of events. Significance tests were made at 90, 95 and 99% confidence interval.

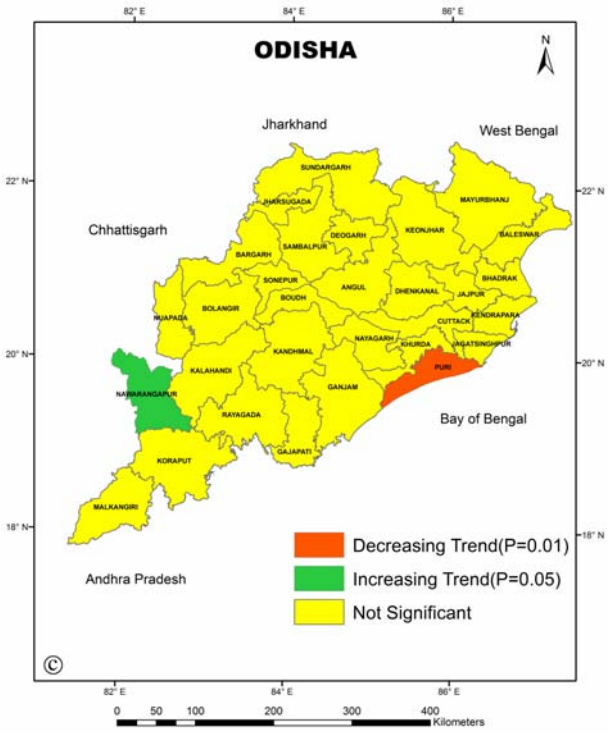

Fig. 1. Extreme heavy rainfall trend in districts of Odisha

Besides the trend analysis, extreme rainfall events were compared between the two periods, before 1991 and during 1991-2014. The first period included all-time record high one-day rainfall reported by India Meteorological Department (IMD, 2002,) while the second was based on the SRC data used for trend analysis as above. For the first period only one all-time high rainfall for a district reported by IMD (2002) was considered, while for the second period, three highest rainfall events in a district were identified.

3. Results

3.1. *Extreme rainfall occurrence*

The state of Odisha as a whole received one extremely heavy, nine very heavy and forty heavy rainfall events in years during 1991 to 2014. The average frequency of extremely heavy rainfall at district level was highest in Kalahandi, 4.8 events per year. In 12 districts the frequency was one or more than one per year. As regards to very heavy rainfall, highest occurrence was in Mayurbhanj (19.3/year), followed by Kalahandi (18.4/year) and Puri (16.1/year). All the districts received very heavy rainfall, minimum being in Deogarh (1.5/year). The Mayurbhanj district received maximum heavy rainfall events (95.5/year), followed by Ganjam (65.4/year) during the period. Most of the districts

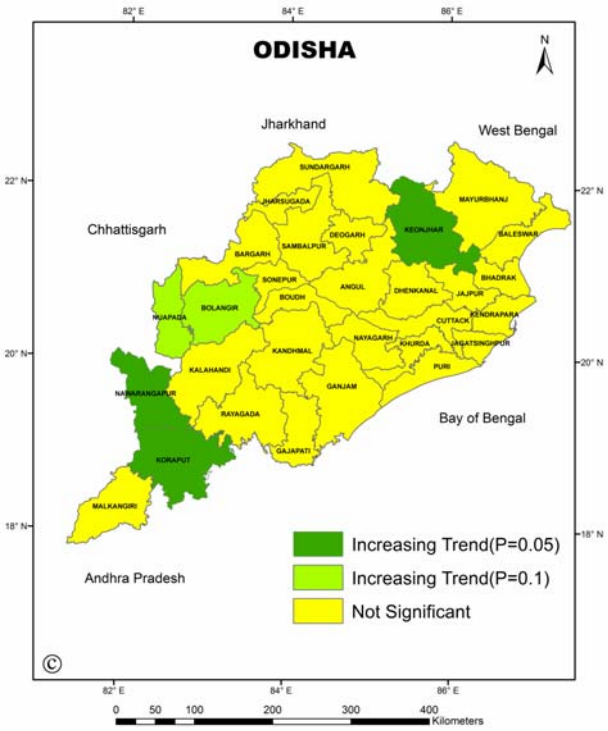

Fig. 2. Very heavy rainfall trend in districts of Odisha

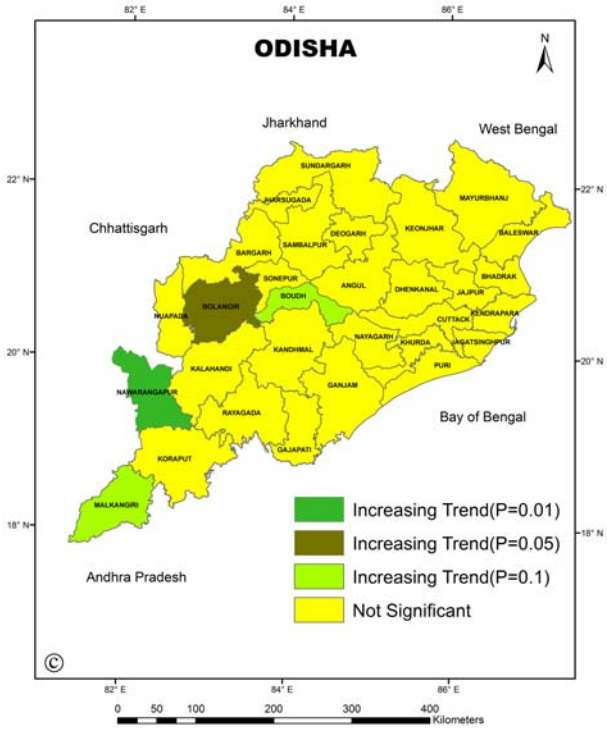

Fig. 3. Heavy rainfall trend in districts of Odisha

receiving more frequent heavy rainfall were the coastal districts. When percent share of each of these three events was analysed, it was 1.9, 18.0 and 80.1% respectively for the state. Among the districts, Kalahandi, received maximum percent of extremely heavy rainfall events (5.78%), followed by Sambalpur (3.09%). Most of the western Odisha districts, namely, Bargarh, Bolanlngir, Sonepur and Sambalpur got more than 2% extremely heavy rainfall events (Fig. 1). In the districts of north coastal and central Odisha, namely, Mayurbhanj, Balasore, Bhadrak, Keonjhargarh, Angul and Dhenkanal, it was only 1 to 2%. In case of the second category, very heavy rainfall events, most of the districts of Odisha received 15 to 20% of total extremes in a year. Puri is the only coastal district, which got maximum percentage (24.05%) of very heavy rainfall events. Other districts, which got more than 20% occurrence of very heavy rainfall events were Boudh, Kandhamal, Kalahandi, Bargarh, Bolangir and Sambalpur and all are loctred interior. As regards to the occurrence of the third category, heavy rainfall events, it was high in case of north and north-western districts of Odisha, namely, Keonjhargarh, Sundargarh, Deogarh and Dhenkanal. Among them the district of Keonjhargarh received it most frequently (85.39%), while the Kalahandi district received the lowest (72.11%). Other than the above districts had the range within 75 to 80% frequency of Heavy Rainfall events.

3.2. *Extreme rainfall trend*

Number of extreme rainfall events showed an increasing trend in few districts, but remained unchanged in all other districts except Puri. During the period between 1991 and 2014, the Extremely Heavy Rainfall event increased significantly (95% significance) in Nawarangapur district, while it decreased in Puri district (Fig. 1). Such a decreasing trend in Puri was significant even at 99% confidence level, which showed a definite decreasing trend of Extremely Heavy Rainfall. Rest of the districts did not show any trend of Extremely Heavy Rainfall even at lower confidence level (90%). The second category, very heavy rainfall events, increased significantly (95% significance) in Keonjhargarh, Nawarangapur and Koraput. In Bolangir and Nuapada the increase was significant at 90% confidence level (Fig. 2). The third category of extreme rainfall, heavy rainfall, increased in Nawarangapur at 99% confidence level, in Bolangir at 95% of confidence level and in Malkangiri and Boudh at 90% confidence level (Fig. 3).

3.3. *Record one-day rainfall events*

All-time record high one-day rainfall events during two periods, (a) before 1912 and from 1991 to 2014 are given in Table 2. Comparison of data between these two periods should be taken cautiously due to different

TABLE 1

Occurrence of extreme rainfalls over Odisha

District	Frequency per year			% of total extremes		
	Extremely heavy	Very heavy	Heavy	Extremely heavy	Very heavy	Heavy
Angul	0.65	5.75	26.10	2.00	17.69	80.31
Balasore	1.02	12.75	60.40	1.35	17.19	81.46
Bargarh	1.20	11.55	42.75	2.16	20.81	77.03
Bhadrak	0.50	5.90	28.10	1.45	17.1	81.45
Bolangir	1.40	11.40	42.10	2.55	20.77	76.68
Boudh	0.15	3.25	10.25	1.1	23.81	75.09
Cuttack	1.55	14.15	61.25	2.01	18.39	79.6
Deogarh	0.15	1.55	9.10	1.39	14.35	84.26
Dhenkanal	0.35	5.05	29.15	1.01	14.62	84.37
Gajapati	0.75	4.65	20.15	2.94	18.2	78.86
Ganjam	1.00	12.20	65.45	1.27	15.51	83.22
Jagatsinghpur	0.55	9.20	36.00	1.2	20.11	78.69
Jajpur	1.55	9.05	53.50	2.42	14.12	83.46
Jharsugada	0.20	3.30	17.60	0.95	15.64	83.41
Kalahandi	4.80	18.35	59.85	5.78	22.11	72.11
Kandhmal	1.70	15.55	51.95	2.46	22.47	75.07
Kendrapara	1.05	10.75	49.00	1.73	17.68	80.59
Keonjhargarh	0.70	6.60	42.65	1.4	13.21	85.39
Khurda	0.65	8.20	39.30	1.35	17.03	81.62
Koraput	0.80	10.35	44.10	1.45	18.73	79.82
Malkangiri	0.70	5.10	24.10	2.34	17.06	80.6
Mayurbhanj	1.55	19.30	95.55	1.33	16.58	82.09
Nawarangapur	1.40	10.90	45.65	2.42	18.81	78.77
Nayagarh	0.45	6.05	27.65	1.32	17.72	80.97
Nuapada	0.30	3.10	13.75	1.75	18.08	80.17
Puri	1.60	16.10	49.25	2.39	24.05	73.56
Rayagada	0.55	5.30	30.35	1.52	14.64	83.84
Sambalpur	1.45	9.65	35.80	3.09	20.58	76.33
Sonepur	0.70	5.45	25.30	2.23	17.33	80.45
Sundargarh	0.50	9.80	55.05	0.77	15	84.24
State	1.00	9.01	39.71	1.90	17.98	80.12

sources, although IMD data were mostly from the same rain gauge stations as of SRC (monitored by IMD). However, it would indicate whether new records have come up in the second period due to global warming because 1990 is considered as the base year. Twenty out of 30 districts in the state have registered new all-time high records during 1991-2014. Kalahandi recorded 825 mm at Th. Rampur on 28th July, 1991, which is the all-time high state record so far. It surpassed the previous record of 344.8 mm at Jaypatna on 22nd June, 1967. The

TABLE 2

Record one-day rainfall events in different districts of Odisha

District	Before 1992 (IMD)			1991-2014 (SRC)		
	Date	Block	Rainfall (mm)	Date	Block	Rainfall (mm)
Angul	19 Aug 1975	Palahara	332.7	05 Aug 2014	Pallahara	402
				28 Jun 2005	Pallahara	340
				12 Aug 1991	K.Nagar	339
Balasore	18 Jul 1987	Balasore	398.8	11 Aug 1993	Baliapal	455
				31 Oct 1999	Oupada	400
				30 Oct 1999	Oupada	345
Bargarh	07 Sep 1939	Padampur	368.3	28 Jul 1992	Bijepur	475
				15 Jun 1994	Bhatali	402
				13 Aug 2006	Bheden	360
Bhadrak	18 Jun 1879	Chandabali	514.6	31 Oct 1999	Bhadrak	446
				30 Oct 1999	Bhadrak	361
				31 Oct 1999	Basudevpur	335
Bolangir	02 Aug 1967	Titilagarh	266.6	30 Aug 2006	Bangomunda	459
				28 Aug 2003	Gudvella	448
				14 Jun 2004	Gudvella	380
Boudh	15 Jun 1936	Balandapada	395	13 Aug 1991	Kantamal	271
				18 Sep 2008	Kantamal	259
				28 Jul 1992	Kantamal	249
Cuttack	10 Aug 1934	Cuttack	416.8	18 Aug 2012	Banki-Dampada	478
				13 Oct 2013	Banki-Dampada	381
				18 Jun 1993	Niali	345
Deogarh	01 Aug 1943	Deogarh	330.2	17 Jul 2001	Deogarh	308
				05 Aug 2014	Barkote	290
				05 Aug 2014	Deogarh	263
Dhenkanal	17 Jul 1915	Bhuban	305	17 Jul 1991	Hindol	305
				25 Oct 2013	Hindol	300
		Hindol		17 Jul 1991	Odapada	278
Gajapati	04 Nov 1990	Mohana	319.2	21 Jul 2012	R.Udaygiri	407
				30 Apr 2012	Nuagada	400
				10 May 1995	Nuagada	350
Ganjam	02 Jul 1984	Digapahandi	485	18 Oct 1999	Polasara	350
				13 Oct 2013	Buguda	323
				18 Oct 1999	Kukudakhandi	297
Jagatsingpur	02 Jul 1989	Jagatsinghpur	498.6	30 Jul 1997	Erasama	540
				15 Nov 1998	Erasama	450
				27 Jul 1992	Tirtol	315
Jajpur	11 Aug 1992	Sukinda	350	30 Oct 1999	Sukinda	390
				30 Oct 1999	Bari	375
		Dharamasala		11 Aug 1992	Dharamsala	350
Jharsuguda	29 Jun 1925	Jharsuguda	350	16 Aug 2012	Laikera	350
				07 Aug 2004	Laikera	306
				16 Aug 2012	Jharsuguda	277
Kalahandi	22 Jun 1967	Jaypatna	344.8	28 Jul 1991	Th. Rampur	825
				03 Jul 2006	Th. Rampur	700
				24 Jun 2013	Th. Rampur	660

TABLE 2 (*Contd.*)

District	Before 1992 (IMD)			1991-2014 (SRC)		
	Date	Block	Rainfall (mm)	Date	Block	Rainfall (mm)
Kandhamal	12 Aug 1991	Phiringia	331	29 Jul 1991	Kotagarh	371
				07 Sep 2003	Tumudibandha	355
				12 Aug 1991	Phiringia	331
Kendrapara	24 Jun 1925	Kendrapada	401.8	29 Oct 1999	Mohakalpara	495
				29 Oct 1999	Garadpur	487
				29 Oct 1999	Derabis	482
Keonjhargarh	09 Jul 1941	Anandapur	343.4	31 Oct 1999	Ghatagaon	423
				31 Oct 1999	Ananndapur	415
				26 Jul 2013	Champua	360
Khordha	07 Jul 1974	Balianta	325	31 Oct 1999	Balianta	372
				30 Oct 1999	Bhubaneswar	364
				30 Oct 1999	Balianta	340
Koraput	14 Oct 1931	Pottangi	546.1	08 Jul 2001	Bandhugan	501
				04 Aug 2006	Nandapur	341
				04 Sep 1994	Dashamantpur	318
Malkangiri	17 Jun 1907	Malkangiri	306.3	17 Jun 1999	Korukonda	392
				18 Jun 1999	K.Gumma	338
				04 Aug 2006	Khoirput	336
Mayurbhanj	12 Oct 1973	Baripada	461.4	18 Jun 2008	Bahalda	424
				13 Aug 2007	Bijatala	375
				10 Aug 1993	Bahalda	361
Nabarangpur	03 Jul 1945	Dasapala	273.1	05 Aug 2010	Dabugaon	486
				03 Jul 2006	Jharigaon	478
				04 Jul 2006	Jharigaon	456
Nayagarh	29 Oct 1917	Nuapada	279.4	13 Jul 2009	Khandapara	412
				13 Jul 2009	Nayagarh	345
				13 Oct 2013	Ranpur	296
Nuapada	01 Oct 1973	Deogarh	350	18 Sep 2008	Boden	350
				18 Sep 2008	Khariar	295
				21 Jul 2014	Nuapada	265
Puri	21 Oct 1862	Puri	480.1	28 Jul 1991	Puri	483
				10 Aug 1991	Puri	342
				14 May 1995	Puri	336
Rayagada	18 Aug1890	Raygada	355.6	03 Jul 2006	Kashipur	400
				07 Aug 2007	Chandrapur	397
				03 Jul 2006	Raygada	299
Sambalpur	19 Aug 1982	Sambalpur	581.9	13 Aug 2006	Jujumura	375
				05 Aug 1997	Dhankuda	371
				17 Jul 2001	Kochinda	369
Subarnapur	16 Jun 1918	Sonepur	365.5	13 Aug 2006	Binika	402
				13 Aug 1991	Sonepur	297
				28 Aug 2003	Tarbha	293
Sundargarh	20 Jul 1920	Bonai	333.5	20 Jun 2003	Sundargarh	347
				20 Aug 2007	Lathikata	328
				29 Jun 2005	Lahunipara	280

same station also registered 700 mm on 3rd July, 2006 and 660 mm on 24th June, 2013. The same station also registered 700 mm on 3rd July, 2006 and 660 mm on 24th June, 2013. Extremely Heavy rainfall of 483 mm at Puri on 28th July, 1991 surpassed the century old record high of 480.1 mm on 21st October, 1862.

4. Discussion

Four features of spatial distribution of extreme rainfalls were revealed from the trend analysis. First, the districts receiving Extremely Heavy Rainfall events are in two clusters. The first cluster comprised of seven coastal districts, namely Mayurbhanj, Balasore, Jajpur, Kendrapada Cuttack, Puri and Ganjam. The second cluster consisted of five interior districts, namely Samabalpur, Bargarh, Bolangir, Kandhamal and Nawarangpur. Secondly, the second category, Very Heavy Rainfall events, increased in four south interior districts, Nawarangapur, Koraput, Bolangir and Nuapada and only one north Odisha district Keonjhargarh. Paradoxically, these districts included Bolangir and Nuapada, which are most often affected by drought. Thirdly, all three categories of rainfall extremes increased in Nawarangapur. The districts adjoining to Nawarangapur also showed increasing trend of extreme events. Kalahandi, showing highest one-day rainfall, is one such adjoining district. Fourthly, most of the districts showing increasing trend of occurrence (except Keonjhargarh) are in interior south Odisha. The frequency of extreme rain events increased in all the interior districts, namely Jharsuguda, Nawarangapur, Bolangir, Gajapati, Jagatsinghpur and Malkangiri, while decreased in coastal districts of Odisha, namely Puri, Khorda, Balasore, Bhadrak and Kendrapada. The results were partly similar to that of Goswami *et al*. (2006), who reported significant rising trends in the frequency and the magnitude of extreme rain events and a significant decreasing trend in the frequency of moderate events over central India.

Trend analysis of all three categories showed a mixed trend in different districts of Odisha. For example, Kalahandi, Keonjhargarh, Koraput, Nuapada, Bolangir and Nawarangapur showed increasing trend in extreme rainfall events, while coastal district Puri showed decreasing trend. Such types of results were also reported by Rakhecha and Pisharoty (1996), mixed trends in different parts of the country. Parts of the Peninsula showed a significant increasing trends at 95% level of confidence. The decreasing trend in Puri was similar to that of southern Peninsula and the lower Ganga valley, exhibiting a decreasing trend at the same level of significance. When frequency and time series trend are considered together, it is found that extreme events are spread across the state, north-south and east-west. The results confirm the findings of Ramesh and Goswami (2007) that in genesis and evolution of extreme rainfalls of intensity greater than 350 mm/day during the June to August period, the oceanic environment has a minor role to play.

New record high one-day rainfall events were found in 20 out of 30 districts of the state. No spatial pattern was found on the districts registering new records, as these included both coastal and interior districts across the state. Repeated occurrence of new record high rainfalls in Kalahandi, three new records during 1991 to 2014, is phenomenal, which needs to be analysed further. In the present studies new all-time high records occurred in 1990s, 2000s and 2010s. Thus the results differed from Kripalani and Kumar (2004), who reported inter-decadal variation due to cyclic occurrence of negative and positive phases of the Indian dipole.

5. Conclusion

Analysis of extreme rainfall events in all three categories during 1991-2014 showed a mixed trend in different districts of Odisha. The state as a whole received one extremely heavy, nine very heavy, and forty heavy rainfall events in a year. In terms of percentage of occurrence of each category out of the total extreme events, maximum % of extremely heavy rainfall occurred in Kalahandi (5.8%), very heavy rainfall in Bolangir (23.8%) and heavy rainfall in Keonjhargarh (85.4%). Trend analysis showed that number of extreme rainfall events increased in few districts, namely, Bolangir, Nuapada, Keonjhargarh, Koraput, Malkangiri, and Nawarangapur and did not change in other districts. Puri district observed decrease in frequency of extremely heavy rainfall category. New all-time record high one-day rainfall events were recorded in twenty districts during 1992 to 2014, surpassing the earlier records, which could be attributed to climate change induced by global warming.

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