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Extreme rainfall analysis of Andhra Pradesh using a probability distribution model : A regional estimate

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सार – इस शोध–पत्र में मानसून और मानसूनोत्तर ऋतुओं के परिणामस्वरूप होने वाली प्रचुर वर्षा वाले प्रायद्वीपीय भारत के तटीय राज्य आंध्र प्रदेश में अत्याधिक वर्षा होने की घटनाओं का विश्लेषण करने का प्रयास किया है। इस अध्ययन के लिए 1901–2000 तक की अवधि के दौरान के सत्तर वर्षों अथवा उससे भी अधिक वर्षों के आँकड़ों वाले 155 स्थानों के संजाल का उपयोग किया गया है। ये स्थान पूरे राज्य में फैले हुए हैं। एक – दिन, दो – दिन और तीन – दिन की चरम वार्षिक वर्षा श्रृंखलाएं तैयार की गई और ये समवृष्टि रेखा विश्लेषण तीन भारी वर्षा वाले क्षेत्रों को निरूपित करती हैं। संभाव्यता वितरण प्रणाली प्रत्येक स्थान की अत्याधिक वर्षा श्रृंखलाओं में जलवायु परिवर्तनों के क्षेत्रीय आकलनों के अनुरूप पाई गई है। चरम मान वितरण नामतः गम्बल और लॉग सामान्य वितरण मानसूनोत्तर के अनुरूप पाई है जो मानसून ऋतु से कुछ मेल खाती है। कॉलमोगोर्व–स्मिरनॉव आँकड़ों से वितरण की अनुरूपता की गुणवता की जाँच की गई है।

ABSTRACT. The study is an attempt to analyze the extreme rainfall events of Andhra Pradesh, a coastal state of Peninsular India, where both monsoon and post-monsoon seasons contribute significant rain. A network of 155 stations having data of seventy years or more during the period 1901-2000 has been used for the study. These stations are well distributed over the state. One-day, two-day and three-day extreme annual rainfall series are made and the isohyetal analysis demarcates three heavy rainfall receiving zones. Probability distribution functions have been fitted for the regional estimates of climate changes in extreme rainfall series of each station. Both the extreme value distribution *viz*., Gumbel and log normal distribution fit well with latter one giving slightly better fit over the former. Goodness of fit of the distribution is tested with Kolmogorov - Smirnov Statistic.

Key words – Extreme rainfall, Probability distribution, Climate change, Regional estimate.

1. Introduction

Modelling of extreme rainfall is essential in the designing of water related structure, in agriculture planning, in weather modification, water management and also in monitoring climate changes. Moreover, knowledge of spatial and temporal variability of extreme rainfall events is very much useful for the design of dam and hydrological planning.

Andhra Pradesh is situated on the east coast of Peninsular India. It experiences heavy to very heavy rainfall associated with the meteorological systems during pre-monsoon, south-west monsoon and also during post monsoon / northeast monsoon seasons. Heavy rains occur over the region due to the passage of westerly moving tropical disturbances and due to strong monsoon currents. Also short period heavy falls occur with intense convective activities during the pre-monsoon season.

A large amount of the variability of rainfall is related to the occurrence of extreme rainfall events and their intensities. Therefore, there is a need to know the magnitudes of extreme rainfall events over different parts of the area under study. The study of spatial variability of extreme rainfall events helps to identify the zone of high and low value of ever extreme rainfall events. A detailed regionalized study is practically useful for the planners and other users. However, not much work has been done in India examining the same, although in some studies *viz*., Rakhecha and Pisharoty (1996) authors have studied the heavy rainfall events during the southwest monsoon season for some selected stations over the country.

TABLE 1

Rainfall normals in mm for the three meteorological sub-divisions of Andhra Pradesh and for the state

Met. sub div.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Coastal A.P.	6.8	8.9	13	22.8	60.3	106.5	169.8	164.1	168	195.1	94.6	21.7	1031
Telangana	4.5	5.7	9.8	16.3	29.1	136.1	244	221.8	172.9	83.5	20.5	4.2	948.4
Rayalseema	3.5	3.4	6.7	18.1	54.8	59.8	91.1	97.3	132.3	122.2	67.8	25.2	682.2
Andhra Pradesh	5.1	6.2	9.8	19.1	48.2	100.2	167.2	160.3	157.9	135	61.9	17.7	888.6

In modelling extreme rainfall/flood frequency, selection of distribution to be used is an important task (WMO, 1989). The choice of suitable distribution function has attracted considerable interest (Gumbel, 1958; Hosking, 1990; Boughton 1980). References to exhaustive literatures are also available in (WMO, 1989). Recently Parida (1999), Unkasevic and Radiomovic (2000), Park and Jung (2002) have tried to fit distribution for extreme rainfall while Katz and Acero (1994) have done the sensivity analysis of extreme precipitation events. Regional analysis of extreme values (temperature) in terms of spatial analogue for climate change was done by Brown & Katz (1995). Regional analysis has also been applied in hydrology for better estimates of flood frequencies (Chowdhury *et al*., 1991; Hosking *et al*., 1985).

In this study, spatial distribution of one-day, two-day and three-day extreme rainfall over Andhra Pradesh are presented. It is found that the annual extreme rainfall values generally follow a positively skewed distribution function. Individual distribution can differ significantly and may vary noticeably from one another in the values estimated for large return period. Since the hydraulic design is often based on estimate of large recurrences interval events, it is important to determine the distribution as accurately as possible. In this study several standard probability distribution functions are tested to find the best fit for the spatial distributions of one-day, two-day & three-day extreme rainfall.

2. Data

Andhra Pradesh consists of three meteorological homogeneous sub-divisions *viz*., Coastal Andhra Pradesh, Telangana and Rayalseema. Climatologically heavy rainfall over Andhra Pradesh is mainly associated with three different synoptic/meso-scale systems. Intense convection leads to the development of thunder storm during pre-monsoon season which causes heavy rainfall in short duration. Sometimes in pre-monsoon season, cyclonic storms/depressions form over south and central Bay of Bengal and move in a northwesterly direction causing heavy to very heavy rainfall over the region. During the southwest monsoon period, monsoon system brings persistent copious rain through out the season. Due to the formation of tropical disturbances/storms over south and central Bay of Bengal and their movement over the region bring incessant rain during post monsoon season. Northeast monsoon also some times brings heavy rainfall over the region.

Monthly rainfall normals (Table 1) over the three sub-divisions and the state based on the period 1941-90 show that average monthly rainfall for three different sub-divisions is maximum in three different months. Coastal Andhra Pradesh which is the most affected by the cyclonic storms gets maximum average monthly rainfall during the month of October. This sub-division receives more than 30% of annual rainfall during the post-monsoon season. While for the sub-divisions Telangana and Rayalseema, average rainfall is maximum during July and September respectively.

Andhra Pradesh has a good network of rainfall observation stations. Rainfall data of large number of stations are available in the archive of the India Meteorological Department. We have considered the data of the complete 20th century *i.e.*, 1901-2000. Out of all the rain gauge stations, only those stations are considered which are evenly distributed and have 70 years or more data. Table 2 shows the list of 155 stations, their longitude, latitude and the availability of the data. Out of 155 stations, 115 stations have the data of 90 years or more.

3. Regional analysis of extreme daily rainfall events

3.1. *Descriptive rainfall statistics*

155 stations selected for the study have a relatively long series of data. From the daily rainfall series, Annual

TABLE 2

Station name, Latitude, Longitude, number of years of data available, 1-day extreme rainfall in cm and the corresponding date of occurrence and the Kolmogorov-Smirnov's statistic D computed from the time series of annual maxima of one-day precipitation fitted with Log normal distribution

S. No.	Station name	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	No. of Years	1-day extreme	Date	D	S. No.	Station name	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	No. of Years	1-day extreme	Date	D
1	Kuppam	12	45	78	21	94	18.5	26 Sep ′78	0.0420	47	Isakapally	14	44	80	7	82	34	02 Oct ′77	0.0823
2	Madakasira	13	56	77	16	94	19.4	31 Oct ′91	0.0424	48	Krishnapatnam	14	16	80	7	86	43.1	23 Oct ′69	0.0359
3	Hindupur	13	49	77	29	94	15.6	15 Sep ′75	0.0388	49	Gooty	15	7	77	38	94	20.1	08 Jul ′90	0.0583
4	Venkatagirikota	13	0	78	30	79	20.1	5 Nov ′03	0.0348	50	Yadki	15	3	77	52	88	19.7	28 Jul ′81	0.0764
5	Palamner	13	12	78	45	94	21.7	20 May ′43	0.0397	51	Yemiganur	15	47	77	29	89	21.9	31 Oct ′16	0.0403
6	Punganur	13	22	78	35	93	19.9	07 Jul ′94	0.0510	52	Adoni	15	38	77	17	91	40	14 Jun ′89	0.0481
7	Madanapalli	13	33	78	30	84	40	13 Aug ′90	0.0434	53	Alur	15	23	77	14	91	17.8	13 Jul ′84	0.0490
8	Vayalpad	13	37	78	38	84	18.2	19 May ′43	0.0276	54	Dhone	15	24	77	52	87	19.2	31 Oct ′16	0.0510
9	Piler	13	39	78	57	83	14.5	22 Oct ′54	0.0646	55	Peapalli	15	14	77	44	91	18	25 Jul ′93	0.0478
10	Tanakal	13	55	78	12	81	19.2	30 Oct ′91	0.0772	56	Pattikonda	15	23	77	31	90	23.2	01 Sep ′65	0.0238
11	Venkatagiri	13	58	79	35	94	27.6	15 Nov ′91	0.1012	57	Gudur	15	47	77	48	94	15	02 Aug ′74	0.0575
12	Satyavedu	13	26	79	58	94	28	24 Dec ′83	0.0458	58	Kurnool Obsy	15	50	78	4	91	16.6	23 May ′52	0.0939
13	Puttur	13	27	79	33	94	25.4	17 Jan ′06	0.0365	59	Giddalore	15	22	78	55	92	18.2	23 May ′52	0.0333
14	Kalahasti	13	46	79	43	88	53	17 Oct ′76	0.0650	60	Aloograda	15	9	78	31	88	33.1	18 Oct ′75	0.0266
15	Tirupati	13	38	79	24	94	26.5	17 Jan ′06	0.0425	61	Nandyal	15	30	78	30	89	38.9	23 May ′52	0.0572
16	Chandragiri	13	36	79	20	94	27.2	17 Jan ′06	0.0369	62	Owk	15	13	78	8	88	15	09 Jul ′89	0.0829
17	Pakala	13	28	79	8	72	25.2	22 Nov ′15	0.0734	63	Koilkuntla	15	15	78	19	91	20.3	31 Oct ′60	0.0764
18	Chittoor	13	13	79	7	92	22.7	30 Nov ′30	0.0213	64	Atmakur	15	53	78	35	93	46.4	06 Oct ′94	0.0738
19	Sullurpet	13	47	80	1	93	42.3	14 Nov ′84	0.0307	65	Nandikottur	15	52	78	16	91	25.8	23 May ′52	0.0478
20	Tada	13	36	80	2	90	42	08 Oct ′43	0.0985	66	Addanki	15	48	79	58	93	29.7	18 May ′69	0.0261
21	Rayadurg	14	42	76	51	94	24.6	25 Jul ′56	0.0356	67	Kanigiri	15	25	79	31	93	43	13 May ′79	0.0323
22	Penukonda	14	5	77	35	94	19	31 Oct ′91	0.0545	68	Podili	15	38	79	37	93	32.2	22 Jul ′84	0.0689
23	Bukkapatnam	14	12	77	47	94	20.6	07 Jul ′89	0.0207	69	Darsi	15	47	79	41	93	28.4	20 Dec ′06	0.0532
24	Dharmavaram	14	25	77	43	94	21.2	12 Sep ′83	0.1372	70	Kandukur	15	13	79	54	93	28.7	01 Nov ′94	0.0445
25	Kalyandrug	14	33	77	7	92	14.1	20 May ′43	0.0813	71	Markapur	15	45	79	18	93	40	13 May ′79	0.0438
26	Anantapur Obsy	14	41	77	37	89	16.8	27 Sep ′74	0.0304	72	Cumbum	15	35	79	7	76	20.3	23 Sep ′49	0.0731
27	Urvakonda	14	57	77	15	94	24.6	10 Nov ′56	0.0800	73	Bapatla	15	54	80	28	94	48.9	10 May ′90	0.1023
28	Pulivendla	14	25	78	14	92	16.3	06 Oct ′44	0.0445	74	Chinaganjam	15	42	80	15	85	31.2	18 May ′69	0.1077
29	Jammalamadugu	14	51	78	24	93	18.7	08 Oct ′58	0.0273	75	Pakala	15	15	80	0	82	30.5	29 Oct ′39	0.0872
30	Proddatur	14	45	78	34	92	24.8	08 Jun ′34	0.0519	76	Mahbubnagar	16	44	77	59	92	17.1	14 May ′79	0.0354
31	Kamalapuram	14	35	78	40	92	21.7	12 Jun ′06	0.0322	77	Gurjala	16	33	79	38	94	17.2	19 Oct ′45	0.0552
32	Cuddapah Obsy	14	29	78	50	97	27	08 Oct ′58	0.0411	78	Macharla	16	28	79	26	92	19.1	19 Oct ′45	0.0681
33	Sidhout	14	28	78	58	94	16.4	06 Jun ′91	0.0336	79	Vinukonda	16	3	79	45	90	32	20 Dec ′06	0.0315
34	Rayachoti	14	3	78	45	93	24.8	06 Nov ′03	0.0195	80	Avanigadda	16	2	80	55	94	50	17 Oct ′69	0.0543
35	Kadiri	14	7	78	10	94	17.3	06 Nov ′03	0.0612	81	Gudivada	16	26	80	59	93	23.2	17 Oct ′69	0.0309
36	Tadpatri	14	55	78	2	94	18.9	20 Jul ′77	0.0417	82	Gannavaram	16	33	80	48	92	20.4	31 Jul ′33	0.0419
37	Lakkireddipalam	14	12	78	42	74	16.5	22 Oct ′54	0.0426	83	Nuzvid	16	48	80	52	79	27.5	23 Jul ′89	0.0348
38	Udayagiri	14	53	79	18	93	32	01 Nov ′94	0.0511	84	Vijayawada	16	31	80	37	88	32.4	17 May ′25	0.0355
39	Nellore Obsy	14	27	79	59	97	52.3	03 Nov ′87	0.0437	85	Jaggiayapet	16	53	80	6	94	19.2	23 Jul ′89	0.0330
40	Gudur	14	9	79	52	87	40	14 Nov ′88	0.0575	86	Nandigama	16	47	80	17	93	25.7	29 Oct ′36	0.0607
41	Rapur	14	12	79	32	94	25.2	06 Dec ′46	0.0254	87	Guntur	16	18	80	27	94	40	20 Nov ′77	0.0804
42	Badvel	14	45	79	4	94	24.5	23 May ′52	0.0280	88	Mangalgiri	16	25	80	35	92	22.4	18 May ′69	0.0359
43	Chitvel	14	10	79	20	80	22.2	08 May ′30	0.1162	89	Sathenapalli	16	23	80	8	94	23.6	02 Nov ′27	0.0749
44	Rajampet	14	12	79	10	94	20.2	06 Nov ′03	0.0641	90	Tenali	16	14	80	39	94	25.8	18 Oct ′82	0.0398
45	Atmakur	14	37	79	38	89	23.9	27 Nov ′07	0.0266	91	Repalle	16	2	80	51	94	47.5	20 Nov ′77	0.0369
46	Kavali	14	55	80	0	94	40.6	17 Oct ′76	0.0238	92	Ponnuru	16	3	80	33	93	36	20 Nov ′77	0.0814

TABLE 2 (*Contd.*)

S. No.	Station name	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	No. of Years	1-day extreme	Date	D	S. No.	Station name	Lat. Deg.	Lat. Min.	Long. Deg.	Long. Min.	No. of Years	1-day extreme	Date	D
93	Narasaraopet	16	14	80	3	94	23.3	08 Oct ’30	0.0421	125	Yelamanchili	17	33	82	52	91	35.6	22 Oct ’28	0.0806
94	Alamur	16	46	81	53	94	38.8	26 Sep ’08	0.0213	126	Polavaram	17	24	82	49	73	35.9	20 Oct ’58	0.1120
95	Kothapeta	16	43	81	54	92	36	23 Jul ’89	0.0459	127	Tuni	17	21	82	33	94	35.5	10 May ’90	0.1022
96	Razole	16	28	81	50	94	27.1	16 Nov ’23	0.0626	128	Pithapuram	17	7	82	15	94	24.2	22 Oct ’28	0.0269
97	Eluru	16	42	81	7	93	23.5	22 Sep ’91	0.0516	129	Prathipadu	17	14	82	12	94	29.9	10 May ’90	0.0684
98	Tadepalligudem	16	50	81	31	93	27.2	23 Jul ’89	0.0408	130	Peddapuram	17	5	82	8	94	26.9	11 May ’90	0.0295
99	Tanuku	16	45	81	43	92	32.1	23 Jul ’89	0.0654	131	Yellavaram	17	26	82	2	76	32.7	26 Sep ’49	0.1044
100	Penugonda	16	39	81	45	80	32.5	23 Jul ’89	0.0415	132	Bhimunipatnam	17	53	83	26	93	52	17 Oct ’82	0.0385
101	Bhimavaram	16	32	81	33	93	33.4	31 Aug ’64	0.0558	133	Visakhapatnam Ap	17	43	83	14	97	29.3	20 Oct ’58	0.0316
102	Narsapur	16	26	81	42	93	28	16 Oct ’44	0.0549	134	Anakapalli	17	41	83	0	94	28.2	22 Oct ’28	0.0375
103	Manginapudi	16	14	81	11	88	29.8	29 Oct ’02	0.1239	135	Nizamabad Obsy	18	40	78	6	97	35.5	06 Oct ’83	0.0803
104	Musulipatnam Obsy	16	11	81	8	90	46.5	06 Nov ’68	0.0159	136	Karimnagar Rev	18	25	79	9	88	19.5	24 Jul ’89	0.0672
105	Kaikalur	16	33	81	12	91	24.1	19 Oct ’33	0.0890	137	Hanamkonda Obsy	18	1	79	34	97	22.8	13 Jul ’03	0.0832
106	Ramachandrapuram	16	50	82	2	88	36.9	27 Sep ’08	0.1001	138	Nuguru	18	20	80	33	72	44.2	29 Jul ’88	0.0434
107	Kakinada Obsy	16	57	82	14	97	50.1	02 Jun ’41	0.0828	139	Srikakulam	18	18	83	54	94	26.7	15 Nov ’01	0.0250
108	Coringa	16	48	82	14	83	39.8	30 Oct ’02	0.0788	140	Parvatipuram	18	47	83	26	91	27.4	25 Jun ’14	0.0406
109	Mummidivaram	16	39	82	7	91	36.9	02 Jun ’41	0.0577	141	Palakonda	18	36	83	45	93	27.9	18 Nov ’23	0.0497
110	Amalapuram	16	34	82	0	94	27.7	10 Sep ’50	0.0368	142	Bobbili	18	34	83	22	91	28.2	14 Oct ’31	0.0823
111	Biccavole	16	57	82	3	76	43.2	20 Oct ’58	0.0633	143	Salur	18	31	83	12	91	29.2	14 Oct ’31	0.0792
112	Sangareddi Rev	17	38	78	5	93	30.7	27 Sep ’08	0.0302	144	Gajapathinagaram	18	18	83	20	89	51.1	14 Oct ’31	0.0534
113	Begumpet Obsy	17	27	78	28	97	19.1	01 Aug ’54	0.0403	145	Chipurupally	18	18	83	34	90	35.4	14 Oct ’31	0.0351
114	Janwada	17	24	78	13	85	23.1	27 Sep ’08	0.0642	146	Vijayanagaram	18	7	83	25	90	40.3	24 Oct ’90	0.0963
115	Nalgonda	17	3	79	16	90	20.5	27 Aug ’49	0.0140	147	Srungavarapukota	18	7	83	8	90	26.3	11 May ’90	0.0689
116	Bhadrachalam	17	40	80	54	93	28.6	05 Oct ’83	0.0914	148	Konda	18	1	83	35	76	38.7	18 Nov ’23	0.0743
117	Chintalapudi	17	4	80	59	93	37	23 Jul ’89	0.1173	149	Sompeta	18	56	84	36	94	28.6	23 Sep ’72	0.0783
118	Tiruvur	17	7	80	37	94	37.8	23 Jul ’89	0.0457	150	Pundi	18	40	84	22	82	25.4	01 Nov ’43	0.0911
119	Rajahmundry	17	0	81	46	94	33.4	26 Sep ’08	0.0741	151	Tekkali	18	37	84	15	94	29	18 Nov ’23	0.0591
120	Rampachodavaram	17	27	81	47	86	25.8	19 Oct ’33	0.1211	152	Narasannapeta	18	25	84	3	93	36.3	08 Sep ’55	0.0421
121	Kovvur	17	1	81	44	93	24.8	23 Jul ’89	0.0570	153	Kalingapatnam Obsy	18	20	84	8	92	33.8	17 Oct ’82	0.0532
122	Polavaram	17	15	81	39	93	25.9	19 Oct ’33	0.0722	154	Asifabad Rev	19	22	79	18	87	24	12 Aug ’86	0.0329
123	Chidavaram	17	50	82	56	93	32.3	17 Oct ’04	0.0528	155	Itchapuram	19	7	84	42	93	35.1	19 Nov ’23	0.0518
124	Narsipatnam	17	40	82	37	93	44.3	23 Sep ’88	0.0300										

Maxima of daily Precipitation (AMP1), Annual Maxima of two - day Precipitation (AMP2) and Annual Maxima of three - day Precipitation (AMP3) are constructed for each of the 155 stations. Figs. 1-3 depict different statistics used in data analysis. Sample statistics including maximum, minimum of AMP, sample median, computed from the time series of AMP1, AMP2 and AMP3 are analyzed for variability. Highest ever recorded one day precipitation alongwith the corresponding date of occurrence for each of the 155 stations are also given in Table 2.

Maximum of 1-day annual maxima over the stations has a large variation from the lowest value of 14.1 cm over Kalyandurg to the highest value of 53 cm over Kalahasti. Similarly in the case of 2-day annual maxima, lowest value of 15.4 cm is over Kalyandurg and highest value of 81.28 cm is over Biccavole. In case of 3-day maxima, lowest value of 17.27 cm is also over Kalyandurg and highest value of 96.66 cm is over Sulurpet. Minimum of 1-day annual maxima over the stations varies from 0.8 cm over Hanamkonda to 6.1 cm over Vijayanagaram. The average value of 1-day extreme rainfall series is not highest over Kalahasti where 1-day annual maximum reaches 53 cm but over Nellore. The highest 1-day annual extreme value over Nellore is 52.3 cm.

The variability of extreme rainfall can also be measured from the standard deviation. Standard deviation

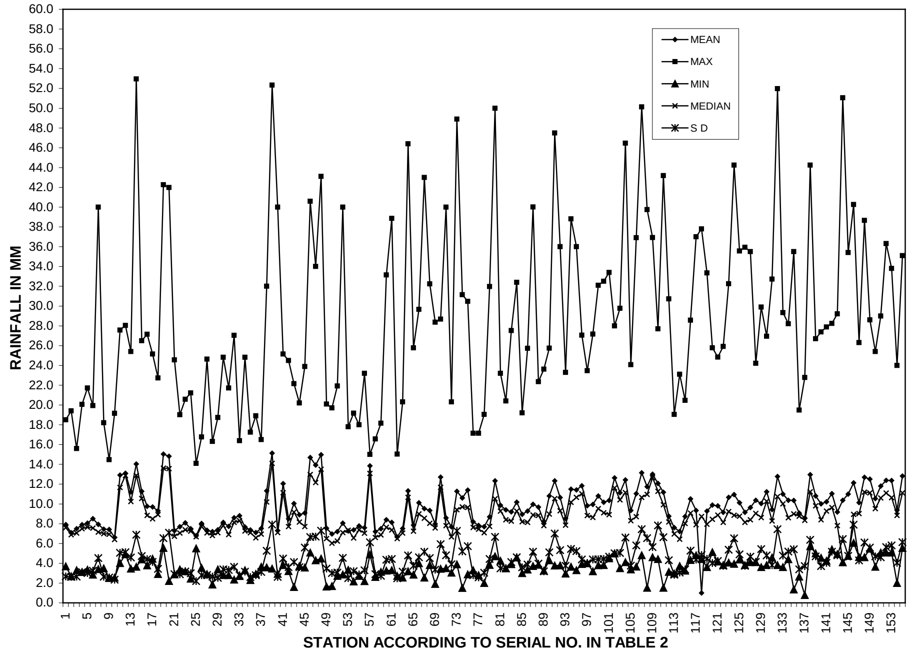

Fig. 1. Descriptive statistics of the 1-day extreme rainfall series (AMP1)

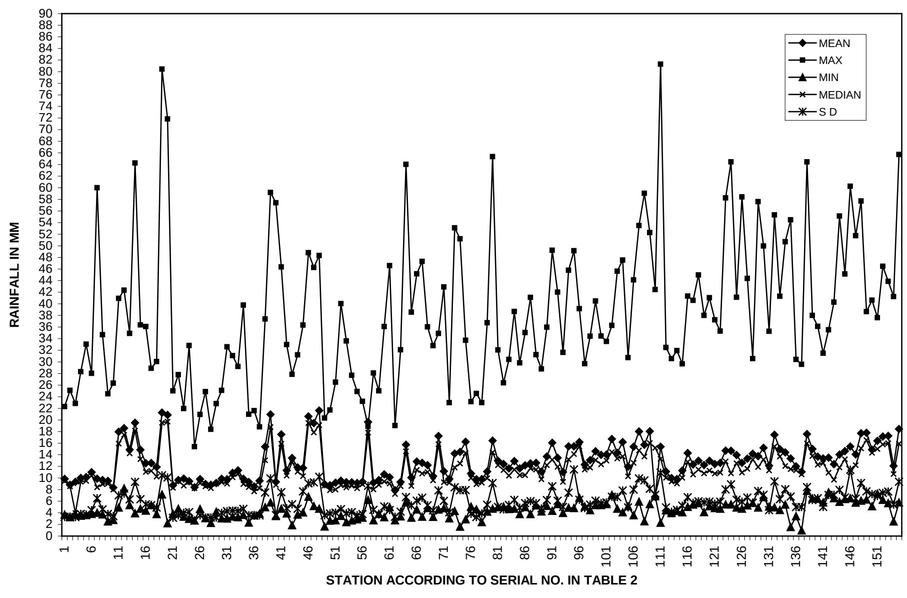

Fig. 2. Descriptive statistics of the 2-day extreme rainfall series (AMP2)

is high in one-day annual maximum precipitation series of Nellore where coefficient of variability is 52%. Lowest value of standard deviation in one-day extreme rainfall series is observed in Kalyandurg where coefficient of variability is only 32%. Therefore, variability of one-day extreme rainfall is high in areas of high value of extreme rainfall and *vice-versa*.

3.2. *Spatial analysis of extreme daily rainfall*

Extreme rainfall over Andhra Pradesh exceeds even 50 cm. From Fig. 1 and Table 2 it can be seen that there are 6 stations which are having maximum one day rainfall of over 50 cm. One - day, two - day and three - day highest rainfall values of 155 stations have been plotted

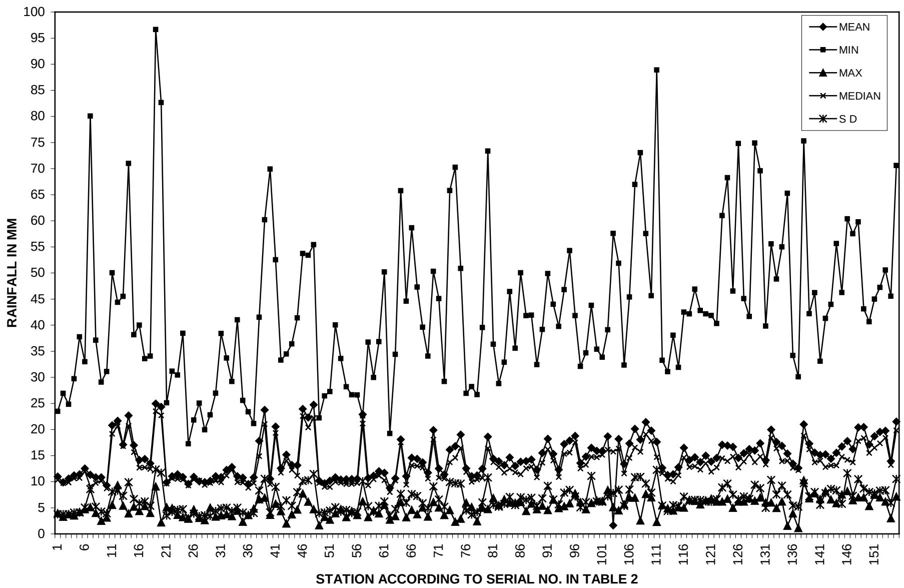

Fig. 3. Descriptive statistics of the 3-day extreme rainfall series (AMP3)

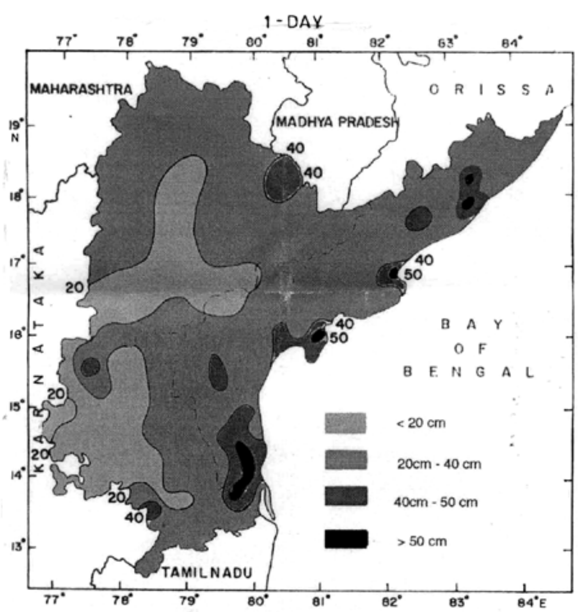

Fig. 4. Isohyetal analysis of one-day extreme rainfall of Andhra Pradesh

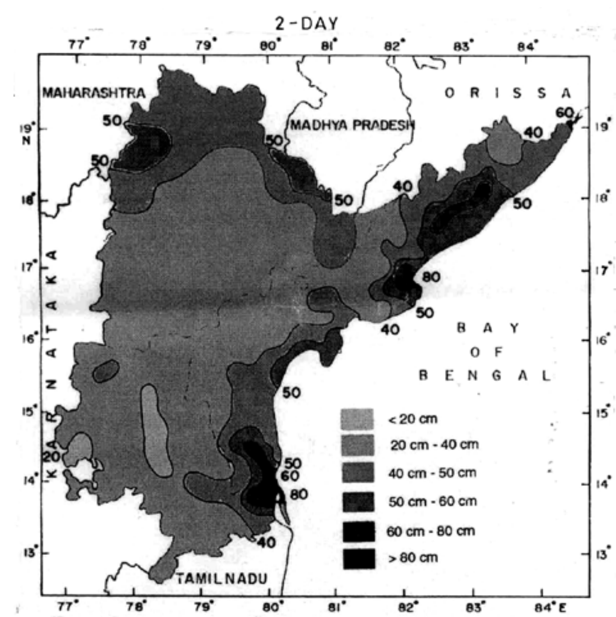

Fig. 5. Isohyetal analysis of two-day extreme rainfall of Andhra Pradesh

separately on three maps. Isohyetal analysis are then done on each of these maps. The resulting patterns are shown in Figs. 4 to 6. Mostly three zones of maxima are seen in Fig. 4 and all of these are along the coast.

First maximum zone which is in the region of north-eastern parts of Chittor district consists of values even higher than 50 cm. It may be mentioned that this region is frequently affected by the cyclonic storms which form

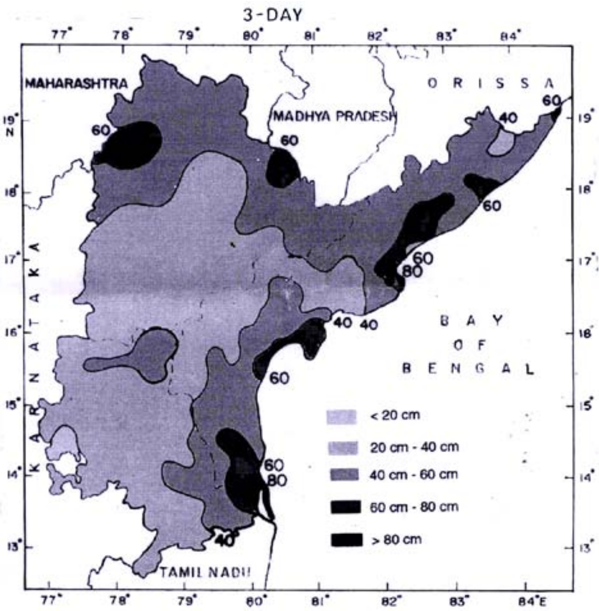

Fig. 6. Isohyetal analysis of three-day extreme rainfall of Andhra Pradesh

over the Bay of Bengal and move over this region in a north-westerly direction. The extreme value of 52.96 cm occurred on 17th October 1976. The low pressure area over south Bay concentrated in to a deep depression on the morning of 15th October, 1976 with its centre near 12° N and 83° E. It continued to move north-westward and lay 50 km to the north east of Chennai on 17th. Later it recurved north-eastwards and crossed Bangladesh coast on 21. Due to its influence, Nellore, Kalahasti, Sullerpet recorded exceptionally heavy rain on 17th.

The second highest value of 1-day annual maximum also occurs over the same area slightly north of the first maxima. It is 52.34 cm over Nellore on 3rd November, 1987. The synoptic situation for this is as follows:

A low pressure area was developed over southeast and adjacent southwest Bay of Bengal on 30th October, 1987. It intensified into a cyclonic storm by the evening of 31st October. Moving west ward, it further intensified into a severe cyclonic storm on 2nd November and lay centered at 0830 hrs of IST near Lat. 13.5° N and Long. 82.0° E. Moving west-north-westwards, the severe cyclonic storm crossed south Andhra coast just north of Nellore around 0530 hrs of IST of 3rd and weakened and lay at 0830 hrs of IST as cyclonic storm about 150 km west-north-west of Nellore.

Low values of highest 1-day rainfall are seen all over Telangana. Almost similar types of patterns can be seen in Fig. 5 and Fig. 6.

3.3. *Spatial distribution of highest rainfall events : Regional analysis*

Probabilistic extreme value theory, which primarily deals with the stochastic behaviour of the maximum and minimum random variables, extreme and intermediate order statistics and exceedance over (below) high (low) thresholds are determined by the underlying distribution. This section highlights the selection of a suitable extreme value distribution.

Mathematical forms of the most commonly used probability distributions frequently applied in the extreme value theory are given below :

(*i*) Extreme value type 1 (Gumbel or EV1)

$$f(x) = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right], \quad -\infty \le x < \infty, \; \alpha > 0$$

(*ii*) Extreme value type 2 (EV 2)

$$f(x) = \exp\left[-\left(\frac{u-e}{x-e}\right)^k\right], \quad k > 0, e \le x, 0 \le e < u$$

(*iii*) Extreme value type 3 (Weibull)

$$f(x) = \frac{b}{|a|}\left(\frac{x-m}{a}\right)^{b-1} \exp\left[-\left(\frac{x-m}{a}\right)^b\right], \quad m \le x, \; if\ a > 0; \quad x \ge m, \; if\ a < 0$$

(*iv*) General extreme value (GEV)

$$f(x) = \exp\left\{-\left[1-k\left(\frac{x-u}{\alpha}\right)\right]^{1/k}\right\}, \; \alpha > 0$$

$$u + \frac{\alpha}{k} \le x \le \infty, \; if\ k < 0$$

$$-\infty < x \le u + \frac{\alpha}{k}, if\ k > 0$$

(*v*) 2 Parameter Lognormal (LN 2)

$$f(x) = \frac{1}{\sqrt{2\pi}}\frac{1}{ax}\exp\left[-\frac{1}{2}\left(\frac{\log x - b}{a}\right)^2\right] \quad 0 < x$$

Regionalization of 1 - day, 2 - day and 3 - day extreme rainfall are tested with all of the five distributions for selecting the best distribution that can be used for regional estimates. Though the procedure of checking the goodness of fit of candidate distribution to extreme value

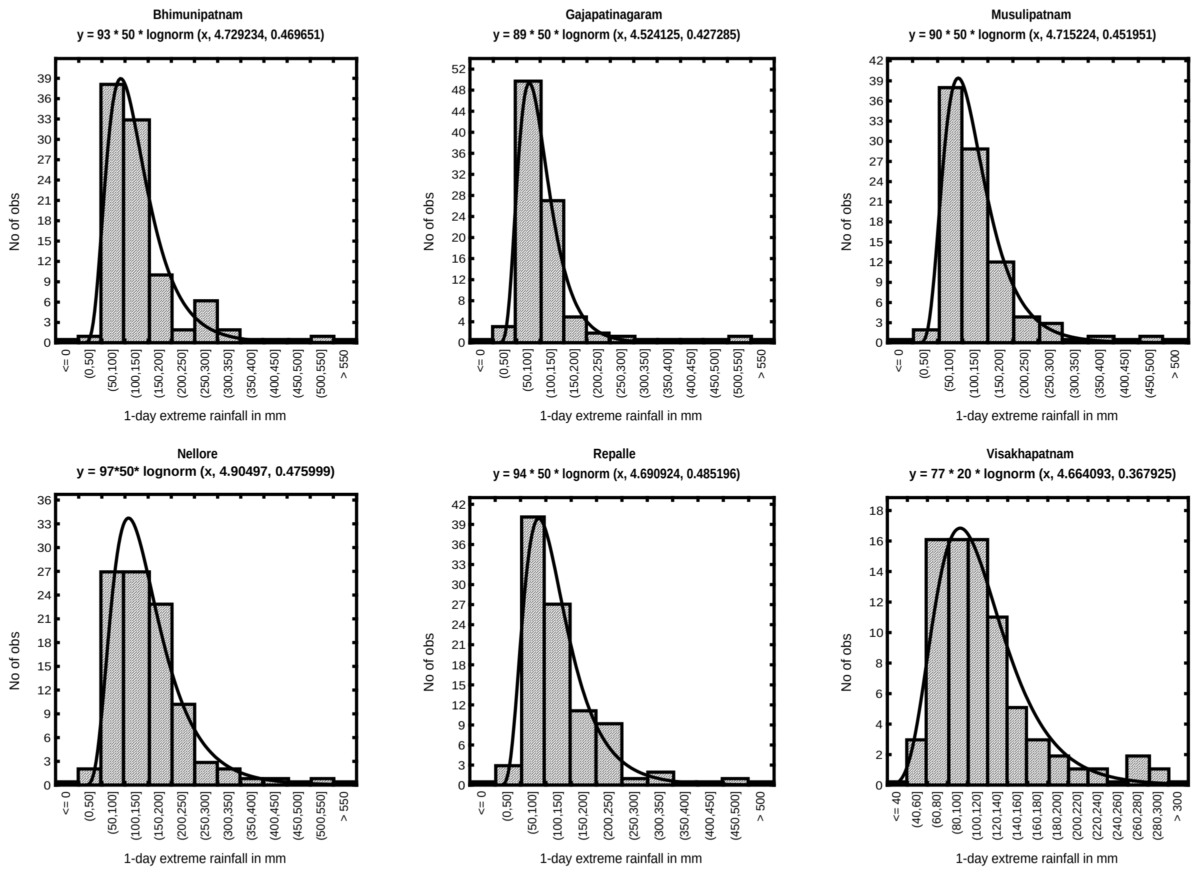

Fig. 7. Histogram and the fitted log normal distribution of one-day extreme rainfall series for the six coastal stations

series is the sole criteria, we have done the Kolmogorov - Smirnov goodness of fit test to examine the best fit. The EV 1 and LN 2 are widely used for extreme value analysis. However, LN 2 distribution can show a reasonable fit to a wider variety of observed data compare to the EV 1 distribution (WMO, 1989).

Table 2 also shows the Kolmogorov-Smirnov's goodness of fit statistic *D* computed from the time series of annual maxima of one-day precipitation fitted with Log normal distribution. The values are compared with the tabular values of *D* for the corresponding number of sample size and these show that the log normal distribution can not be rejected at 5% level of significance for each of stations. The log normal distribution is a best fit for the time series of annual maxima of one-day precipitation of Andhra Pradesh. Histogram and the fitted Log normal distribution curve for the one-day annual maximum series for six coastal stations *viz*., Bhimunipatnam, Gajapatinagaram, Musulipatnam, Nellore, Repalle and Visakhapatnam are shown in Fig. 7.

The quantile (or design value) corresponding to a return period of *T* years (abbreviatedly, *T* years return value) is defined by a magnitude $x(F)$, with $F = 1-1/T$. Return period analysis for indicating distribution of the maximum expected daily precipitation in regional modeling of extreme rainfalls has been done by Garcia-Ruitz *et al*. (2003). Isopluvial maps of the estimated design values corresponding to the return periods of 5, 10, 25 and 100 years for AMP have been produced. Fig. 8 shows the distribution of the 24 hour maximum precipitation corresponding to a return period of 100 years. The results obtained show a relatively close similarity between Fig. 4 & Fig. 8. The values are high along the coast and also in the north-east part of the state. The lowest values are seen in the south-west parts of the state.

4. Implications on climate change

According to the report of Intergovernmental Panel on Climate Change, extreme weather events are becoming

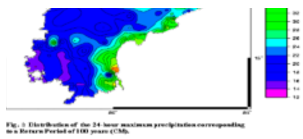

Fig. 8. Distribution of the 24 hour maximum precipitation corresponding to a return period of 100 years (CM)

more intense and causing more losses. We have studied the temporal and the spatial distribution of changes in extreme rainfall. Trend analyses are done for one-day extreme rainfall series of all the 155 stations.

Trends are estimated by fitting linear regression equation and the slope co-efficient is tested with *t*-statistic.

It is noticed that out of 155 stations only 13 stations reported significant changes (95%) in one-day extreme rainfall. Interestingly, most of these stations are situated in coastal Andhra Pradesh where average rainfall as well as one-day extreme rainfall is higher than the other regions. Three stations *viz.*, Coringa, Visakhapatnam and Chitvel show significant decreasing trend in one-day extreme rainfall. Coringa is in east Godavari district which is adjacent to Visakhapatnam district respectively while Chitvel is in Cuddapa district. It may be noticed that the second highest one-day extreme rainfall zone is over Visakhapatnam district (Fig. 4). Not a single station in Telangana sub-division, where one-day extreme rainfall is less than 40 cm (Fig. 4) shows any significant trend. This infers even the view of World Meteorological Organization (WMO) that there is a clear and alarming trend towards wilder weather conditions. The frequency and intensity of extreme weather events increases due to a change in the distribution of heat, which disrupts the flow of energy through the climate system, altering the circulation patterns of the atmosphere and oceans and also modifying the Earth's hydrological cycle. High temperature increases evaporation and transpiration and raises the air capacity to hold moisture, making more of it available to fall as rain. Thus it increases the occurrences of heavy rainfall incidences.

5. Conclusions

Extreme rainfall analyses are presented in two parts. We have selected 155 stations from the large network of more than 1700 stations using the criteria of more than 70 years of data availability. First part consists of basic statistics, foremost important in the data analysis are calculated and discussed. One-day extreme rainfall is high in along the coastal areas and low in the western and the southwestern regions. Also, the variability is high along the coastal areas and low in the western and southwestern regions. There are some stations where in a particular year highest daily rainfall was significantly less than even 1 cm.

Spatial analysis of extreme rainfall events have been carried out for regional estimates in the second part. Both methods of isohyetal analysis and modelling by a suitable probability distribution function approaches have been followed in this study. From the isohyetal analysis zones of high extreme values are explained. The results of this regional analysis of extreme rainfall events have significant potential implications concerning the extreme rainfall events change as a part of changing climate. The proposed statistical model for spatial differences in climate is consistent with satisfactory fit of two parameter lognormal distribution. Significant changes in extreme rainfall are noticed in the high rainfall receiving zones of coastal Andhra Pradesh. These support the views of Intergovernmental Panel on Climate Change, regarding global warming that extreme weather events have a significant increasing trends and these extreme events all go into calculating the monthly and annual averages.

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