TREND ANALYSIS OF RAINFALL IN KONKAN REGION OF MAHARASHTRA

A Thesis submitted to

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

of
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in
SOIL AND WATER CONSERVATION ENGINEERING

by
MISS. MANDALE VARSHA PRAKASH
B. Tech (Agril. Engg.)

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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APPENDIX-I

Table I.1 Standard Meteorological Weeks

Week No.	Month	Dates	Considered time period	
			Month	Date
22	,,	28- Jun.3	June	**1-7**
23	June	4-10	,,	**8-14**
24	,,	11-17	,,	**15-21**
25	,,	18-24	,,	**22-28**
26	,,	25- Jul.1	July	**29-05**
27	July	2-8	,,	**06-12**
28	,,	9-15	,,	**13-19**
29	,,	16-22	,,	**20-26**
30	,,	23-29		**27-02**
31	,,	30- Aug. 5	August	**03-09**
32	August	6-12	,,	**10-16**
33	,,	13-19	,,	**17-23**
34	,,	20-26	,,	**24-30**
35	,,	27- Sept. 2	September	**31-06**
36	September	3-9	,,	**07-13**
37	,,	10-16	,,	**14-20**
38	,,	17-23	,,	**21-27**
39	,,	24-30	’’	**28-04**
40	October	1-7	October	**05-11**
41	,,	8-14	,,	**12-18**
42	,,	15-21	,,	**19-25**
43	,,	22-28	,,	**26-31**

APPENDIX-II

Table. II.1 Annual and monthly rainfall of Jamsar

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1986	1725.2	422.4	711.1	541.7	24.6	0
1987	2045.8	224.2	800	823.8	103.8	94
1988	3104	185.4	2059.4	570.8	256.4	32
1989	2073.8	338.8	966.4	609	105.2	54.4
1990	2666	246.6	1014.8	930.8	368	105.8
1991	3012.6	573	1833.6	520.4	85.6	0
1992	2642.6	427.8	659.8	1117.4	429.8	7.8
1993	3116	409.2	1155.4	421.2	949.4	180.8
1994	5215.6	1031	1791.8	1567.2	785.6	40
1995	2097.6	37.8	1120.4	611	124.4	204
1996	2972.6	414.8	1586	798.8	88.2	84.8
1997	2395.22	186.1	1003.8	1127.5	74.22	3.6
1998	1838.3	95.8	671.5	411.6	560.2	99.2
1999	2135.7	632	848.5	165.9	375.2	114.1
2000	1754.9	199.6	763.7	547.8	182.9	60.9
2001	2189.6	524.8	638	772.5	114.8	139.5
2002	2622.4	1223	355.9	925.8	117.7	0
2003	2688	689.4	784.6	569.4	604.6	40
2004	2940.4	592.7	546.8	1686.6	112.1	2.2
2005	3620.7	944.6	794.1	878	893.6	110.4
2006	3910.7	447.8	1571.2	1661.6	182.6	47.5
2007	2950.7	503.1	955.6	1113.6	378.4	0
2008	3263	423.8	1047.6	1034.8	709.6	47.2
2009	1703.4	22.6	1260.2	232.4	106.8	81.4
2010	2563.4	247	1003.8	815.4	364.4	132.8
2011	2994	310.2	1098.2	1114.4	407.2	64

Table. II.2 Annual and monthly rainfall of Savarkhand

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1982	1975.2	220	651.4	812	265.8	26
1983	2685.4	328.8	842.4	948.4	443	122.8
1984	2601.6	495.8	1403.2	470.8	148.6	83.2
1985	2006.8	284.2	740.2	662.8	143.6	176
1986	1738.8	442	692.4	439	67.8	19.2
1987	1927.9	251.6	835.2	742.3	72.8	26
1988	3077	350.2	1665.6	554.6	504	2.6
1989	2081.5	235	776.7	659.8	365.6	44.4
1990	3040.6	79.4	476.8	864	1069.2	333.6
1991	2300.6	629.2	1066.2	516	79.2	10
1992	2550.1	395.8	467.6	1169.9	487.4	29.4
1993	2766	457	1151.2	424.8	580.8	152.2
1994	3270.8	574	1416	954.4	326.4	0
1995	1641	49.6	961.6	307.8	264.2	57.8
1996	2214.8	294.8	955.4	588.8	172.2	203.6
1997	2661.8	336.6	1146.6	887.4	291	0.2
1998	3007	322.2	789.4	578	1042.8	274.6
1999	2355.4	977.8	328.8	299.8	240.6	508.4
2000	2445.6	508.4	989.8	714.6	122.8	110
2001	2331.9	721.2	773.4	520.2	295.1	22
2002	2243	1082.4	243.6	830.6	86.4	0
2003	2801.8	630	1020.8	682.2	443.2	25.6
2004	2768.6	279.6	871.2	1428.4	188.2	1.2
2005	3473	778.6	976	684.2	952.8	81.4
2006	3371.6	531.6	1213.8	1094.4	442.6	89.2
2007	2633.7	434.4	530.7	1166.3	502.3	0
2008	3016.5	493.4	980	952.1	582.6	8.4
2009	1704.7	131.2	1063.2	111.5	231.8	167
2010	2682.2	269.8	1033.8	913.8	357.8	107
2011	3031.9	297.6	1093.2	1166.7	401.4	73

Table. II.3 Annual and monthly rainfall of Khapari

Year	Rainfall (mm)					
	Annual	**June**	**July**	**August**	**September**	**October**
1991	2439	-	-	-	-	-
1992	1807.4	280.8	387.6	726.2	325.0	87.8
1993	2809.4	607.6	766.8	609.4	463.7	64.8
1994	3146.6	574.4	1408.6	779.2	317.0	67.4
1995	1534.6	125.6	639.8	298.6	419.8	50.8
1996	2670	279.2	1022.6	730.6	402.6	235.0
1997	2518	343.4	975.8	920.2	235.4	43.2
1998	2036.6	228.4	567.5	461.2	622.6	157.0
1999	2363.9	490.6	825.3	244.7	708.1	95.3
2000	2887.1	392.6	710.5	518.6	192.4	73.1
2001	2310.4	429.0	719.3	722.8	258.4	180.9
2002	2374.1	845.0	352.9	811.4	362.5	2.3
2003	2512.3	607.6	766.8	609.4	463.7	64.8
2004	2565.3	255.7	609.3	1275.8	354.5	70.0
2005	3564.3	586.3	1278.9	894.6	717.7	86.9
2006	3073.7	479.4	1144.1	1232.0	533.6	164.0
2007	2440.1	426.6	700.2	892.9	420.4	0.0
2009	1824.6	103.5	837.9	310.4	412.2	160.6
2010	2447.43	368.0	733.7	698.2	425.8	221.7
2011	2233.6	477.6	659.6	716.6	280.4	99.4

Table. II.4 Annual and monthly rainfall of Karjat

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1989	1324.4	713.9	1120.6	880	379.6	64.8
1990	4708.9	655.3	1322.6	2181	344.4	186.6
1991	4574.1	929.2	1604	1824.9	184.6	17.2
1992	3140	243.9	696	1449.5	567.8	170.4
1993	3929.2	699.9	1536.9	613.4	732.3	288.2
1994	3995.7	854.9	1646.1	830.4	526.8	89.7
1995	2580.7	108.6	1125.9	632.5	551.5	128.2
1996	2555	395.7	1254.8	727.9	300.9	261.8
1997	3404.6	668.7	1202.6	1217.1	180.2	20.4
1998	2979.1	340.5	874.6	794.1	586	227.6
1999	-	-	-	-	-	-
2000	-	-	-	-	-	-
2001	-	-	-	-	-	-
2002	3136.8	904.8	905.1	1099.8	225.4	57.9
2003	3121.5	808.7	1031.6	723.8	554.4	3
2004	3186.3	308.2	912.8	1573.7	252.6	28.8
2005	3978.2	616.1	2238.7	1064.4	27.9	27.9
2006	3144.6	534.4	1002.9	1151.6	230.6	182.2
2007	2173.9	459.7	503.9	888.6	261.7	4.8
2008	3748	413.4	998.1	1443.5	707.6	130.1
2009	118.1	115.9	1084.7	1135.1	322.9	74.8
2010	-	-	-	-	-	-
2011	4141.6	691.5	1446	1134.9	869.2	83.952
2012	2323.3	352.6	1042.1	130.2	601.3	197.1
2013	4327.8	1141.5	1990.7	582.1	573.3	23.2
2014	3434.2	78.5	1643	958.1	571.4	120.1

Table. II.5 Annual and monthly rainfall of Chowk

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1980	2813.96	596.902	954.659	960.666	264.626	37.1119
1981	3118.5	478.3	1072.1	809.1	629.3	129.7
1982	2840.3	488.6	865	1108.1	322.1	56.5
1983	3494.5	388.2	1072.2	1640.3	288.3	105.5
1984	2773.8	501.9	1535.2	407.8	269.8	59.1
1985	2624.4	322.9	1013.9	712.5	428.3	146.8
1986	1814.17	404.9	547.4	757.3	104.4	0.17115
1987	2371.3	281.5	886.1	957.1	144	102.6
1988	3806.7	447.4	1810	739.8	675.9	133.6
1989	2541.1	459	550.9	1021.2	374	136
1990	4774.7	726.1	1095.6	2223.6	403.8	254.1
1991	3333	720.8	1660.6	843.4	82.7	25.5
1992	3227.66	250.1	779.96	1425.2	639.2	133.2
1993	3934.4	572.2	1578.2	701.3	764.4	318.3
1994	2198	410.9	665	604.2	450.9	67
1995	2713.1	206.5	1462.5	404	492.1	148
1996	2839.7	170.7	1401	729.5	310	228.5
1997	3123.6	779	1115.5	941.5	263	24.6
1998	3153.1	503.4	856.5	928.3	592.9	272
1999	3520.1	889.5	1342.6	371.3	624.9	243.8
2000	3640.6	703	1498.5	958.5	186.4	105
2001	2897.6	760.5	911	846.3	257.9	101.5
2002	2742.5	757.9	446.5	1266	272.1	0
2003	3093.2	796.7	1049.4	729.2	498.4	19.5
2004	3250.2	356.3	1038	1514.6	310.2	31.1
2005	4725	642.8	1829.8	1101.8	1122.6	28
2006	4237.2	678.4	1547.2	1528.4	293.8	189.4
2007	3493.1	723.6	983.6	1299.2	486.7	0
2008	2357.8	70.8	1384.5	194.7	414.5	293.3
2009	3613.1	640.2	1445	967.8	436	124.1
2010	4049.4	566.6	1606.6	1137.2	463.8	275.2

Table. II.6 Annual and monthly rainfall of Varandoli

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1981	4165.5	819	1457.9	1096.8	683.9	107.9
1982	3317.2	566.5	1311.1	996.2	339.1	104.3
1983	4757.2	713.6	1249.1	1659	962.1	173.4
1984	4258	1068.8	1891	748.8	330.2	167.6
1985	3934.6	972.8	1591.6	934	281.4	116.8
1986	3407.4	1250.4	825.4	1200.2	121.8	0
1987	3083.4	560.4	872.4	908	312.8	269.8
1988	4266.4	562	2044.8	785.4	840.2	34
1989	3623.2	947.8	1333.2	959.4	336.4	46.4
1990	5369.7	1135.8	1542	1731.8	397.5	307.8
1991	3963.4	929.2	1988.8	908.8	114	22.6
1992	3363.4	301.4	957	1660	417.8	27.2
1993	4292.25	676.45	1674.8	969.2	740	196.8
1994	5075.9	1296.3	1989.6	1048.2	600.8	113.2
1995	2728.6	264.8	1360.2	479.6	448.6	171.2
1996	2775.41	264.8	1360.2	479.6	448.6	171.2
1997	4097.7	997.9	1376.4	1321.6	241.4	59
1998	4328.5	977.7	1221.8	1110.7	607.4	389.2
1999	3711.1	1008.6	1574.7	470.8	386.5	234.8
2000	3559.7	889.6	1216	1081.8	206.3	79.8
2001	2854.7	410.7	1203.3	798	298.7	100.6
2002	2956.2	712.7	782.6	1156.6	282.3	22
2003	3401.6	1072.6	1121.2	909	255.8	43
2004	3887.8	696	1065.2	1711.6	365	50
2005	4696.2	967.4	1560.6	1355.2	754.4	58.6
2006	4101.5	553.2	2073.6	1210.3	206.5	57.9
2007	4292.2	1505.8	1191	1037.6	557.8	0
2008	3862.5	1010.2	819.2	1273.4	712.4	47.3
2009	2627	179.4	1522.4	399.2	320.3	205.7
2010	3623.5	295.9	1450.2	955.7	739.4	182.3
2011	4156.8	803.2	1620.6	1112.7	561.8	58.5

Table. II.7 Annual and monthly rainfall of Dapoli

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1981	4982.4	186.6	2172.6	1736.4	498.2	241.6
1982	2749	483.4	1020.0	746.5	314.1	73.7
1983	4469.7	1177.2	1359.0	1171.4	675.2	86.9
1984	3018	755.2	1570.2	424.6	201.4	65.0
1985	4974.2	2025.3	1459.7	1080.3	99.8	196.8
1986	2421.7	1093.5	419.0	847.7	43.2	0.5
1987	2427.7	1089.5	584.7	386.6	71.3	266.2
1988	3445.5	511.2	1348.4	775.8	794.1	14.8
1989	3199.4	646.2	1448.6	740.8	246.6	106.4
1990	5290.8	997.0	900.0	2051.0	649.4	472.8
1991	3772.5	965.2	1989.6	736.8	73.9	1.4
1992	2992.7	290.2	1120.9	1240.5	250.0	88.9
1993	3848	789.3	1285.4	848.6	788.1	131.8
1994	2918.5	675.2	983.2	555.5	612.6	79.0
1995	3140.1	361.3	1116.1	665.6	753.2	204.0
1996	3112.5	404.1	1496.6	668.9	364.4	174.5
1997	3843.1	995.3	1455.2	853.6	405.5	10.4
1998	3829.6	714.6	1388.1	1013.4	395.5	274.6
1999	4226.2	1695.1	1298.8	454.6	441.4	169.9
2000	4619.05	1218.3	1684.8	1301.9	102.4	109.0
2001	2403.4	410.0	876.5	741.4	233.8	61.6
2002	2739.5	980.8	568.1	799.8	278.8	85.0
2003	3004.8	822.6	1320.3	578.7	273.8	9.2
2004	3535.6	1093.4	1050.2	953.1	307.2	35.8
2005	3654.2	672.3	1333.0	817.6	717.9	110.0
2006	3558.8	686.2	1248.6	841.8	444.2	140.4
2007	4261.97	1273.5	971.1	1067.6	919.4	11.8
2008	3011.4	861.6	744.4	781.1	591.6	10.1
2009	2697.3	259.6	1190.5	439.4	511.0	166.0
2010	4721.1	1161.4	1750.0	688.0	905.2	126.8
2011	4932.2	918.4	2034.2	1336.1	524.5	115.6
2012	3654	933.8	1035.3	908.7	520.6	255.6
2013	4748	1713.2	1763.7	609.4	282.6	365.4
2014	3370.2	347.6	1665.7	871.6	463.9	13.4

Table. II.8 Annual and monthly rainfall of Karambawane

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1991	3671.4	1081.5	1793.2	685.6	99.4	11.7
1992	2957.7	304.2	879.8	1431.5	224.6	117.6
1993	4546.5	909	1767.2	905.6	624	314
1994	3498.6	851.4	1428.2	544.4	375.8	199
1995	2956.81	420.4	1712.8	794.2	707.4	279.2
1996	2864.6	168.8	1604	628	285.2	178.6
1997	3671.1	829.8	1319.7	1243	201.2	77.4
1998	4620	963	989	1156.2	689	822.8
1999	3860.3	1222.5	1389	420.3	383.5	445
2000	4034.5	502.5	1498.6	1371	343.2	319.2
2001	3038.6	634.8	1147.6	887.4	261.6	107.2
2002	2730.8	826	761.4	799.2	290	54.2
2003	3686.8	952.4	1378.8	855	331.8	168.8
2004	3630.6	991.2	943.8	1064.4	602.8	28.4
2005	4786.5	910	2044.2	883.4	831	117.9
2006	5366.8	1434.2	1812.2	1136.8	715.6	268
2007	4822.2	1781.6	999.4	1245	796.2	0
2008	3717.6	1178.8	765.8	972.2	661	139.8
2009	3230.4	284.4	1669.6	498.6	517.8	260
2010	4563.4	581.2	2097.6	770.6	754.6	359.4
2011	5488.8	991	1592.4	1668.4	928.6	308.4

Table. II.9 Annual and monthly rainfall of Mulde

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1991	2976.7	606.4	1361.8	717.5	109.6	116.3
1992	3072.1	945.2	846.5	963.1	183.5	119.6
1993	3444.15	636.0	1386.3	603.4	389.4	403
1994	3308	1149.9	962.7	661.8	204.9	315
1995	3751.8	1044.0	1341.8	862.2	265.2	186.4
1996	2935.2	833.6	1109.8	499.5	193.6	245.3
1997	3650.7	1063.4	1296.3	1000.2	54.5	58
1998	3374.3	913.5	973.0	586.3	549.8	263.4
1999	3484.6	1353.8	1256.2	233.7	206.2	213.4
2000	3286.4	836.8	1241.0	673.9	145.5	121.5
2001	2693.8	547.7	989.7	685.4	136.5	164.5
2002	2599.7	825.9	555.0	661.9	228.2	252
2003	2750.4	912.2	912.9	600.8	247.7	76.8
2004	2996.1	1046.9	890.8	682.4	170.4	82.4
2005	3559.11	764.6	1359.4	709.7	501.4	144.4
2006	3433.8	823.5	850.3	557.5	474.9	256.4
2007	3889.5	1050.3	852.2	926.2	733.1	121.6
2008	3308.6	890.0	614.6	971.8	677.2	40.4
2009	3672.6	468.2	1515.2	400.5	456.6	604.8
2010	4240.9	846.5	1580.8	701.2	535.3	312.1
2011	4314.2	1088.6	1430.6	990.7	546.1	193.6
2012	3403.9	830.4	1043.4	874.9	409.3	241.9
2013	2889.7	381.8	1295.6	603.1	351.6	123.3
2014	2887.7	381.8	1295.6	603.1	366.1	177.8

Table. II.10 Annual and monthly rainfall of Vengurla

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1981	3452.3	1401.2	955.1	849.1	219.3	16.6
1982	3839.1	851.3	1059	1599.3	203.4	30.8
1983	2506	-	-	-	-	-
1984	2508	816	977	410	170	133
1985	3921	1685	1039	665	95	387
1986	2025	807	555	527	32	19
1987	2782	1062	671	569	113	292
1988	2997	651	1145	655	497	49
1989	2442	874	742	469	267	73
1990	1224	387	274	343	200	42
1991	2626	659	1374	478	45	42
1992	2647	871	841	625	171	63
1993	2889.1	511.6	1275.8	503.1	396.2	109.4
1994	2452.8	818	762.4	416.6	198.4	204.4
1995	3426.6	687	1451.8	781.4	312.6	176.8
1996	2747.7	823.1	1047.2	389.2	101	382.6
1997	3069.2	981.4	987.6	866.6	51.8	27.4
1998	3138	1013.2	908	518.4	294.6	291.4
1999	3244	1513.2	1059.8	227.4	118.4	57.8
2000	3601.4	921.6	1375.6	653.4	196	126
2001	2149.4	486.2	906	373	106	118
2002	2249.2	776.2	479	572	139	138
2003	2597.9	903.9	1006.8	433.8	195	50
2004	2580.03	922	768.8	504.8	143.63	57
2005	2883.8	745.4	1051.6	339.8	579.4	93.6
2006	2743.7	465.2	548	405.3	486.2	357.8
2007	3596.65	940.83	722.62	1010.2	731.4	102
2008	2586.6	634.2	748	691.6	399.4	23
2009	3788.88	762.8	1580.78	254.2	320.6	685
2010	4261	1148	1463.8	778.8	483	189.2
2011	3604.2	1145.8	998	801	569.6	65.8

Table. II.11 Annual and monthly rainfall of Amboli

Year	Rainfall (mm)					
	Annual	June	July	August	September	October
1981	7829.8	1716	2384	2449	1127.8	25
1982	7285.8	1115.4	2883	2391.2	333.2	308.6
1983	6560.8	1504	1891.2	2131.4	826	181.2
1984	6230.6	1473	2691.6	1602	227	237
1985	7152	1473	2691.6	1602	227	237
1986	5413.5	2464	1996	1958	281	383
1987	4873.4	1743.2	1406.1	1748.8	270.2	55.8
1988	6865	1074.8	1629.2	1352.6	355.6	241.8
1989	6252.2	891.6	2668.4	2025.8	1021	222.2
1990	7744.4	1740	2400.4	1521.6	409.4	121.4
1991	5570.6	1678	2327	2616.6	751	152
1992	8504	454	2902.6	1794	240	93
1993	7962.9	560.6	1806.4	4619	563	445
1994	8166.1	856	2752	2519	1675.9	28
1995	7686.3	1649	3181	2277.3	683.4	265
1996	7387.9	828	3470	1751	1165	434
1997	7029.1	1365.1	2761.8	1601	1126	534
1998	7711.2	1640.5	2418	2474	343	153.6
1999	8139.54	1347	2131.2	2333	1199	701
2000	6777.1	2183.8	3746	1209.74	700	300
2001	6020	1726.5	2109.6	2271	457	213
2002	5947.5	1162	2275.2	1960.8	362	260
2003	5492.4	1563	1720	2036	428	200.5
2004	6933.3	1385	1834.4	1551	634	88
2005	8405	2045	1882	2328	289.2	231
2006	7747.6	1724	2469	2086	1752	374
2007	7739.2	1562	2776	1918.4	1183	308.2
2008	5930.9	1577.2	2165.4	2333.6	1663	0
2009	6360.2	341.7	3839	728.2	651.8	370.2
2010	7701.5	995.2	2552.6	1687.6	763.4	361.4
2011		1753.5	2315.8	2164.2	1232.2	235.8

I. INTRODUCTION

In India, precipitation is mainly in the form of rainfall. The rainfall received is an important factor for determining the availability of water for agriculture and other usages. It is one of the key climatic variables that affect, both the spatial and temporal patterns of water availability. One of the challenges posed by climate variability is ascertainment, identification and quantification of trends in rainfall and their implications on river flows. This trend analysis helps in water resource management through appropriate measures and formulation of adaptation measures through appropriate strategies. Rainfall trend analysis, on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change from the scientific community. (IPCC, 1996).

Global climate changes may influence long-term rainfall patterns, impacting the availability of water, along with the danger of increasing occurrences of droughts and floods. In India problem is more severe than other countries due to uneven distribution of resources. About 16.5 per cent of world population is living in India on 2.5 per cent of world's total land having only 4 per cent water resources. Demand and supply gap of water is increasing continuously and per capita availability of water is also decreasing (Anonymous, 2012). Changes in climate over the Indian peninsular region, particularly due to South West monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country. The heavy concentration of rainfall in the monsoon months (June–September) results in scarcity of water during the non-monsoon periods in many parts of the country. Freshwater availability in many river basins in India is likely to decrease due to climate change (Gosain *et al*., 2006). This decrease in availability of water along with population growth and rising living standards, could adversely affect many people in India by the 2050s (IPCC, 2007).

Maharashtra state is one of the important states from the point view of climate change impact. The geographical area of Maharashtra state is 30.7 Mha of which, 22.5 Mha is cultivable. Out of this, 40 per cent is drought prone and 7 per cent is flood prone. A highly variable rainfall ranging from 400 to 4500 mm occurs from 40 to 100 rainy days in the State. Annual availability of water resources consists of 16.4 Mha-m surface water and 2.05 Mha-m as subsurface water. Average annual water availability in four major river basins *i.e.* Krishna, Godavari, Tapi and Narmada having 58 per cent of State's available water resource, comprises 92 per cent of the cultivable land and 75 per cent of the people (Anonymous, 2013).

Konkan region is a coastal belt of Maharashtra state. It has 42 per cent of State's available water resources, only on 10 per cent geographical area having 8 per cent of cultivable area and supports 25 per cent population of the State (Anonymous, 2013). The Konkan region receives rainfall from 2500 to 4500 mm annually during monsoon i.e. (June to September). Still, region faces water scarcity for drinking purpose in the month of April and May.

Rice is a major *kharif* crop and depends on weather condition of the region. In the coastal belt of Konkan region, mono-cropping is followed with rice cultivation on 4.07 lakh ha *i.e.* about 83 per cent of cultivated area, during *kharif* season, due to heavy rainfall (Anonymous, 2013). Production and productivity of rice crop globally, as well as, in Konkan is adversely affected due to variation in the climatic parameters (Ogbuene, 2010, Gopakumar, 2011, Emmanuel and Fanan, 2012). Other than rice Mango, cashew and coconut are the major perennial horticulture crops cultivated in the region (Anonymous, 2013), which provide employment opportunity, food and source of income to the individuals. In last few years, production, productivity and quality of mango, especially Alphanso variety, is adversely affected due to agro-climatic changes (Datta, 2013). Due to climate variability in the region, the production of mango has dropped drastically in the last few years, from 3.20 lakh MT during 2010 to 2.56 lakh MT in 2011 and 1.23 lakh MT in 2012 from total 1.80 lakh ha area under mango cultivation (Anonymous, 2013). Konkan region has 1.75 lakh ha area under cashew, which is about 30.8 per cent of total area under cashew in India. It is expected that production and productivity of cashew, in long run, will suffer seriously from growing air pollution (Gadgil, 2010). Coconut occupies 1.1 per cent area in the region out of India's total area under coconut crop (Anonymous, 2013). In the Western Ghats region, the yield of coconut, a perennial plantation crop, is projected to increase by up to 30 per cent in the region due to climate change. The increase in coconut yield is mainly attributed to projected increase in rainfall and relatively less increase in temperature (Naresh *et al*., 2011).

Variation in the monsoon rainfall has both social and economic impact, as in India, agriculture largely depends on rainfall. So study of trend in rainfall pattern is essential for better planning and adaptation for extreme events. The observed data that exhibit high seasonality, methods to analyze trends should be those that incorporate the seasonal component. Spatial differences in trends can occur as a result of spatial differences in the changes in rainfall and temperature and spatial differences in the catchment characteristics that translate meteorological inputs into hydrological response (Burn and Elnur, 2002). Trend may be loosely defined as "long-term change in the mean level", but there is no fully satisfactory mathematical definition. However, trend analysis helps in 'forecasting'. The base of scientific forecasting is statistics. Trend analysis was carried out to examine the long term trends in rainfall over different subdivisions. The rainfall trend is very crucial for the economic development and hydrological planning for the country. Trend is present when a time series exhibits steady upward growth or a downward decline, at least over successive time periods.

The more accurate information about meteorological parameters and their trends are also needed for the formulation of weather model, which will help to improve sustainability of water resource management planning. Agricultural production is not insulated from the vagaries of weather, despite many years of advance and improved micro level planning in the country. Climate and weather conditions influence the human activities and environmental resources sustainability, (Bhalme, 1997 and Ogbuene, 2007). Crop yields and environmental resource sustainability in India is adversely affected due to climate change and highly depend on climatic condition of the area (IPCC, 2013). The future rainfall trend will have its impact globally and will be felt severely in developing countries with agrarian economies, such as India.

So the trend analysis of rainfall will be useful to construct the future scenario of water availability. The trend analysis of the weekly, monthly and annual rainfall data of the Konkan region is an attempt to study the rainfall variations of the selected stations, which will be useful for forecasting the future temporal and spatial availability of water. Therefore, the present study was under taken with the following objectives;

1. Analysis of variations in weekly, monthly and annual rainfall data.

2. Detection of the trend in the weekly, monthly and annual rainfall data.

3. Analysis of the rainfall trend using different methods.

II. REVIEW OF LITERATURE

The previous studies on the topics of trend analysis of climatic parameters i.e. temperature, relative humidity, sunshine hours, wind velocity, rainfall, pan evaporation and computed reference evapo-transpiration, by various statistical methods.The impact of climate change on rainfall, statistical method to identify influence of climatic parameter on rainfallliterature wasreferred and reviewed under succeeding sections.

Panse and Sukhatme (1954) had given the methodology for testing the significance of test statistic at different probability levels and testing the significanceof the results obtained from experimentsor observational programmes in agricultural research.

Parthasarathy and Dhar (1975) conducted trend analysis of annual rainfall of India. They processed the annual rainfall of 60 year period from 1901 to 1960 which was collected from 3000 rain gauges distributed uniformly throughout the country. They analyzed the rainfall data by using statistical methods such as Mann-Kendall rank statistics, Student’s t-test and low-pass filter. They found that the mean values of the annual rainfalls for the 30 years period from 1931 to 1960 showed a significant increase of about 5 per cent.

Kottegoda (1980) had given the turning point test for detection of presence of trend or randomness in the given data series. If the data series was thought to trend component, the Kendall’s rank correlation test was suggested to check its significance. The methodology for both the testes is explained in detail under the heading materials and methods.

Helsel and Hirsch (2002) developed a statistical procedure for trend analysis builton regression and hypothesis testing. The explanatory variable of interest was time, though spatial or directional trends were investigated. Detection of both sudden and gradual trends over time with and without adjustment for the effects of confounding variables had been employed. Various tests were classified, and their strengths and weaknesses compared. Mann-Kendall test and Sen’s Slope estimator test were the more reliable methods for estimation of nature of the trend and magnitude of the trend of meteorological parameters.

Bihrat and Mehmetcik (2003) detected the existence of a trend in a hydrological time series by statistical tests. The power of the parametric t-test for trend detection was estimated by Monte Carlo simulation for various probability distributions and compared with the power of the non-parametric Mann-Kendall test. Annual stream flow records in various regions of Turkey were analyzed by the two tests to compare their powers in detecting a trend.Results indicated that t-test had less power than the non-parametric Mann-Kendall test when the probability distribution was skewed.

Goswami (2006) studied increasing trend of extreme rain events over India in a warming environment. He reported significant rising trends in frequency and magnitude of extreme rain events over India during the monsoon seasons from 1951 to 2000. However, there was significant decreasing trend in the frequency of moderate rainfall events as a result the seasonal mean rainfall did not show any significant trend.

Modarres *et al*., (2007) studied rainfall trends in arid and semi-arid regions of Iran. They investigated by analyzing the data for annual and monthly rainfall and number of rainy days per year collected for 20 stations. The result showed that all the analyzed time series were homogenous at $P<0.05$ according to the Thom test. Mann Kendall test was applied to annual rainfall time series at $P<0.05$ or $P>0.01$. These trends were statistically significant for monthly time series and during the winter and spring season.

Guhathakurta and Rajeevan(2008) studied the monthly, seasonal and annual rainfall trends for a period of 1901 to 2003 all over the India. They carried out the trend analysis for monthly rainfall series of June, July, August and September for the season as a whole for all the 36 meteorological subdivisions of India. They observed that June rainfall had increasing trend for western and southwestern parts of country, where as decreasing trends were observed for the central and eastern parts of the country. Result suggested that June and August rainfall exhibited significant increasing trends, while contribution of July rainfall exhibited decreasing trends. They concluded that,though the Indian monsoon rainfall as a whole did not show any significant trend, significant rainfall trends in the annual rainfall wereobserved over some specific areas for the subdivisions namely Konkan and Goa, Madhya Maharashtra, North Interior Karnataka, Rayalseema, Coastal Andhra Pradesh, Gangetic West Bengal,Assam and Meghalaya and Jammu and Kashmir.

Krishnakumar *et al.,* (2008) studied the monthly, seasonal and annual rainfall trends in twentieth century over Kerala, India during the period 1871 to 2005. They collected monthly rainfall data from the daily weather reports published by the IMD, Trivandrum. They checked the temporal changes in rainfall data by using Mann-Kendall rank statistics and linear trend. Rainfall during winter and summer seasons showed insignificant increasing trend.

Patra (2008) studied rainfall trends in twentieth century (1871–2006) over Orissa State, India. He classified the temporal variation in monthly, seasonal and annual rainfall over the state during the period 1871 to 2006. Long term changes in rainfall characteristics were determined by both parametric and non-parametric tests. The analysis revealed a long term insignificant decline trend of annual, as well as, monsoon rainfall, whereas increasing trend in post-monsoon season over the state of Orissa. Rainfall during winter and summer seasons showed an increasing trend. Statistically, monsoon rainfall could be considered as very dependable, as the coefficient of variation was 14.2 per cent. However, there was decreasing monthly rainfall trend in June, July and September, whereas increasing trend in August. This trend was more predominant in last 10 years.

Longobardi and Villani (2009) made trend analysis of annual and seasonal rainfall in the Mediterranean area. They selected 211 gauged stations, mainly located within the Campania region, southern Italy and analyzed the data for the period 1918–1999. An accurate database had been set up through a data quality and time series homogeneity process. Direct and indirect methods were combined in their study to test for annual rainfall data homogeneity. Potential changing points were identified through Metadata Inspection, t –test and a modified Ward's method test. Statistical analysis of the database highlighted that the trend appeared predominantly negative, both at the annual and seasonal scale, except for the summer period, when it appeared to be positive over the whole reference period, positive and negative trends were significant respectively, for 9per cent and 27per cent of the total stations and over the last 30 years, a negative trend was instead significant for 97per cent of the total stations.

Karpouzos *et al*., (2010) conducted trend analysis of precipitation data in Pieria Region of Greece. They detected possible precipitation changes in annual, monthly and seasonal basis by using monotonic trend tests, such as Mann-Kendall test, sequential version of Mann-Kendall test, Sen's estimator of slope and a step change test of distribution free CUSUM test. They analyzed the precipitation data for the period 1974-2007. The result of M-K test for the regional analysis showed a downward trend in annual, autumn, winter and spring. Mann-Kendall tests results were also checked with Spearman's rank test in order to enhance the reliability of trend identification outputs.

Tabari and Marofi (2010) studied changes of pan evaporation in the West of Iran. The main purpose of this study was to investigate temporal variations in pan evaporation and the associated changes in maximum, mean and minimum air temperatures and precipitation for 12 stations in Hamedan province in western Iran for the period 1982–2003. Significant trends were identified using the Mann–Kendall test, the Sen's slope estimator and the linear regression. Analysis of the Epan data revealed a significant increasing trend in 67per cent of the stations at 95per cent and 99per centconfidence levels. To put the changes in perspective, the trend in Epan averaged over all the 12 stations was (+) 160 mm per decade. Trend analysis of the meteorological variables for Epan changes showed warming trends in Tmax, Tmean and Tmin series in almost all the stations, which were significant over half of the total stations.

Singh *et al*., (2010) studied trend in temporal variation of rainfall over India. Monthly, seasonal and annual trends of rainfall had been studied using monthly data series of 135 years (1871–2005) for 30 sub-divisions (sub-regions) in India. Half of the sub-divisions showed an increasing trend in annual rainfall. During June and July, the number of sub-divisions showed increasing rainfall. In August, the number of sub-divisions was showing an increasing trend, whereas in September, the situation was opposite. A majority of the sub-divisions showed very little change in rainfall in non-monsoon months. The five main regions of India showed no significant trend in annual, seasonal and monthly rainfall. Annual and monsoon rainfall had decreased, while pre-monsoon, post-monsoon and winter rainfall had increased at the national scale. Rainfall in June, July and September had decreased, whereas in August it had increased, at the national scale.

Thakur (2010) examined daily data of rainfall, maximum and minimum ambient temperature, relative humidity, sunshine hours and evaporation at Dapoli and Wakawali stations for predicting impact of climate change. Results revealed the linearly rising trend in daily data of rainfall, maximum and minimum ambient temperature, relative humidity, sunshine hours and evaporation at Dapoli and Wakawali stations for predicting impact of climate change. The linearly rising trend in maximum and minimum temperature was found for both the stations. Relative humidity was found to have increasing trend at Dapoli and decreasing trend at Wakawali station. Rainfall, bright sunshine hours and wind velocity showed decreasing trend and evaporation had increasing trend for both the stations.

Drapela and Drapelova (2011) studied application of Mann-Kendall test and the Sen's slope estimates for trend detection in deposition data from BilyKriz (Beskydy Mts., the Czech Republic). Data from precipitation monitoring station located at BilyKriz in Beskydy Mts. were analyzed in order to find out whether and how the decrease of emissions in the Czech Republic and neighbouring countries was reflected in the composition precipitation. Statistically significant decrease of mean annual concentrations of Zn, Pb, Cd, Ni, Fe in bulk precipitation and of H^+, K^+, Mg^{2+}, Ca_2^+, NO_3^-, SO_4^{2-}andCl$^-$ in precipitation were found by applying Mann-Kendall test. No trend was found for Na^+, Mn, and F^- and for total wet deposition of potential acid.

Jain and Kumar (2012) carried out the trend analysis of rainfall and temperature data for India. They conducted Regression analysis with time as the independent variable and rainfall/temperature as the dependent variables. They observed that six river basins had shown increasing trend in annual rainfall in the 0.27–10.16 mm/yr range, whereas 15 river basins had shown decreasing annual rainfall in the 0.45–4.93 mm/yr range. Further, four river basins had shown increasing trend in rainy days and 15 river basins had shown the opposite trend.

Kulkarni (2011) conducted a dry spell analysis of Dapoli for a period of 1972 to 2010. The average annual rainfall of Dapoli was 3587 mm and average number of rainy days for Dapoli was 75 by using 2.5 mm/day criteria.

Solatani *et al.*, (2011) studied the rainfall and rainy days trend in Iran. The Mann-Kendall test was used for determining monotonic trends and was based on ranks. They investigated rainfall variability all over Iran by analyzing data for annual and monthly rainfall and number of rainy days, which had been collected at 33 stations. Mann-Whitney tests showed that all the analyzed time-series, except Khoramabad and Kerman, were homogeneous at 10 per cent significance level. The Mann-Kendall test applied to the annual and monthly rainfall time-series showed that most of the stations of Iran had no statistically significant trends in all the seasons. Only local and isolated trends in the rainfall data were found.

Choudhury *et al*., (2012) madetrend analysis of long term weather variables in mid altitude Meghalaya, north-east India. Long time (1983-2010) weather variables were analyzed to detect trend, using non-parametric Mann Kendall test. In mid-altitude of Meghalaya, the results revealed that total annual rainfall trend increased non-significantly at the rate of 3.72 mm per year. Contribution of monsoon months declined marginally, while pre-monsoon and post-monsoon months increased non-significantly. Number of rainy days and extreme rainfall events (RX_1 day maximum >100 mm) exhibited a non-significant increasing trend at the rate of 1.7 days and 1.9 days per decade, respectively. Maximum temperature showed increasing trend, while minimum temperature and annual evaporation showeddecreasing trend. Climatic water balance studies (rainfall and PET) reflected an increasing trend of water surplus during May to July, whereas a reverse trend was observed during post monsoon months (December to February).

Kazimierz and Leszek (2012) analyzed the daily rainfall and runoff data of 48 years from a small agricultural catchment located in central Poland. No land use changes in that period had been reported. To evaluate the trend of three annual hydro-meteorological parameters, *i.e*. precipitation, runoff and runoff coefficient, the Mann-Kendall test was applied,as it was simple to use and it was often applied for climatological and hydrological trend analysis (Hipel and McLeod 1994; Khambhammettu 2005; Kundzewicz*et al*.,2005; Hamed 2008; Sahooa and Smith 2009; Węglarczyk 2010). It indicated no trend in respect of precipitation, and decreasing trends in respect of runoff and runoff coefficient at a 95per centlevel of significance. Linear approximation of the annual runoff values indicated a decrease in runoff of 1.2 mm per year for the analyzed period.

Maragatham (2012) conducted a trend analysis of rainfall for all over India**.**Differentmethods such as graphical, semi-average, moving average, least square method for analyzing time series for the period 1901 to 2000 were comparedto detect best trends in it. He found that the least square method gave accurate results in comparison.

Moazed *et al.*, (2012) studied the changes in rainfall characteristics of the Karun and Dez watershed in southwestern Iran, to identify the occurrence of significant statistical trends and change points in the rainfall characteristics time series. They also evaluated magnitude and direction of trends, prior and after the change points, and evaluated magnitude of change points to determine the change points and trends of rainfall characteristics of various time series. Petitt and Mann-Kendall tests were applied for analysis of time series.

Mondal (2012) studied the monthly and annual trends of Birupa river basin of north eastern part of Cuttack district, Orissa for theduration of 40 years from 1970 to 2010. They processed daily rainfall data to find the monthly and annual trends using Mann-Kendall test, Modified Mann-Kendall test,together with Sen’s slope estimator, to check the magnitude of slope. They found the maximum annual rainfall in year 1983 of 2810 mm and minimum annual rainfall in year 1996 of 1118 mm. Z statistic of Mann-Kendall test revealed that there was a rising trend of rainfall in the months of August, July and September and falling trend of rainfall in December, January and February.

Nagh *et al.*, (2012) conducted rainfall trend analysis using 50 years historical data in newly developed Bernam catchment in Peninsular Malaysia for the years 1948 to 2002. They converted a daily point rainfall data into a catchment rainfall data, using Thiessen

Polygon method. They observedthe spatial and temporal variability of rainfall. Different statistical parameters such as mean, range, standard deviation, standard error, coefficient of variation were calculated for rainfall, in order to observe the deviation from long term means as monthly and seasonal basis. They found that wet months in study catchment occurred during inter monsoon instead of monsoon themselves.

Sing and Darroch (2012) carried out the trend analysis of global radiation (1960-2003), transmissivity (1960-2003) and bright sunshine hours (1973-2003) over Nagpur during pre-monsoon (March to May) and monsoon seasons (June-September). They used Mann-Kendall Test to test the significance of reported trend. They concluded that global radiation had a statistically significant declining trend in both pre-monsoon and monsoon seasons. Bright sunshine hours were also found to be statistically significant for pre monsoon but no trend was observed for the monsoon. Transmissivity had also declined significantly in pre-monsoon and monsoon

Ze-Xin and Thomas (2012) studied the spatio-temporal variability of reference evapo-transpiration and its contributing climatic factors in Yunnan Province, SW China. Using the FAO Penman–Monteith method, monthly reference evapo-transpiration (ET0) for 119 stations was estimated for 1961–2004. An ordinary linear regression in the form of $y' = \alpha t + ß$ was used to estimate the rate of change, and statistical significance of linear trend was evaluated using Student's t-test. The magnitude of the trend was calculated by the slope of the linear trend and spatial distribution of linear trends was interpolated on the map using ArcMap Software. The results revealed that area-averaged annual and seasonal ET_0 rates declined, with most remarkable rate during pre-monsoon and monsoon seasons. Most of the stations with negative trends were concentrated in the eastern and northern parts of Yunnan Province. Over the 44year period, wind speed (WS), relative sunshine duration (SD) and relative humidity (RH) all showed decreasing trends, whereas maximum temperature (TMX) increased slightly.

Arafat and Monira (2013) determined the trends of rainfall of largest island Bhola in Bangladesh. Rainfall data from 1966 to 2011 were used in the study to find out the monthly variability of rainfall. Mann-Kendall test and Sen's Slope Estimator were applied for the determination of trend and slope magnitude. The Mann-Kendall Test represented both positive and negative trend in the area, although not much significant. Individually, the months of January, March, May, October and December showed positive trend and the months of February, April, June, July, August, September, November and December depicted negative trend.

Deshmukh and Lunge (2013) studied the temperature and rainfall trends in Buldana district of Vidarbha, Maharashtra state, India. They used monthly averages of total mean rainfall, minimum and maximum atmospheric temperatures data during 1975-2005by the India Meteorological Department, Pune. For trends, they used statistical methods such as regression analysis and coefficient of determination ($R^{2)}$. They observed that monthly mean of maximum (MMAX) temperatures had increased significantly for all the months, except the month of October for which there was a very weak decrease in MMAX temperature. The monthly mean of maximum (MMAX) temperature had annually increased by 2.69390C and total mean rainfall TMRF had increased by 10.137 mm during the last 31 years.

Gaikwad (2013) studied the trends of different meteorology parameters on the basis of temporal, spatial and half decadal for Harnai, Dapoli and Wakawali stations in Dapoli tahsil of Ratnagiri district of Maharashtra state, India. Evapo-transpiration for all the three stations was estimated by using Penman-Monteith (PM-56) and Hargreaves-Samani methods as per the data available. The analysis showed that reference evapo-transpiration had linearly decreasing trend at Dapoli (3.2 mm per year) and Wakawali (14.53 mm per year), however it hadan increasing trend at Harnai (0.45 mm per year). The results also revealed that reference evapo-transpiration was increasing as the distance from sea shore increased.

Sonali and Nagesh (2013) reviewed trend detection methods and their application to detect temperature changes in India. Spatial and temporal trend in annual, monthly, winter, pre-monsoon, monsoon and post-monsoon extreme temperatures for three time slots viz. 1901–2003, 1948–2003 and 1970–2003 were estimated for time series of extreme temperatures of India as a whole and seven homogeneous regions, viz. Western Himalaya (WH), Northwest (NW), Northeast (NE), North Central (NC), East coast (EC), West coast (WC) and Interior Peninsula (IP).Trends were detected with Least squares linear regression (LR) test, Mann–Kendall test (MK), Spearman rank correlation (SRC) test, Sen's slope (SS), Trend-free pre-whitening (TFPW) with MK, Variance correction (VC) approach with MK test based on Hamed and Rao (1998) (MK-CF1), Variance correction (VC) approach with MK test based on Yueand Wang (2004) (MK-CF2), Block bootstrap (BBS) with MK i.e. BBS-MK, Block bootstrap (BBS) with SR i.e. BBS-SR, Sequential Mann–Kendall test (SQMK) and Innovative trend analysis approach based on Sen (2012) methods. The results revealed that a consistent increasing trend was detected in minimum temperature for most of the regions all over India during the last three decades.

Application of Sen's slope methodology also indicated that magnitudes of trend in most of the regions during last three decades were more intense for minimum temperature as compared to maximum temperature. During 20th century (1901–2003), significant maximum temperature trends were found during winter season for all the temperature homogeneous regions as well as in all India, except NW region. Significant positive trends were found during post monsoon season in NC region for all the considered time slots viz. 1901–2003, 1948–2003 and1970–2003. Result also showed that the M-K test and Sen's Slope test were more reliable for detection of nature of trend and magnitude of trend, followed by MK-CF2, SQMK and LR test.

Ewona *et al*., (2014) analyzed the trend of rainfall patterns in Nigeria, using regression parameters. Rainfall data over a thirty year period from twenty three weather measuring stations were analyzed. Monthly mean daily total rainfall showed marked latitudinal dependence as seen in the positive slopes against latitude. Rainfall showed consistent increase during the thirty years of this study. The parameter decreased with latitude at the rate of 18.87 per degree rise in latitude. Katsina stood out as the lowest rainfall station, while Calabar was identified as the highest rainfall station in Nigeria.

Murumkar *et al*., (2014) conducted the trend and periodicity analysis in rainfall pattern for Akluj, Baramati, Bhor and Malsiras stations in Nira Basin, Central India.They used Mann-Kendall (MK), Modified Mann-Kendall (MMK) and Theil and Sen's slope estimator tests for trend and periodicity analysis using 104 years' seasonal and annual rainfall data. They observed that Monsoon and post-monsoon seasonal rainfall showed a rising trend, while the summer and winter seasonal rainfall showed a falling trend. Significant increasing trends were detected in annual rainfall at 10% significance level for the Akluj and Bhor stations. Bhor station showed maximum change in the magnitude of trend for annual and monsoon series.

Sarwar *et al.,* (2014) examined the spatial and temporal rainfall variability from 1940 to 2007 in the south west coastal region of Bangladesh. Time series statistical tests were applied to examine the spatial and temporal trends in three time segments (1948–1970, 1971–1990 and 1991–2007) and four seasons (Pre-monsoon; Monsoon; Post-Monsoon and Winter), during the period 1948–2007. Eight weather stations were divided into two zones: exposed (exposed to sea) and interior (distant to sea). Overall, rainfall increased during the period 1948–2007, while the trends had intensified during post-1990s. Post-monsoon and winter rainfall was observed to follow significant positive trends at most weather stations during the time period 1948–2007. Sequential Mann Kendall test revealed that the changes in two zones rainfall trends had started around mid-80, where step change was found only for four seasons in Khulna station and also for winter season in all the weather stations.

Jadhav and Shardul (2014) determined the trends of different meteorological parameters in the Konkan region. The meteorological data were analyzed for Dapoli, Palghar and Wakawali stations. Trends were estimated with the help of Moving average and Regression analysis. The results revealed that rainfall and reference evapo-transpiration for all the three stations had decreasing trend. Average annual temperature had increasing trend and relative humidity decreasing trend at Dapoli, Palghar and Wakawali stations. Wind speed showed increasing trend for Dapoli and decreasing trend at Wakawali station.

Spatial and temporal variation of rainfall has prime importance in crop and water resource planning. Different tests are available for the analysis of variation depending on the parameters to be analyzed, data availability, type of data, number of stations to be analyzed and purpose of analysis. The above cited literature indicate that Mann Kendall test was more reliable for trend detection of rainfall at various stations in single study and Sen's Slope test was more reliable for estimation of magnitude of a trend.

III. MATERIAL AND METHODS

3.1 Study area

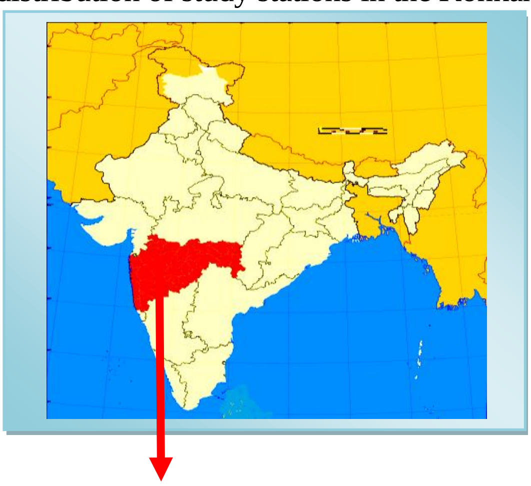
The present study was undertaken for Konkan region which is, western coastal part of Maharashtra state along the Arabian Sea in India.

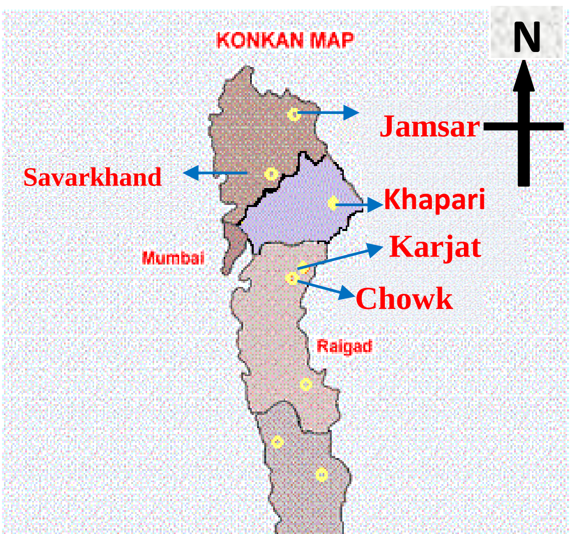
3.2 Features of study area

The Konkan region is coastal part of Maharashtra covering total geographical area of 3.09 Mha. The Konkan region lies between $15^0$6’ N to $20^0$22’ N latitude and $72^0$39’ E to $73^0$48’ E longitudes, falls under heavy rainfall ranging from 2500 mm to 4500 mm. The region receives 46 per cent of total precipitation of the state on just 10 per cent of total geographical area of the state. The ambient temperature varies from 7.5^0C to 38.5^0C and relative humidity varies from 55 per cent to 99 per cent in different seasons. The Konkan region has undulating topography of Sahyadri verges with highly drainable lateritic and non-lateritic soils. Though the region comes under heavy rainfall zone it faces water scarcity in summer season.

3.3 Location map of the stations

Geographical location of the study station is presented in Figure 3.1 which shows the spatial distribution of study stations in the Konkan region.





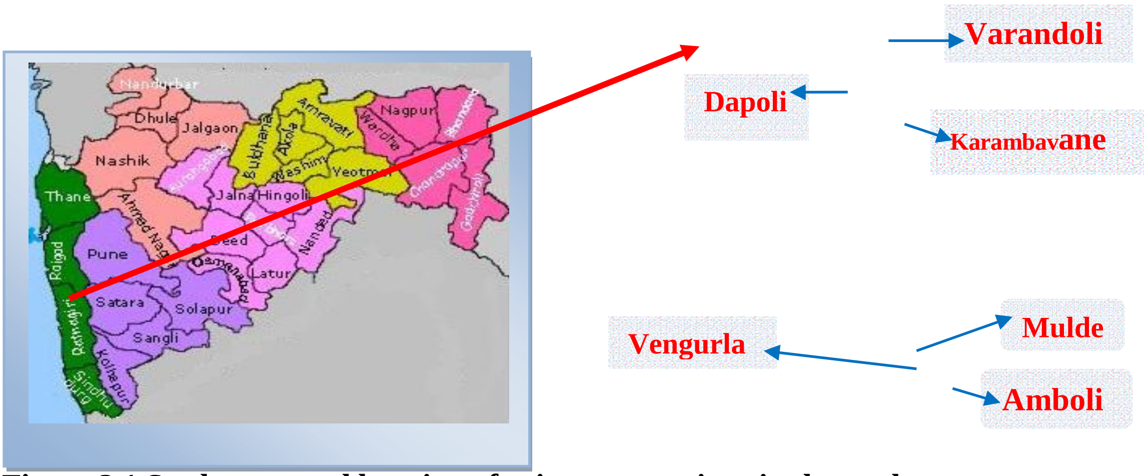


Figure 3.1 Study area and location of raingauge stations in the study area

3.4 Data Collection

Daily rainfall data of Jamsar, Savarkhand, Khapari, Karjat, Chowk, Varandoli, Dapoli, Karambavane, Mulde, Vengurla and Amboli stations of Konkan region was collected from Department of Agronomy, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli and Water Resources Department, Hydrology Project (Surface Water), Government of Maharashtra, Nasik. The geographical locations of raingauge stations and duration of rainfall data collected is presented in Table 3.1 and 3.2 respectively.

3.5 Software/programme

Microsoft office sub-module MS-Excel was used for data analysis. The formulation and conditional statements was also executed in MS-excel. MAKESENS excel template was used for trend detection and estimation of magnitude of Trend (Salmi *et al.*, 2002)

Table 3.1 Geographical location of rainfall stations

District	Taluka	Station	Latitude	Longitude
Palghar	Jawhar	Jamsar	19°90'N	73°23'E
	Wada	Savarkhand	19°65'N	73°14'E
Thane	Murbad	Khapari	19°26'N	73°38'E
Raigad	Karjat	Karjat	18°91'N	73°32'E
	Karjat	Chowk	18°83'N	73°28'E
	Mahad	Varandoli	18°08'N	73°42'E
Ratnagiri	Dapoli	Dapoli	17°75'N	73°18'E
	Chiplun	Karambavane	17°53'N	73°18'E
Sindhudurg	Sawantwadi	Amboli	15°96'N	73°99'E
	Kudal	Mulde	16°01'N	73°70'E
	Vengurla	Vengurla	15°43'N	73°42'E

Table 3.2 Availability of data for study stations

Station	Period (year)		Missing data	No. of years data available	Source
	From	To			
Jamsar	1986	2011	-	26	Unit of Hydrology Deptt., Nasik
Savarkhand	1991	2011	-	21	Unit of Hydrology Deptt., Nasik
Khapari	1992	2011	-	20	Unit of Hydrology Deptt., Nasik
Karjat	1989	2014	1989,1999, 2000, 2001, 2009	21	Dr. BSKKV, Dapoli
Chowk	1980	2011	2008	30	Unit of Hydrology Deptt., Nasik
Varandoli	1981	2011	-	30	Unit of Hydrology Deptt., Nasik
Dapoli	1981	2014	-	34	Dr. BSKKV, Dapoli
Karambavane	1991	2011	-	21	Unit of Hydrology Deptt., Nasik
Amboli	1981	2011	-	31	Unit of Hydrology Deptt., Nasik
Mulde	1991	2014	-	24	Dr. BSKKV, Dapoli
Vengurla	1981	2011	1983	30	Dr. BSKKV, Dapoli

3.6 Variation of Rainfall

Mean, standard deviation and coefficient of variation for Weekly, Monthly (June, July, August, September and October) and annual rainfall series for all the Stations were estimated for the available data as per the following standard procedure (Panse and Sukhatme, 1954).

3.6.1 Mean

Mean represents measure of central tendency. Mean of a series is equal to the sum of all variables divided by their number.

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad \ldots (3.1)$$

Where,

$\overline{X}$ = Mean

Xi = Variables

N = Total number of variables

3.6.2 Standard deviation

Standard deviation is the best measure of dispersion. It gives more weight to extreme items and less to those which are near the mean.

$$\sigma = \sqrt{\frac{1}{N-1}} \sum_{i=1}^{N}(X_i - \overline{X})^2 \qquad \ldots (3.2)$$

Where,

σ = Standard deviation

Xi = Variables

$\overline{X}$ = Mean

N = Total number of variables

3.6.3 Coefficient of variation

Coefficient of variation is the percentage variation in the mean, the standard deviation being treated as the total variation in the mean.

$$\mathrm{CV} = \frac{\sigma}{\overline{X}} X\ 100 \qquad \text{... (3.3)}$$

Where,

CV = Coefficient of variation

$\overline{X}$ = Mean

σ = Standard deviation

3.7 Trend Analysis of Rainfall

Trend analysis (increase or decrease) of all the independent weather parameters (*e.g.* weekly, monthly and annual rainfall) was statistically examined in two phases. Firstly, the non-parametric Mann-Kendall test is used. The presence of a monotonic increasing or decreasing trend was tested based on normalized test statistics (Z) value. In the second phase, the rate of increase or decrease in trend was estimated by using nonparametric Sen's slope estimator (Choudhury *et al.*, 2012, Drapela and Drapelova, 2011, Helsel and Hirsch, 2002). The trend analysis to detect the presence of raising and falling trends in a weekly, monthly and annual rainfall series were performed using following methods:

3.7.1 Mann-Kendall Test (M-K)

The data values were evaluated as ordered time series. The following procedure was carried out for Mann Kendall method analysis.

1. Arrange data as ordered time series.
2. Let x_1, represent first data point i.e. .x_k at time k and x_2, x_3,…x_n represent n data point at x_j .

3. Compare the first year data point i.e x_k with x_2, x_3,……x_n i.e. x_j year data point.
4. Assign values to the available data point as per equation 3.5.
5. Count total number of positive and negative data point occurred in the time series data which is termed as t_p.
6. Identify how many sets of continuous +1 or -1 values were occurred in the data series and termed as tied groups.
7. n is the total number of years in the data series.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_k\right) \qquad \ldots (3.4)$$

$$Sign\ (x_j - x_k) = \begin{cases} 1 & if \quad x_j - x_k > 0 \\ 0 & if \quad x_j - x_k = 0 \\ -1 & if \quad x_j - x_k < 0 \end{cases} \qquad \ldots (3.5)$$

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \qquad \ldots (3.6)$$

Where,

q = Number of tied groups,

t_p = Number of data values in the p^{th} group.

n = Number of years data

The standard test statistic Z computed as follows

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if \quad S < 0 \end{cases} \qquad \ldots (3.7)$$

The presence of a statistically significant trend was evaluated using the Z value. A positive/negative value of Z indicates an upward /downward trend. In the present study, at confidence level of 99, 95 and 90 per cent the positive or negative trends is determined by the test statistic. At the 99 per cent significance level, the null hypothesis of no trend is rejected if |Z| > 2.575; at the 95 per cent significance level, the null hypothesis of no trend is rejected if |Z| > 1.96; and at the 90 per cent significance level, the null hypothesis of no trend is rejected if |Z| > 1.645.

3.7.2 Sen´s slope estimator

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. The Sen's method can be used in cases where the trend can be assumed to be linear. If a linear trend is present in a time series, then the true slope (change per unit time) was estimated by using a simple nonparametric procedure developed by Sen (1968). This means that linear model can be described as.

1. Arrange the available data according to time series
2. To derive an estimate of the slope Q_t, the slopes of all data pairs were calculated

$$Q_t = \frac{x_j - x_k}{j-k}, i = 1,2,3 \dots N, j > k \qquad \dots (3.8)$$

3. If there was n values x_j in the time series we get as many as N = n(n-1)/2 slope estimates Q_t.

4. The Sen's estimator of slope is the median of these N values of Q_t.

5. The N values of Q_t were ranked from the smallest to the largest and the Sen's estimator is,

$$Qt = \begin{cases} Q_{\frac{N+1}{2}} & if\ N\ is\ odd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) & if\ N\ is\ even \end{cases} \qquad \dots (3.9)$$

Example of Sen's slope:

Year	Rainfall				
2000	**X_1**	-	-	-	-
2001	**X_2**	$\frac{x_2 - x_1}{2001 - 200}$	-	-	-
2002	**X_3**	$\frac{x_3 - x_1}{2002 - 200}$	$\frac{x_3 - x_2}{2002 - 2001}$	-	-
2003	**X_4**	$\frac{x_4 - x_1}{2003 - 200}$	$\frac{x_4 - x_2}{2003 - 2001}$	$\frac{x_4 - x_3}{2003 - 2002}$	-
2004	**X_5**	$\frac{x_5 - x_1}{2004 - 200}$	$\frac{x_4 - x_2}{2004 - 2001}$	$\frac{x_5 - x_3}{2004 - 2002}$	$\frac{x_5 - x_4}{2004 - 2003}$

Median of all slope values of above table gives Q_t of which magnitude of trend and positive nature shows increasing and negative nature decreasing trend of rainfall

3.7.3 Turning Point Test

In turning point test the presence of high and low values were examined by determining number of turning points in the series. Turning point test is applicable for all values except first and last in time series. Spatial and temporal variation of annual and monthly rainfall trends were analysed for a period of available data by using turning point test. It is used as preliminary test for detection of presence of trend or randomness in the given data series (Kottegoda, 1980).

1. In an observed sequence x_t, t = 1, 2, 3, 4…………N, a turning point P occurs at time t = i, if x_i is either greater than x_{i-1} and x_{i+1} or less than the two adjacent values.
2. If we consider three unequal observations, following six possible combinations of orders of the magnitudes of three are useful to detect the presence of the turning point in the data series. Turning point of annual and monthly rainfall at selected stations was estimated by using following table for considered time periods.

(i)	$x_{i-1} > x_i > x_i+1$	Not a turning point
(ii)	$x_{i-1} > x_{i+1} > x_i$	Turning point
(iii)	$x_i > x_{i-1} > x_{i+1}$	Turning point
(iv)	$x_i > x_{i+1} > x_{i-1}$	Turning point
(v)	$x_{i+1} > x_{i-1} > x_i$	Turning point
(vi)	$x_{i+1} > x_i > x_{i-1}$	Not a turning point

3. The expected number of turning points in the given data series were calculated by following formula;

$$E(p) = \frac{2}{3}(N - 2) \qquad \dots (3.10)$$

4. The variance of the expected number of turning points was calculated by the following formula;

$$Var(p) = \frac{16N-29}{90} \qquad \dots (3.11)$$

5. The standard measure of the turning point test, Z (test statistic) was calculated by using following equation;

$$Z = \frac{p-E(p)}{[var(p)]^{\frac{1}{2}}} \qquad \dots (3.12)$$

Where,

N = data size

P = actual number of turning points

The significance level is a means of measuring whether a test statistic is very different from values that would typically occur under the null hypothesis. Specifically, the significance level is the probability of a value as extreme as, or more extreme than the observed value, assuming "no change" (the null hypothesis). In other words, significance is the probability that a test detects trend when none is present. At the 99 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 2.575$; at the 95 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 1.96$; and at the 90 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 1.645$.

3.7.4 Moving Average method

Knowledge on the spatial variability and temporal trends of mean rainfall is essential for efficient management of water resource and agriculture. In the present study rainfall data of selected stations were analysed for annual and monthly basis. The concept of moving averages is based on the idea that any large irregular components of time series at any point in time have a less significant impact on the trend, if the observation at that point in time series is averaged with such values immediately before and after the observation under consideration. The time series analysis was used to determine the trend in total rainfall over time for the weather station in the study area, and the 5-year moving average was used to smoothen out the variations present within data sets. Annual and monthly trends of rainfall at selected stations were estimated using five year moving average over the considered time period.

$$Y_{i+1/2(n-1)} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad \ldots (3.13)$$

Where,

$Y_{i+1/2(n-1)}$ = moving average,

X_i = monthly average of rainfall

n = moving average order.

3.7.5 Regression Method

The test statistic for linear regression is the regression gradient. Regression equations were used for the trend analysis of annual and monthly rainfall of eleven selected stations in the Konkan region. Regression constants a and b were therefore extracted from these equations. The regression parameters which were reported in the form of graph showed that the constant a, which is a reflection of the trend and b is the interceptor constant. This is one of the most common tests for trend and in its basic form assumes that data is normally distributed. A more useful approach to study the simultaneous variation of two (or more) characters was to study the regression when a relationship existed. y is the dependent variable and x is the independent variable.

1. The regression represented by a straight line is a linear regression. If a and b denotes these following estimate the regression line can be written as,

$$Y = a + bx \qquad \text{… (3.14)}$$

Where, Y= value obtained by substituting in above equation corresponding to x

2. a and b are that quantity $\sum(y - Y)^2$ are minimum. This is known as the principal of least squares.

У = the observed value of the dependent variable.

∑Y = summation of overall pairs of observation.

3. When a and b are calculated from the following formulae

$$a = \bar{y} - b\bar{x} \qquad \text{... (3.15)}$$

$$b = \frac{\sum(y-\bar{y})(x-\bar{x})}{\sum(x-\bar{x})^2} \qquad \text{… (3.16)}$$

Where,

$\sum(y - \bar{y}) / (x - \bar{x})$ = Sum of deviation of x and y from respective means

IV. RESULTS AND DISCUSSION

The most common variables applied in climate change studies are surface observations of precipitation, solar radiation, humidity, wind speed, temperature and snow cover (Choudhury, *et.al,* 2012). Aside few sporadic findings about climate change and its possible impacts mostly based on rainfall and to a lesser extent on temperature (Hussain, *et.al.,* 2009) the region is less explored , making the future climate change scenario more uncertain for devising any conclusive mitigation and adaptation measures. Rain fed agriculture dominates the region and food grain production chain is hampered by any abrupt change in climate variables, particularly rainfall pattern poses a serious threat to food and environmental security of the entire region. Therefore, in present study the trend of rainfall at various stations of Konkan region were estimated by using Mann-Kendall, Sen's Slope, Moving average, turning point test and Regression methods. The result of each method is discussed in following sections.

4.1 Variation of rainfall in the Konkan region

4.1.1 Annual rainfall

The annual rainfall of selected stations are presented in Table 4.1, which shows that highest average annual rainfall among the selected station was observed at Amboli station (6981 mm) of Sindhudurg district in the Konkan region. Whereas the lowest average annual rainfall among the selected station was observed at Khapari station (2478 mm) of

Thane district. Highest standard deviation was observed at Karjat station with 52 percent coefficient of variation however the minimum deviation was observed at Mulde with 14 per cent coefficient of variation.

Table 4.1 Annual rainfall variation at selected study stations

Name of Station	Availability of data	Average Rainfall (mm)	Min. Rainfall (mm)	Max. Rainfall (mm)	SD (mm)	CV (per cent)	District-wise	
							SD(mm)	CV (Per cent)
Jamsar	1986-2011	2702	1703	5216	778	29	639	25
Savarkhand	1982-2011	2547	1641	3473	499	20		
Khapari	1991-2011	2478	1535	3564	480	19	480	19
Karjat	1989-2014	3328	1324	4709	1457	52	945	31
Chowk	1980-2010	3197	1814	4775	693	22		
Varandoli	1981-2011	3824	2627	5370	684	18		
Dapoli	1981-2014	3635	2403	5291	832	23	828	22
Karambawane	1991-2011	3893	2731	5489	823	21		
Mulde	1991-2014	3330	2600	4314	454	14	696	17
Vengurla	1981-2011	2922	1224	4261	648	22		
Amboli	1981-2010	6981	4873	8504	987	14		
Average	-	3530	-	-	758	23	-	-

District wise Deviation of annual rainfall was maximum in Raigad (945 mm) followed by Ratnagiri (828 mm), Sindhudurg (696 mm), Palghar (639 mm) and Thane (480) with coefficient of variation 31 per cent, 22 per cent, 17 percent, 25 per cent and 19 per cent, respectively.

4.1.2 Monthly rainfall variability

Average monthly rainfall contribution to the average annual rainfall for the study stations for available data period were calculated and presented in Table 4.2. July month contributes highest amount of rainfall followed by July, August, June, September and October at all study stations except Mulde and Vengurla station.

Table 4.2 Monthly rainfall contribution to the total annual rainfall.

Name of station	Yearly	June (%)	July (%)	August (%)	September (%)	October (%)
Jamsar	2702	16	38	31	12	2
Savarkhand	2547	17	36	29	15	4
Khapari	2478	17	32	26	17	4
Karjat	2801	15	35	32	12	4
Chowk	3197	16	36	30	13	4
Varandoli	3824	21	36	27	12	3
Dapoli	3635	24	35	24	12	3
Karambawane	3893	22	36	22	13	6
Mulde	3330	25	34	21	10	6

Vengurla	2922	30	33	20	9	5
Amboli	6981	20	35	29	11	4

4.1.2.1 Variation of rainfall in the month of June

The average rainfall in June month is shown in Table 4.3 for the selected stations of Konkan region. The highest average rainfall for June month was observed at Amboli station (1406.20 mm) and lowest at Khapari station (415.51mm). Maximum standard deviation was shown at Amboli (488.07 mm) and lowest at Khapari (184.57 mm) with a coefficient of variation 34.71 percent and 44.38 percent, respectively. A result also shows that, at Mulde observed rainfall was most consistent as compared to all other station and highest variation observed at Jamsar station. All stations receive more than 400 mm rainfall in June month. Average rainfall received in the month of June in the region was 725 mm with 309 mm standard deviation and 25 percent coefficient of variation. Ratnagirir district showed maximum deviation whereas Palghar showed maximum variation of rainfall in June month.

Table 4.3 Rainfall variation at selected stations in the month of June

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise	
						SD (mm)	CV (per cent)
Jamsar	436.67	22.60	1223.00	293.95	67.32	267.05	61.62
Savarkhand	429.41	49.60	1082.40	240.15	55.93		
Khapari	415.86	103.50	845.00	184.57	44.38	184.57	44.38
Karjat	547.09	78.50	1141.50	290.29	53.06	277.21	44.97
Chowk	525.66	70.80	889.50	207.29	39.43		
Varandoli	787.45	179.40	1505.80	334.06	42.42		
Dapoli	859.06	186.60	2025.30	426.93	49.70	409.89	48
Karambawane	848.51	168.80	1781.60	392.84	46.30		
Mulde	843.38	381.80	1353.80	244.09	28.94	341.85	32.39
Vengurla	875.47	387.00	1685.00	293.39	33.51		
Amboli	1406.20	341.70	2464.00	488.07	34.71		
Average	725	-	-	309	25		

4.1.2.2 Variation of rainfall in the month of July

July month receives highest amount of rainfall in the monsoon season in Konkan region. Average monthly rainfall in July was maximum at Amboli (2454 mm)followed by Karambawane (1409.25 mm) and Varandoli (1395.09 mm) where as lowest rainfall was observed at Khapari (795.11 mm). Maximum monthly rainfall in July was observed at Karjat (2238.70 mm) in the year 2005 and lowest at Vengurla station (274 mm) in the year 1990. Maximum regional rainfall deviation in July month was observed at Jamsar (422.36

mm) and minimum rainfall deviation at Khapari with coefficient of variation 28.86 percent and 34.28 percent, respectively. All stations except Khapari (792 mm) received more than 900 mm rainfall in July month. Southern part of Konkan region receives more rainfall in July month as compared to northern part. Only Mulde station in southern part of study region received more than 1100 mm average rainfall in July month. Coefficient of variation in monthly rainfall was observed highest at Jamsar station which is northern most station of the region.

Maximum rainfall variation in July month was observed at Dapoli and Vengurla station in south Konkan. All other selected station showed less than 30 percent variation. Average rainfall in the month of July was 1251 mm with standard deviation 379 mm and 31 per cent coefficient of variation. Maximum deviation of rainfall in the month of July was maximum in Ratnagiri district followed by Sindhudurg, Raigad, Palgharand and Thane, district with coefficient of variation 30.52 per cent, 26.98 per cent, 30.74 per cent, 37.80 per cent and 34.28 percent, respectively. Average rainfall received in the study region during July month was 1251 mm with 379 mm standard deviation and 31 per cent coefficient of variation.

Table 4.4 Rainfall variation at selected stations in the month of July

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise	
						SD (mm)	CV (per cent)
Jamsar	1040.08	355.90	2059.40	422.36	40.61	369.84	37.80
Savarkhand	905.21	243.60	1665.60	317.33	35.00		
Khapari	795.11	352.88	1408.60	272.55	34.28	272.55	34.28
Karjat	1235.62	503.90	2238.70	413.96	33.50	385.62	30.74
Chowk	1161.45	446.50	1829.80	379.48	32.67		
Varandoli	1395.09	782.60	2073.60	363.42	26.05		
Dapoli	1283.90	419.00	2172.60	413.29	32.19	409.98	30.52
Karambawane	1409.25	761.40	2097.60	406.68	28.86		
Mulde	1123.40	555.00	1580.80	278.60	24.80	391.62	26.98
Vengurla	959.12	274.00	1580.78	309.02	32.22		
Amboli	2454.08	1406.10	3839.00	587.26	23.93		
Average	1251	-	-	379	31	-	-

4.1.2.3 Variation of rainfall in the month of August

In the month of August ample amount of rainfall was received all over the Konkan region. All selected stations received more than 600 mm average rainfall, except Vengurla station in August month. Table 4.5 shows that average monthly rainfall in August was maximum at Amboli (2033.61 mm) and lowest at Vengurla station (590.33 mm). Amboli station exhibited maximum deviation as compared to all other stations and minimum deviation at Mulde station with coefficient of variation 31.65 percent and 27.49 percent, respectively. Mulde station received more uniform rainfall in August month as compared to remaining station and Jamsar station adduces maximum variation in among the study stations. Average monthly rainfall in August month was 952.76 mm whereas all stations except Mulde and Vengurla received more than 700 mm average monthly rainfall in the month of August. Raigad district showed maximum deviation in rainfall during August month followed by Sindhudurg, Palghar, Ratnagiri and Thane district with coefficient of variation 40.07 per cent, 34.94 per cent, 44.4 per cent, 37.33 per cent and 39.17 per cent, respectively. The Konkan region receives 952.76 mm average rainfall in the month of August with 362.13 mm standard deviation and 38.88 per cent coefficient of variation.

Table 4.5 Rainfall variation at selected stations in the month of August

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise	
						SD (mm)	CV (per cent)
Jamsar	829.59	165.90	1686.60	400.01	48.22	349.76	44.4
Savarkhand	738.19	111.50	1428.40	299.51	40.58		
Khapari	708.05	244.70	1275.84	277.35	39.17	77.35	39.17
Karjat	1047.12	130.20	2181.00	454.64	43.42	407.39	40.07
Chowk	962.25	194.70	2223.60	417.93	43.43		
Varandoli	1047.39	399.20	1731.80	349.60	33.38		
Dapoli	874.55	386.60	2051.00	354.13	40.49	339.47	37.33
Karambawane	950.51	420.30	1668.40	324.81	34.17		
Mulde	698.78	233.70	1000.20	192.11	27.49	368.49	34.94
Vengurla	590.33	227.40	1599.30	269.69	45.68		
Amboli	2033.61	728.20	4619.00	643.67	31.65		
Average	952.76	-	-	362.13	38.88	-	-

4.1.2.4 Variation of rainfall in the month of September

Monsoon rainfall decline in September month and received less rainfall as compared to June, July and August months at all stations. The maximum rainfall observed at Amboli station (740 mm) in September and lowest rainfall at Vengurla station (261.16 mm). All stations received less than 500 mm rainfall except Karambawane (505.92 mm) and Amboli (740 mm). Variation of rainfall from its mean was highest at Amboli and minimum at Khapari with 62.1 percent and 35.26 percent coefficient of variation in the month of September. Except Vengurla station all stations recorded more than 300 mm in

September month. Highest deviation was observed in Sindhudurg district followed by Palghar, Raigad, Ratnagiri and Thane whereas maximum variation was observed in Palghar district followed by Sindhudurg, Ratnagiri, Raigad and Thane district.

Table 4.6 Rainfall variation at selected stations in the month of September

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise	
						SD (mm)	CV (per cent)
Jamsar	327.13	24.6	949.4	272.94	83.44	270.60	77.74
Savarkhand	372.40	67.80	1069.26	268.26	72.03		
Khapari	416.62	192.36	717.73	146.88	35.26	146.88	35.26
Karjat	434.2	27.9	869.2	215.75	49.69	217.28	50.30
Chowk	415.07	82.7	1122.6	215.46	51.91		
Varandoli	447.46	114	962.1	220.62	49.31		
Dapoli	433.96	43.2	919.4	245.71	56.62	244.15	52.29
Karambawane	505.92	99.4	928.6	242.59	47.95		
Mulde	339.03	54.5	733.1	187.67	55.36	275.97	62.22
Vengurla	261.16	32	731.4	180.71	69.19		
Amboli	740	227	1752	459.52	62.1		
Average	426.63	-	-	241.46	51.53		

4.1.2.5 Variation of rainfall in the month of October

October month is the recession stage of monsoon rainfall and received lowest rainfall as compared to all monsoon season months in the Konkan region. Average rainfall in October month received maximum at Amboli (250.35 mm) and minimum at Jamsar (67.17 mm) and many times for a considered study period October month did not receive rainfall at every station. Table 4.7 reveals that highest deviation was observed at Karambawane (185.53 mm) and lowest at Jamsar (57.46 mm) with coefficient of variation 85.9 percent and 85.55 percent respectively. All stations except Amboli and Karambawane received less than 200 mm rainfall in October month. Generally rainfall in October month goes on increasing from north to south in the study region. Mulde and Vengurla station received at least more than 600 mm rainfall in October month whereas most of the stations did not receives rainfall in October month for considered time period. Standard deviation of rainfall at selected stations was increases as rainfall increased. Palghar, Thane and Raigad district were showed less than 100 mm deviation in the month October whereas Ratnagiri and Sindhudurg showed 148.03 mm and 143.31 mm deviation, respectively. Maximum variation of rainfall in the month of October was observed in Palghar district followed Ratnagir, Raigad, Sindhuudurg and Thane.

Table 4.7 Rainfall variation at selected stations in the month of October

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per	District-wise

					cent)	SD (mm)	CV (per cent)
Jamsar	67.17	0	204	57.46	85.55	86.74	105.95
Savarkhand	91.83	0	508.40	116.02	126.35		
Khapari	101.32	0	235	67.19	66.32	67.19	66.32
Karjat	108.58	3	288.2	86.97	80.1	92.71	80.06
Chowk	122.23	0	318.3	95.69	78.28		
Varandoli	116.74	0	389.2	95.48	81.79		
Dapoli	125.73	0.5	472.8	110.52	87.9	148.03	86.52
Karambawane	217.93	0	822.8	185.53	85.13		
Mulde	201.4	604.8	40	124.42	61.77	143.31	75.40
Vengurla	146.75	685	16.6	150.34	102.44		
Amboli	250.35	0	701	155.16	61.98		
Average	140.91	-	-	113.16	83.41		

Table 4.8 Variation of monthly and annual rainfall in the Konkan region

Name of Station	June (Per cent)	July (Per cent)	August (Per cent)	September (Per cent)	October (Per cent)	Annual (Per cent)
Jamsar	67.32	40.61	48.22	83.44	85.55	29
Savarkhand	55.93	35	40.58	72.03	126.35	20
Khapari	44.38	34.28	39.17	35.26	66.32	19
Karjat	53.06	33.5	43.42	49.69	80.1	52
Chowk	39.43	32.67	43.43	51.91	78.28	22
Varandoli	42.42	26.05	33.38	49.31	81.79	18
Dapoli	49.7	32.19	40.49	56.62	87.9	23
Karambawane	46.3	28.86	34.17	47.95	85.13	21
Mulde	28.94	24.8	27.49	55.36	61.77	14
Vengurla	33.51	32.22	45.68	69.19	102.44	22
Amboli	34.71	23.93	31.65	62.1	61.98	14

4.1.3 Average weekly rainfall at study stations

The average weekly rainfall at selected stations is presented in Table 4.8. This showed that at every selected station except Dapoli rainfall increases continuously from 22nd to 26th SMW. Maximum rainfall received in the SMW of 30th at Jamsar, Savarkhand, Karjat, Karambawane and Vengurla station whereas Amboli, Mulde, Varandoli and Chowk received highest rainfall in 28th SMW and Khapari in 29th SMW. At most of the stations rainfall after 38th SMW decreased continuously except Mulde and Vengurla station. Maximum amount of annual rainfall was received in between 26th to 36th SMW in northern part of study region whereas in between 23rd to 40th SMW in southern part of the study region. Average weekly rainfall at Jamsar (123 mm), Savarkhand (115 mm), Khapari (110 mm), Karjat (146 mm), Chowk (140 mm), Varandoli (172 mm), Dapoli (163 mm), Karambawane (179 mm), Mulde (146 mm), Vengurla (124 mm) and Amboli (313 mm). Maximum and minimum standard deviation of weekly rainfall were observed at Amboli (201 mm) and Khapari (92 mm) station, respectively whereas highest and lowest weekly rainfall variation were observed at Varandoli (163 per cent) and Amboli (85 per cent),respectively.

Table 4.9 Average weekly rainfall (mm) variation at selected stations.

Week		**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**Avg.**
Jamsar	Avg	24	68	127	151	229	169	252	266	272	233	226	128	149	98	71	74	82	27	19	16	15	3	123
	SD	32	100	150	194	191	140	259	220	214	207	212	98	131	89	85	116	160	39	30	43	33	10	125
	CV`	133	147	118	129	84	83	102	83	79	89	94	76	88	91	120	157	194	146	159	269	221	293	134
Savarkhand	Avg	23	83	139	143	175	163	239	203	255	181	187	125	147	104	82	102	81	32	33	11	19	10	115
	SD	39	100	105	167	146	141	210	142	217	160	167	98	161	85	74	144	91	38	50	22	39	33	110
	CV	167	120	75	117	84	87	88	70	85	88	89	78	110	81	90	141	112	120	153	189	206	345	123
Khapari	Avg	30	44	112	153	159	152	150	224	221	220	142	122	146	138	97	93	81	58	39	17	14	2	110
	SD	63	50	84	137	131	117	125	151	203	191	108	111	116	87	63	89	63	50	43	21	21	4	92
	CV	212	113	75	90	82	77	83	67	92	87	76	91	79	63	65	95	78	87	112	126	151	228	101
Karjat	Avg	10	61	127	147	216	200	222	269	361	276	238	266	188	169	175	81	58	61	45	32	11	9	146
	SD	19	147	139	124	164	132	209	203	272	215	222	327	194	178	169	77	71	78	45	48	27	22	140
	CV	189	243	110	84	76	66	94	76	75	78	93	123	103	105	96	96	121	128	99	148	246	248	123
Chowk	Avg	31	76	156	175	266	183	302	248	266	251	233	190	166	151	89	72	92	60	45	21	14	1	140
	SD	77	101	118	146	234	190	258	166	271	202	240	166	130	126	91	74	89	55	59	39	31	3	130
	CV	251	132	76	83	88	104	85	67	102	81	103	87	79	84	103	103	97	92	129	189	226	280	120
Varandoli	Avg	61	150	222	239	333	243	375	336	318	275	292	180	186	154	92	89	101	65	51	16	11	5	172
	SD	95	126	144	186	299	187	251	182	232	191	228	132	128	148	76	113	96	54	60	30	25	11	136
	CV	157	84	65	78	90	77	67	54	73	69	78	73	69	96	83	128	95	83	118	190	216	242	104
Dapoli	Avg	30	125	262	254	233	299	272	287	293	257	246	176	137	212	138	91	91	59	60	41	15	9	163
	SD	71	180	234	230	173	261	222	168	187	191	246	170	99	206	129	90	117	69	72	75	28	18	147
	CV	235	144	89	90	74	87	82	59	64	74	100	96	72	97	94	99	129	117	118	185	182	197	113
Karambbawane	Avg	75	212	216	226	321	297	314	323	347	275	207	154	222	199	100	96	105	76	77	57	19	15	179
	SD	168	222	160	223	247	228	246	259	218	156	139	78	167	173	92	109	74	62	78	91	26	26	147
	CV	223	105	74	99	77	77	78	80	63	57	67	51	75	87	93	114	71	82	101	159	134	181	98
Mulde	Avg	61	113	246	224	246	244	266	242	244	219	172	136	117	181	105	62	66	64	94	50	41	18	146
	SD	94	119	144	171	169	181	169	169	129	133	114	78	88	150	84	72	89	64	122	44	52	27	112
	CV	155	106	58	76	69	74	64	70	53	61	66	57	75	83	80	116	136	100	130	89	125	155	91
Vengurla	Avg	60	148	248	205	233	209	174	205	241	175	134	121	93	136	72	43	60	41	80	28	18	12	124
	SD	112	146	162	169	203	207	124	161	156	164	108	75	70	189	75	49	99	61	144	41	23	16	116
	CV	186	99	65	82	87	99	71	78	65	93	81	62	76	139	105	115	167	148	179	143	129	142	110
Amboli	Avg	118	268	432	421	548	460	637	590	544	546	531	381	373	266	168	156	154	112	87	51	30	11	313
	SD	138	190	258	256	318	262	358	323	272	302	308	159	244	234	152	165	166	98	74	63	53	22	201
	CV	118	71	60	61	58	57	56	55	50	55	58	42	66	88	91	106	108	87	85	125	175	208	85

4.2. Trend analysis of Rainfall

4.2.1 Mann Kendall Method

4.2.1.1 Annual and Monthly

The non-parametric Mann–Kendall trend test was applied to detect trends in the time series data and results are presented in Table 4.8 Annual and monthly rainfall trends over the Konkan region of Maharashtra state were obtained using the Mann-Kendall test. Results show that annual rainfall at all stations did not show any trends within the 99 per cent and 95per cent confidence level. Rainfall trend in the month of June, July, August and October at all study stations did not exhibit any trend within considered level of significance. However predominant increasing trend were found in September month at Karambawane within 99per cent confidence level and 95per cent confidence level at Mulde, Vengurla and Amboli stations whereas Jamsar, Savarkhand, Khapari, Karjat, Chowk, Varandoli and Dapoli stations did not shows any significant trend. Annual rainfall didn't exhibit any trend throughout the Konkan region. September month showed increasing trend at Dapoli, Karambawane, Mulde, Vengurla and Amboli station. Northern part of Konkan region did not show any trend in monthly rainfall however southern part showed increasing trend in the month of September. Except September month, June, July, August and October month the trend was not observed in the Konkan region at 99 per cent and 95 per cent confidence level.

Table 4.10 Annual and Monthly Mann Kendall trend statistics for selected station

Name of the station	Yearly Trend	Monthly Trend (Z Statistic)				
	Z Statistics	June	July	August	September	October
Jamsar	1.15	0.66	-0.42	1.23	1.5	0.46
Savarkhand	1.89	1.07	0.85	1.39	1.14	-0.32
Khapari	0.69	0.45	0.52	0.39	0.91	0.26
Karjat	-0.23	-0.82	-0.33	-0.94	0.94	-0.91
Chowk	1.87	0.79	0.89	0.21	0.57	0.1
Varandoli	-0.58	-0.53	-0.63	0.29	0.22	-0.75
Dapoli	0.62	0.5	0.12	-0.21	1.66	0.09
Karambawane	1.96	1.24	-0.15	0.63	2.87 ***	0.21
Mulde	0.72	-1.34	0	0.15	2.51 **	0
Vengurla	1.29	-0.04	0.46	-0.64	2.5 **	1.27
Amboli	0.18	0.02	0.39	-0.53	2.36 **	0.9

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

4.2.1.2 Weekly trend

Weekly rainfall trend at selected stations were calculated and presented in Table 4.10. It was observed that, 22-26, 29, 32, 39, 40 and 43 weeks didn't exhibit any trend to all selected stations. Jamsar station shows decreasing trend in 28^{th} (2.27) and 33^{rd} (2.96) week within 95per cent and 99per cent confidence level, respectively and all remaining weeks trend did not exhibit. Decreasing trend in 28^{th} and 33^{rd} SMW was observed at Savarkhand and all remaining weeks did not exhibit any trend. Khapari station showed that none of the SMW exhibit any trend. Karjat showed decreasing trend in 42^{nd} SMW and all other week did not show any trend. Chowk station showed increasing trend in 27^{nd} and 41^{st} SMW with 90 per cent confidence level. Varandoli station exhibited increasing trend in 28^{th} SMW only. Dapoli station is situated middle part of Konkan region and did not exhibited any trend throughout the monsoon season. Karambawane station showed increasing trend in 37^{th} SMW and decreasing trend in 42^{nd} SMW with 95 per cent confidence level. Weekly rainfall trend exhibit only in 36^{th}, and 38^{th} SMW and showed increasing trend at Mulde with 95 per cent confidence level. From Table 4.9 revealed that increasing trend at Vengurla station were observed in 36^{th} and 37^{th} SMW. Amboli station showed increasing trend in 27^{th} and 35^{th}SMW with 95 per cent confidence level. Only increasing trend was observed at Chowk in (27^{th} and 41^{st}SMW), Mulde (36^{th} and 38^{th} SMW), for Vengurla (36^{th} and 37^{th} SMW) and Amboli (27^{th} and 35^{th}SMW) stations whereas only decreasing trend was observed at Jamsar and Karjat stations and both increasing and decreasing trends were observed at Savarkhand (28^{th} 30^{th} 33^{th} week), Varandoli (28^{th} SMW), and Karambawane (37^{th} and 42^{nd} SMW) stations in some of the weeks. Southern part of the study area shows only increasing trend and northern part shows decreasing trend of weekly rainfall. Palghar district evinced decreasing trend whereas Thane district did not show any trend. Raigad and Ratnagiri district exhibited both increasing as well as decreasing trend at different stations. Sindhudurg district showed only increasing trend of weekly rainfall in the study region. It is also observed that, increasing or decreasing trends in rainfall for all stations except Jamsar, Savarkhand, Khapari, and Dapoli were observed during recession of monsoon season. But during growing season there was no trend found in the rainfall for Konkan region.

Table 4.11 Mann Kendall trend statistics for weekly rainfall (mm) at all selected stations

Week	Jamsar	Savarkhand	Khapari	Karjat	Chowk	Varandoli	Dapoli	Karambawane	Mulde	Vengurla	Amboli
22	-0.47	0.77	-0.13	0.84	0.84	0.28	1.10	1.29	0.50	-0.07	-0.15
23	-0.56	0.55	-0.10	0.26	-0.37	-0.80	0.86	-1.03	0.92	-0.49	-0.34
24	-0.57	-1.23	-0.19	0.25	0.07	-1.27	0.44	0.21	-0.55	-1.19	-0.87
25	0.57	1.46	-0.84	0.02	0.54	-0.02	-0.03	1.48	-0.65	-1.05	0.66
26	1.19	1.12	1.23	-0.02	0.68	0.53	-0.74	0.88	-0.65	0.41	0.29
27	0.26	1.57	0.45	0.07	1.97 **	0.97	0.74	0.39	0.00	-0.41	2.26 **
28	-2.27**	-2.31**	-0.52	0.00	-1.02	-2.02 **	0.40	-1.60	-0.60	-0.20	-0.76
29	-0.71	-0.57	0.19	-0.52	-0.25	-0.80	0.00	0.00	0.25	-0.24	-0.80
30	1.06	1.67*	0.97	-0.57	1.16	0.76	0.95	1.06	-0.55	-1.12	0.49
31	1.54	1.07	1.88	1.38	0.92	0.22	0.21	1.48	0.40	-0.87	0.73
32	-0.09	-0.93	-0.45	0.02	-1.36	-0.63	-0.62	0.15	0.40	-1.39	-1.43
33	-2.69 ***	-2.14 **	-1.23	-1.71	-1.05	-1.51	-1.85	-0.60	-0.55	-1.26	-0.70
34	0.31	0.92	0.71	-1.85	1.80	1.72	-0.39	-0.63	-1.24	-1.51	1.04
35	1.70	1.26	0.97	-0.63	1.63	1.39	1.96	1.30	0.65	0.70	2.67 ***
36	0.48	0.25	0.45	-0.21	0.39	0.00	0.85	1.66	2.23 **	2.09 **	1.24
37	1.58	1.55	1.04	0.99	1.10	0.92	0.68	2.18 **	1.96	2.06 **	1.58
38	0.35	-0.10	0.26	1.24	-0.24	-0.87	1.68	1.09	2.31 **	1.08	-1.05
39	-1.63	-0.01	0.26	-1.59	0.00	-1.04	-0.48	0.24	0.72	0.32	1.09
40	1.54	0.24	1.30	-0.31	0.05	0.09	0.67	0.52	-0.40	-0.44	0.05
41	0.42	0.77	0.66	0.00	2.32 **	1.72	0.31	0.24	-1.29	0.02	1.70
42	-0.14	0.55	-0.17	-2.20 **	-1.00	-1.56	0.33	-2.03 **	-1.50	1.11	-0.21
43	0.71	-1.23	-0.23	-1.13	0.95	-1.64	-0.03	0.34	0.93	-0.13	-1.07

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

4.2.2Sen's Slope Test

4.2.2.1 Annual trend

Sen's slope test was used to estimate the magnitude of trend and the results of yearly and monthly trends are presented in Table 4.10. From the Table it was revealed that, at Jamsar, Savarkhand, Khapari, Chowk, Dapoli, Karambawane, Mulde, Vengurla and Amboli stations showed increasing rainfall trend on annual basis whereas, Karjat and Varandoli showed decreasing trend. The maximum increasing trend of average annual rainfall was observed at Karambawane (60.81 mm) and minimum at Amboli (4.41 mm). All study stations showed increasing trend more than 10 mm except Karjat, Varandoli and Amboli stations. The similar kind of results was reported by Das *et al.*, 2006 (Increasing trend in annual rainfall in West Coast and Central parts of India).

4.2.2.2 Monthly trends

In June month at all station except Karjat, Varandoli, Mulde and Vengurla rainfall is in decreasing trend. Highest increasing and decreasing rainfall trend in month of June were observed at Karambawane and Karjat station, respectively whereas; lowest increasing and decreasing trend was observed at Amboli and Vengurla station, respectively. July month showed increasing trend at Savarkhand, Khapari, Chowk, Dapoli, Mulde, Vengurla and Amboli station and decreasing trend at Jamsar, Karjat, Varandoli and Karambawane. Both increasing and decreasing trend of average July month rainfall was less than 10 mm at all stations. Increasing trends were observed in northern and decreasing trend in southern part of Konkan region in August month. Rainfall in August month at Karjat, Dapoli, Vengurla and Amboli station showed decreasing trend. A significant positive trend of average monthly rainfall was observed at all stations except at Karjat, Chowk and Varandoli with increasing trend more than 5 mm in September month. Average monthly rainfall of October showed trend less than 4 mm increase/decrease in rainfall.

Table 4.12 Annual and monthly trend statistic of Sen's Slope test for selected stations

Name of Station	Yearly Trend (Qt)(mm)	Monthly Trend (Qt)(mm)				
		June	July	August	September	October
Jamsar	20.54	3.3	-3.18	14.49	5.41	0.51
Savarkhand	22.88	4.73	6.42	10.16	5.05	-0.14
Khapari	12.14	6.11	7.32	6.8	5.47	0.56
Karjat	-15.1	-12.98	-9.72	-16.7	4.38	-2.67
Chowk	26.91	5.06	8.29	1.27	1.96	0.18
Varandoli	-7.33	-4.4	-4.59	0.87	1.18	-1.48
Dapoli	11.6	4.63	2.23	-1.52	7.49	0.18
Karambawane	60.81	17.02	-4.29	12.29	26.74	1.61
Mulde	13.21	-9.24	0.14	0.39	13.58	-0.09
Vengurla	17.17	-1	1.57	-3.68	9.64	1.98
Amboli	4.41	0.32	3.84	-5	16.99	3.31

4.2.2.3 Weekly trend

Weekly rainfall trend was estimated by using Sen's Slope test and results are presented in Table 4.11. It was observed from Table that, Jamsar station showed negative trend in 24^{th}, 28^{th}, 29^{th}, 32^{nd}, 33^{rd} and 39^{th} weeks. The SMW no. 22^{nd}, 23^{rd}, and 41^{st} to 43^{rd} didn't observed any trend whereas week no. 26^{th}, 30^{th}, 35^{th} and 37^{th} showed average weekly increasing trend which had highest rate in 26^{th} (6.85 mm) week.

Savarkhand varied maximum increasing and decreasing trend in week 30^{th} (7.8 mm) and 28^{th} (8.53 mm), respectively. Week no. 22^{nd}, 39^{th}, 40^{th} and 41^{st} did not exhibit trend at Savarkhand.

At Khapari no trend exhibited in 22^{nd}, 42^{nd} and 43^{rd} weeks whereas decreasing trend was observed in 23^{rd}, 24^{th}, 25^{th}, 28^{th}, 32^{nd} and 33^{rd} week. Average weekly maximum and minimum increasing and decreasing trend at Khapari was observed in 31^{st} (12.49 mm) and 25^{th} (2.43 mm) week, respectively. Increasing trend evinced from 34^{th} week to 41^{st} week at Khapari. About more than half weeks did not observed any trend at Karjatand only 31^{st}, 37^{th} and 38^{th} weeks showed increasing trend. Significant decreasing trend were observed at Karjat station in 29^{th}, 30^{th}, 33^{rd}, 34^{th} to 36^{th} and 39^{th} weeks. Fragile increasing and decreasing trends were observed at Chowk station in 22^{nd}, 39^{th}, 40^{th}, 42^{nd} and 43^{rd} week didn't show any trend. Decreasing trend was observed in 23^{rd}, 28^{th}, 29^{th}, 32^{nd}, 33^{rd} and 38^{th} weeks at Chowk and more than 50 percent week showed increasing trend.

Varandoli station showed negative trend at more than 40 percent weeks and did not show any trend in 22^{nd}, 36^{th}, 40^{th}, 42^{nd} and 43^{rd} weeks. Highest average weekly increasing and decreasing trends were observed in 34^{th} (3.92 mm) and 28^{th} (11.43 mm), respectively. Most of the weeks at Karambawane station showed increasing trend whereas 23^{rd}, 28^{th}, 29^{th} and 42^{nd} weeks showed decreasing trend and only 43^{rd} week did not exhibit any trend. Mulde station showed decreasing trend in ten weeks whereas increasing trend in twelve weeks and all week exhibit either increasing or decreasing trend. Maximum increasing and decreasing trend were observed in 35^{th} (5.22 mm) and 26^{th} (3.52 mm), respectively. Vengurla showed decreasing trend from 24^{th} to 34^{th} week except 26th week and increasing trend from 35^{th} to 42^{nd} week except 40^{th} week. Table 4.11 also indicated that at Amboli station 22^{nd}, 42^{nd} and 43^{rd} week didn't show any trend. More than 50 percent week showed increasing trend and magnitude of increasing trend was more than decreasing trend at Amboli station. From Table it is observed that Sen's Slope and Mann Kendall results showed similar nature of trends in weekly rainfall.

Table 4.13 Weekly rainfall trend statistic of Sen’s Slope test

Week	Jamsar	Savarkhand	Khapari	Karjat	Chowk	Varandoli	Dapoli	Karambawane	Mulde	Vengurla	Amboli
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.35	0.00	0.00
23	0.00	0.64	-0.19	0.00	-0.15	-2.55	0.94	-5.49	1.49	-1.06	-1.35
24	-0.82	-2.90	-1.23	0.00	0.14	-3.78	1.77	2.12	-2.43	-4.60	-4.28
25	1.70	2.00	-2.43	0.00	1.20	-0.17	-0.08	7.33	-2.89	-2.31	1.43
26	6.85	3.36	6.14	0.00	2.63	2.61	-2.15	8.66	-3.52	1.09	2.37
27	0.98	4.01	2.46	0.00	4.02	3.03	2.41	2.78	0.10	-1.17	12.14
28	-8.36	-8.53	-1.18	0.00	-5.40	-11.43	1.29	-14.23	-2.62	-0.45	-4.46
29	-3.62	-0.97	3.42	-5.16	-0.68	-1.87	0.05	-0.27	0.95	-0.95	-4.70
30	6.10	7.80	7.61	-2.67	4.86	2.98	2.58	12.06	-1.36	-5.01	3.59
31	4.61	3.53	12.49	6.70	2.80	1.60	1.12	11.65	1.36	-2.38	4.56
32	-1.11	-2.14	-1.70	0.00	-3.35	-1.88	-0.72	0.80	1.08	-1.79	-7.55
33	-6.07	-3.88	-1.95	-7.62	-2.29	-4.10	-3.01	-1.97	-1.22	-2.40	-2.01
34	1.20	1.37	1.28	-8.28	3.91	3.92	-0.43	-4.55	-2.36	-1.49	2.61
35	3.52	1.70	3.25	-1.91	3.83	3.00	6.60	5.47	3.52	0.56	10.60
36	0.71	0.30	1.60	-0.23	0.58	0.00	1.92	4.40	5.22	2.46	3.00
37	2.27	1.35	1.93	1.00	1.06	0.78	0.85	6.72	2.10	1.12	3.73
38	0.07	-0.03	0.95	1.13	-0.40	-0.89	1.49	3.09	1.80	0.23	-1.86
39	-1.20	0.00	0.44	-1.60	0.00	-1.01	-0.15	0.30	0.97	0.09	1.58
40	0.04	0.00	2.97	0.00	0.00	0.00	0.26	1.09	-0.71	-0.16	0.00
41	0.00	0.00	0.19	0.00	0.40	0.15	0.02	0.00	-1.31	0.00	1.10
42	0.00	0.64	0.00	0.00	0.00	0.00	0.00	-1.54	-1.34	0.04	0.00
43	0.00	-2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00

4.2.3 Turning point test

4.2.3.1 Annual rainfall

In turning point test the presence of high and low values were examined by determining number of turning points in the series. Turning point occurs for all values except first and last in time series. Spatial and temporal variation of annual and monthly rainfall trends were analyzed for a period of available data by using turning point test. The results of annual rainfall are presented in Table 4.12 which revealed that Chowk (7.5 mm/year), Varandoli (6.09 mm/year) and Amboli (10.31 mm/year) stations showed average annual decreasing trend at 95 per cent confidence level. Except Chowk, Varandoli and Amboli stations neither the increasing nor decreasing trends were exhibited at any station during the considered time periods. It could be interfered from Table 4.12 that Konkan region didn't show any trend in northern part on annual basis rainfall but some stations in middle and south Konkan showed significant decreasing trend in annual rainfall.

Table 4.14 Annual rainfall trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	15	26	16.00	-0.53	0.94	No Trend
Savarkhand	18	30	18.67	0.18	-1.88	No Trend
Khapari	10	19	11.33	-1.78	0.38	No Trend
Karjat	13	19	11.33	-1.78	-0.47	No Trend
Chowk	14	31	19.33	0.36	-7.50 ***	Exist Trend
Varandoli	15	31	19.33	0.36	-6.09 ***	Exist Trend
Dapoli	24	34	21.33	0.89	1.50	No Trend
Karambawane	11	21	12.67	-1.42	-0.07	No Trend
Mulde	13	24	14.67	-0.89	0.94	No Trend
Vengurla	19	31	19.33	0.36	-0.47	No Trend
Amboli	15	30	18.67	0.18	-10.31 ***	Exist Trend

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

4.2.3.2 Monthly rainfall

Rainfall trend of June month was calculated by using turning point test and results are presented in Table 4.13. From Table, it is observed that Chowk (3.75 mm/year) showed increasing trend for average monthly rainfall whereas at Vanadoli (3.28 mm/year) and Amboli (3.28 mm/year) decreasing trend was observed. All other stations did not show any trend in June month. Northern part of study region did not exhibit any trend, whereas south Konkan also didn't show any trend except Amboli station. Chowk evinced increasing trend and Varandoli decreasing trend which are located in middle of the Konkan region. Rainfall trend of June month of selected stations showed trend at some stations but it differs in magnitude. Chowk and Varandoli both stations are located in northern and southern part of Raigad district respectively which showed exactly opposite trend in June month rainfall. Raigad district exhibited both increasing and decreasing trend which revealed the heterogeneity of rainfall within the district. Sindhudurg district also showed significant decreasing trend in south part of the district.

Table 4.15 June month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	16	26	16.00	-0.53	0.00	No Trend
Savarkhand	19	30	18.66	0.178	0.94	No Trend
Khapari	10	18	10.67	-1.96	0.17	No Trend
Karjat	14	19	11.33	-1.78	-0.75	No Trend
Chowk	22	31	19.33	0.36	3.75**	Exist Trend
Varandoli	17	31	19.33	0.36	-3.28**	Exist Trend
Dapoli	20	34	21.33	0.89	-0.75	No Trend
Karambawane	10	21	12.67	-1.42	0.94	No Trend
Mulde	13	24	14.67	-0.89	0.94	No Trend
Vengurla	17	29	18.00	0.00	0.00	No Trend
Amboli	17	31	19.33	0.36	-3.28**	Exist Trend

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

July month rainfall was analysed by using turning point test and test statistic is presented in Table 4.14. From the Table it is observed that, only Amboli (3.28 mm) showed average monthly decreasing trend at 95 per cent confidence level. All stations except Amboli did not show any trend at 95 per cent level of confidence. Rainfall in July month remains unchanged at all respective stations for considered period. Amboli is the heavy rainfall receiving station situated in southern most part of Konkan region and whole region didn’t show any trend except Amboli.

Table 4.16 July month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	No Trend
Jamsar	16	26	16.00	-0.53	0.00	No Trend
Savarkhand	18	30	18.66	0.18	-1.86	No Trend
Khapari	12	18	10.67	-1.96	-0.34	No Trend
Karjat	13	19	11.33	-1.78	-0.47	No Trend
Chowk	18	31	19.33	0.36	-1.88	No Trend
Varandoli	18	31	19.33	0.36	-1.88	No Trend
Dapoli	20	34	21.33	0.89	-0.75	No Trend
Karambawane	12	21	12.67	-1.42	0.23	No Trend
Mulde	15	24	14.67	-0.89	-0.19	No Trend
Vengurla	19	29	18.00	0.00	0.00	No Trend
Amboli	17	31	19.33	0.36	-3.28***	Exist Trend

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

Rainfall in month of August at various stations were analysed by using turning point test and results are presented in Table 4.15.From the Table it is observed that, significant average monthly increasing trend exhibited only at Savarkhand (9.38 mm), Chowk (2.34 mm) and Varandoli (2.34 mm). Except above said three stations did not show any trend. All these three stations were situated in northern Konkan region and south part of study area did not show any trend in August month.

Table 4.17 August month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Trend
Jamsar	16	26	16.00	-0.53	0.00	No Trend
Savarkhand	22	30	18.66	0.18	9.38 ***	Exist Trend
Khapari	11	18	10.67	-1.96	-0.09	No Trend
Karjat	14	19	11.33	-1.78	-0.75	No Trend
Chowk	21	31	19.33	0.36	2.34 **	Exist Trend
Varandoli	21	31	19.33	0.36	2.34 **	Exist Trend
Dapoli	23	34	21.33	0.89	0.94	No Trend
Karambawane	12	21	12.67	-1.42	0.23	No Trend
Mulde	13	24	14.67	-0.89	0.94	No Trend
Vengurla	20	29	18.00	0.00	0.00	No Trend
Amboli	19	31	19.33	0.36	-0.47	No Trend

Note:; ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

September average monthly rainfall showed decline trend at Savarkhand (4.68 mm) and positive trend at Chowk (2.34 mm) with 95per cent confidence level and presented in table4.16. From the Table it is observed that, south part of Konkan region having heavy rainfall zone did not observe any rainfall trend in September month except Savarkhand and Chowk. North part of the Konkan region showed decreasing trend whereas; middle part showed increasing trend in month of September.

Table 4.18 September month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	14	26	16.00	-0.53	1.88	No Trend
Savarkhand	17	30	18.66	0.18	-4.68 ***	Exist Trend
Khapari	11	18	10.67	-1.96	-0.09	No Trend
Karjat	12	19	11.33	-1.78	-0.19	No Trend
Chowk	21	31	19.33	0.36	2.34 **	Exist Trend
Varandoli	18	31	19.33	0.36	-1.88	No Trend
Dapoli	23	34	21.33	0.89	0.94	No Trend
Karambawane	11	21	12.67	-1.42	0.59	No Trend
Mulde	14	24	14.67	-0.89	0.38	No Trend
Vengurla	16	29	18.00	0.00	0.00	No Trend
Amboli	18	31	19.33	0.36	-1.88	No Trend

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

October month is the recession period of monsoon rainfall in the Konkan region. Trend statistic of turning point test for October month is presented in Table 4.17. In October there was no trend at stations for considered period with 95% confidence level.

Table 4.19 October month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Trend
Jamsar	17	26	16.00	-0.53	-0.94	No Trend
Savarkhand	19	30	18.66	0.18	0.94	No Trend
Khapari	12	18	10.67	-1.96	-0.34	No Trend
Karjat	16	19	11.33	-1.78	-1.31	No Trend
Chowk	20	31	19.33	0.36	0.94	No Trend
Varandoli	19	31	19.33	0.36	-0.47	No Trend
Dapoli	22	34	21.33	0.89	0.38	No Trend
Karambawane	12	21	12.67	-1.42	0.23	No Trend
Mulde	14	24	14.67	-0.89	0.38	No Trend
Vengurla	18	29	18.00	0.00	0.00	No Trend
Amboli	19	31	19.33	0.36	-0.47	No Trend

Note: ** Observe significant trend at the 95% confidence level if Z >±1.96; *** Observe significant trend at the 99% confidence level if Z >±2.54.

From the above results it is inferred, that June month exhibited increasing trend at Chowk and decreasing trend at Varandoli and Amboli stations. July month evinced decreasing trend at Amboli. Only August month showed increasing trend at savarkhand, Chowk and Varandoli stations. Both increasing as well as decreasing trends were observed in September month at Savarkhand and Chowk stations, respectively.

4.2.4 Moving Average Method

4.2.4.1 Annual rainfall

The time series analysis was used to determine the trend in total rainfall over available data period for the rainfall stations in the Konkan region. The annual rainfall trends were estimated by five year moving average method is presented in Figure 4.1 to 4.11.Annual rainfall at Jamsar and Mulde station were analyzed and results are presented in Figure 4.1 to 4.9 which did not show any significant trend. Savarkhand, Khapari, Chowk, Dapoli, Karambwane, Vengurla and Amboli station evinced increasing trend of annual rainfall and presented in Figure 4.2, 4.3, 4.5, 4.7, 4.8, 4.10 and 4.11, respectively. Decreasing trend was exhibited at Karjat and Varandoli station which is shown in Figure 4.4 and 4.6, respectively. Palghar, Thane, Ratnagiri and Sindhudurg district showed increasing trend whereas Raigad district showed increasing as well as decreasing trend. Both increasing and decreasing trend of annual rainfall was observed in north part of Konkan whereas south Konkan showed only increasing trend.

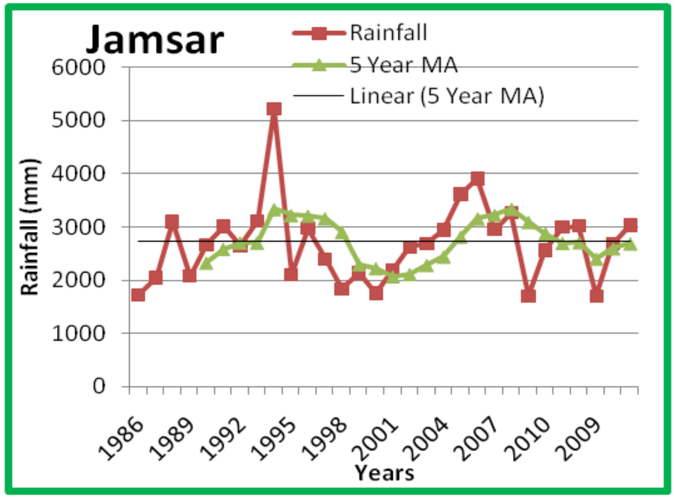


Fig. 4.1 Annual moving average of Jamsar

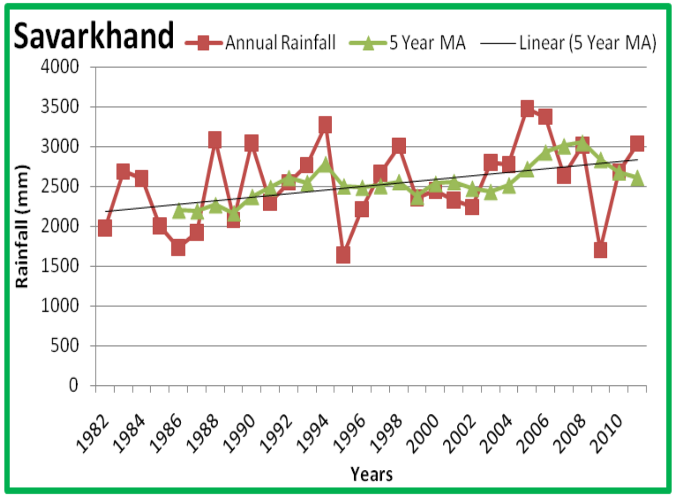


Fig 4.2Annual moving average of Savarkhand.

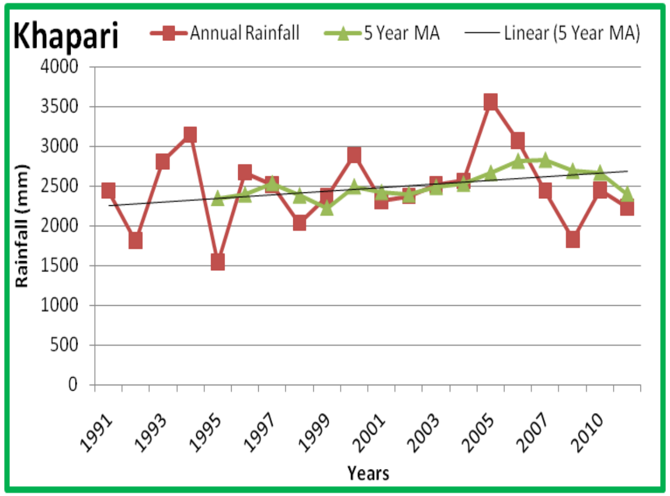


Fig 4.3 Annual moving average of Khapari

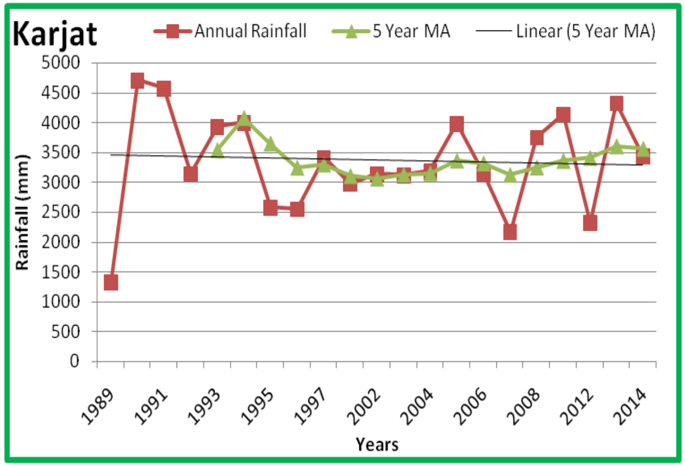


Fig. 4.4 Annual moving average of Karjat

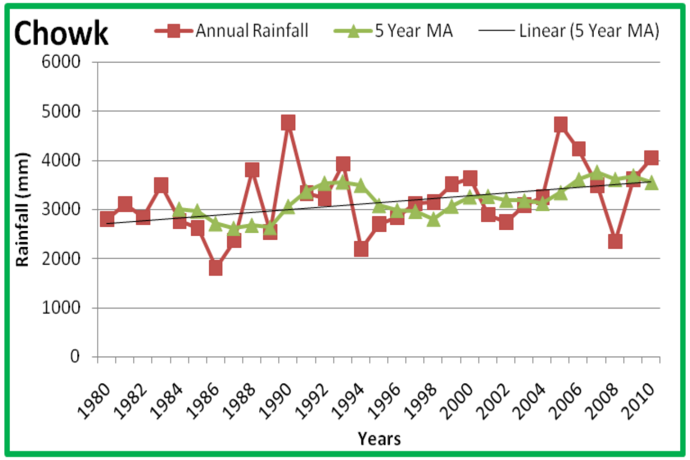


Fig. 4.5 Annual moving average of Chowk

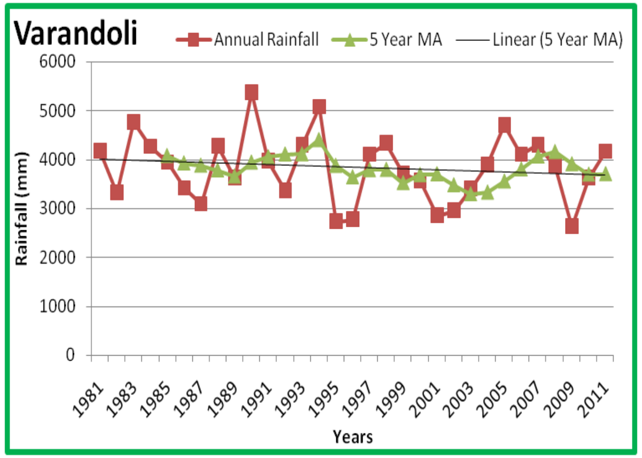


Fig. 4.6 Annual moving average of Varandoli

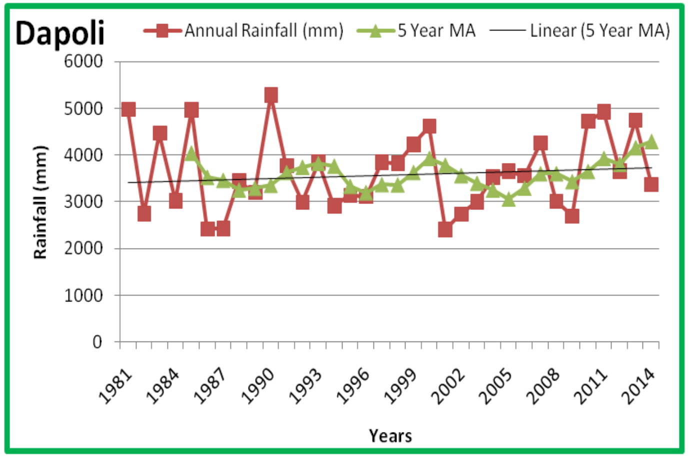


Fig. 4.7 Annual moving average of Dapoli

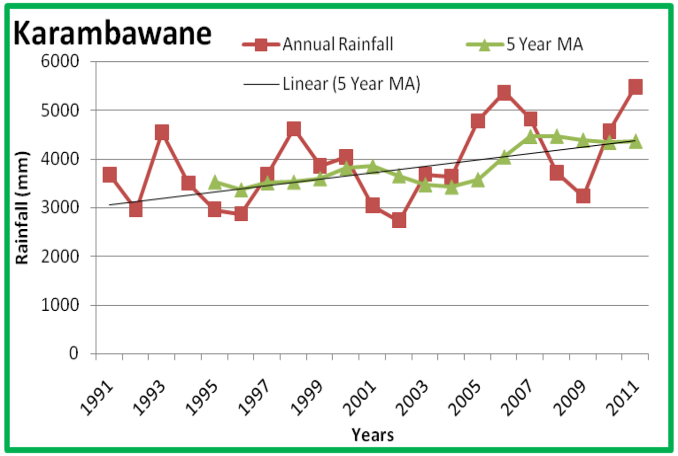


Fig. 4.8 Annual moving average of Karambwane

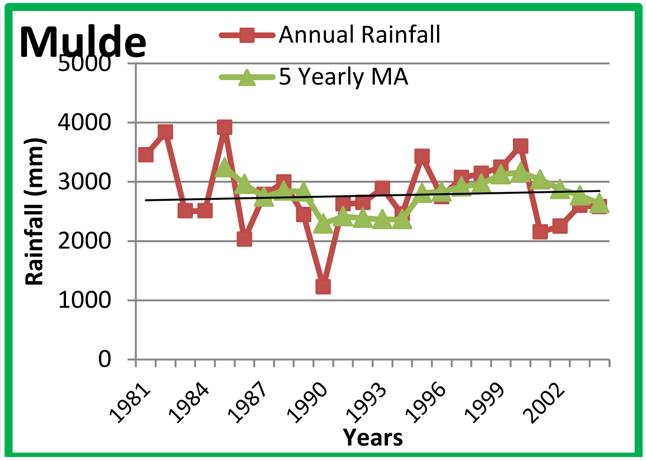


Fig. 4.9 Annual moving average of Mulde

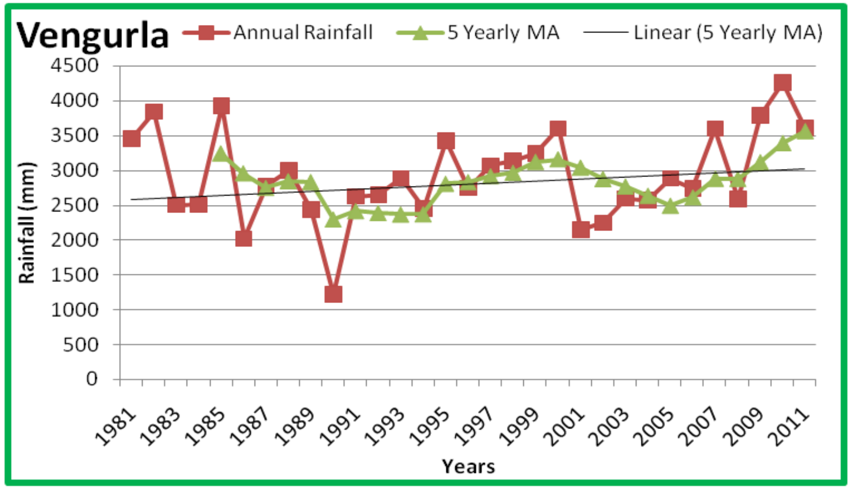


Fig. 4.10 Annual moving average of Vengurla

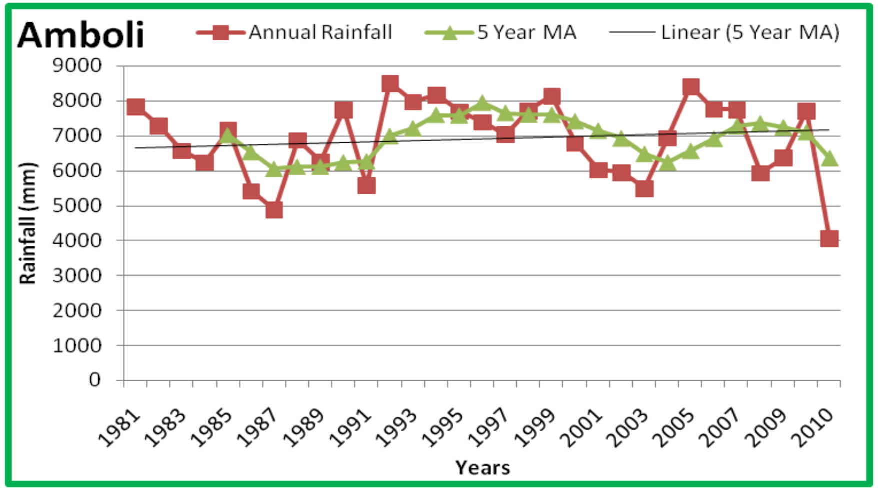


Fig. 4.11 Annual moving average of Amboli

4.2.4.2 Monthly rainfall

Monthly rainfall at Jamsar showed increasing trend in June, August and September whereas July and October month showed decreasing trend. A result of monthly rainfall moving average is shown in Figure 4.12. Maximum increasing rate was observed in June month and maximum decreasing trend in July month. Savarkhand station showed increasing trend in June, August and September month and maximum rate was observed in June month. July and October months showed decreasing trend at Savarkhand and rate of decline in amount of rainfall in October month was more as compared to July month which is shown in Figure 4.13

Monthly moving average of Khapari station was calculated and showed in Figure 4.14.Monthly rainfall at Khapari in June, August and September month showed increasing trend whereas July and October month did not exhibit any significant trend. Thane district exhibited increasing trend in June August and September months.

Karjat station is situated in the north of the Raighad district of the Konkan region and showed decreasing trend in June, July, August and October months which is shown in Figure 4.15.However September month at Karjat showed very weak increasing trend. Monthly rainfall at Chowk station reveals that all months showed increasing rainfall trend which is shown in Figure 4.16. Maximum rate of increase in rainfall was observed in June month and lowest in August month at Chowk station. Varandoli showed decreasing trend in June, July and October months whereas August month didn’t show any significant trend. September month showed very weak increasing trend. Only July month showed significant trend at Varandoli and results are shown in Figure 4.17.

Monthly rainfall trends at Dapoli station were estimated and results are presented in Figure 4.18. July and September month rainfall showed increasing trend at Dapoli. In June month rainfall there was no trend whereas August and October month showed decreasing trend at Dapoli which did not affect the annual rainfall because magnitude of increasing trend in September month was higher than both months having decreasing trend. Karambawane station showed decreasing trend in June, July and October month whereas only September month showed increasing trend and results are shown in Figure 4.19. August month did not show any trend at Karambwane however magnitude of decreasing trend in October month was very negligible. July (Figure 4.45) and October (Figure 4.48) month showed decreasing trend.

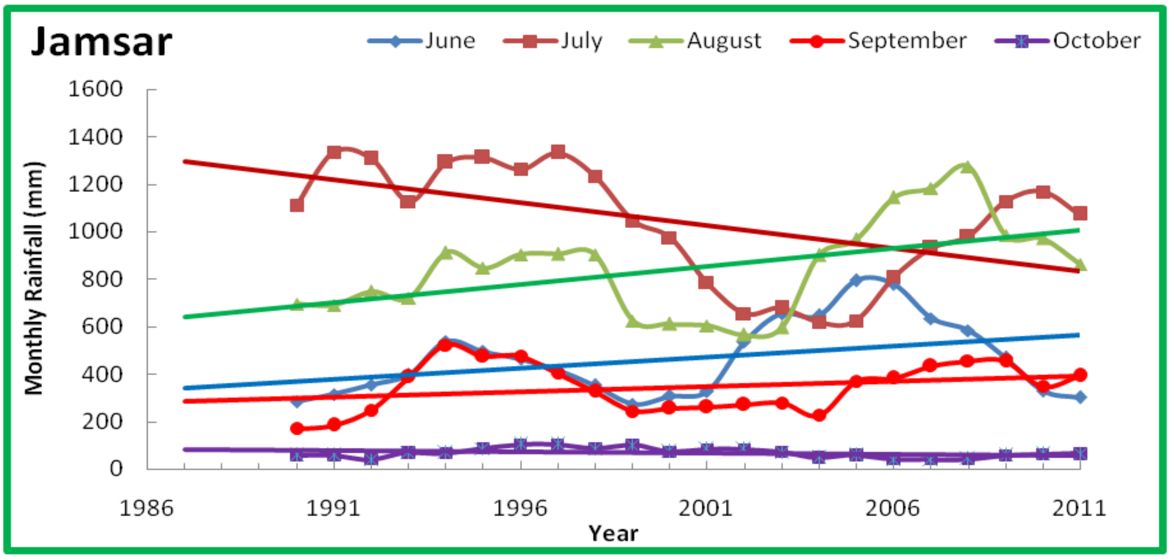


Figure 4.12 Monthly rainfall trends at Jamsar

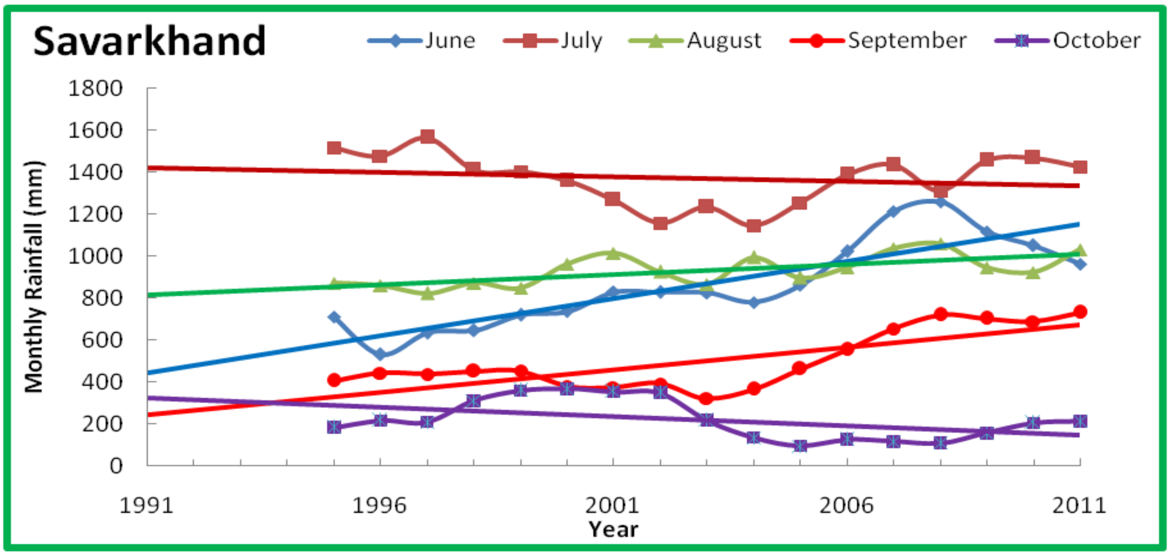


Figure 4.13 Monthly rainfall trends at Savarkhand

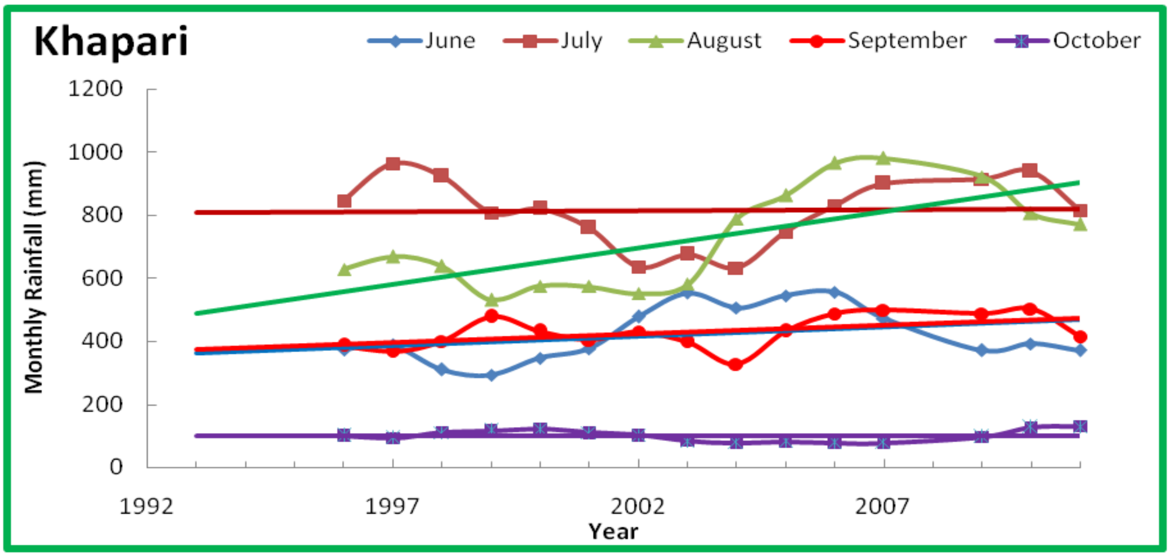


Figure 4.14 Monthly rainfall trends at Khapari

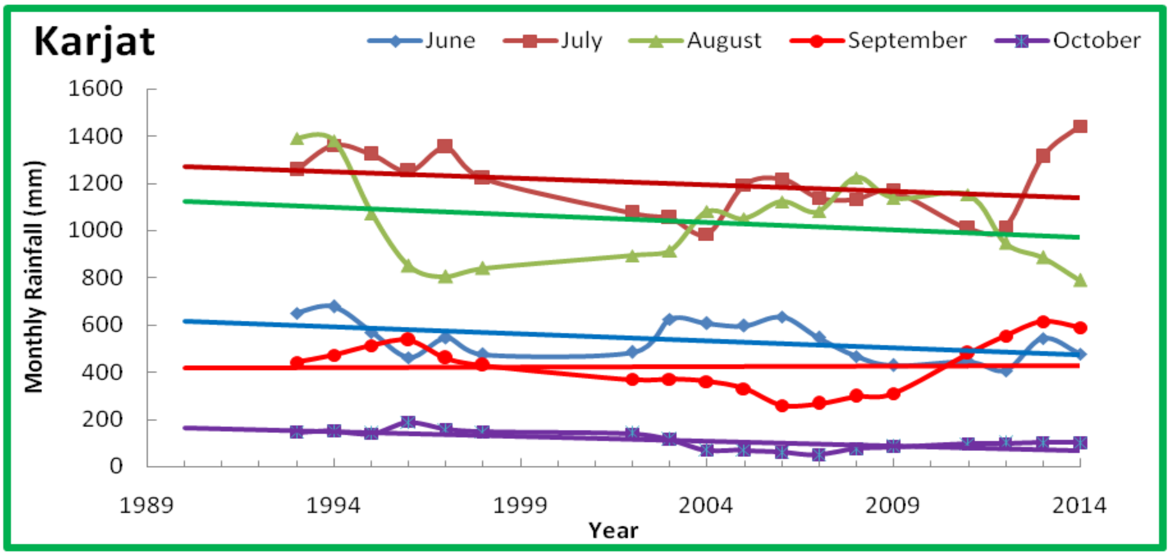


Figure 4.15 Monthly rainfall trends at Karjat

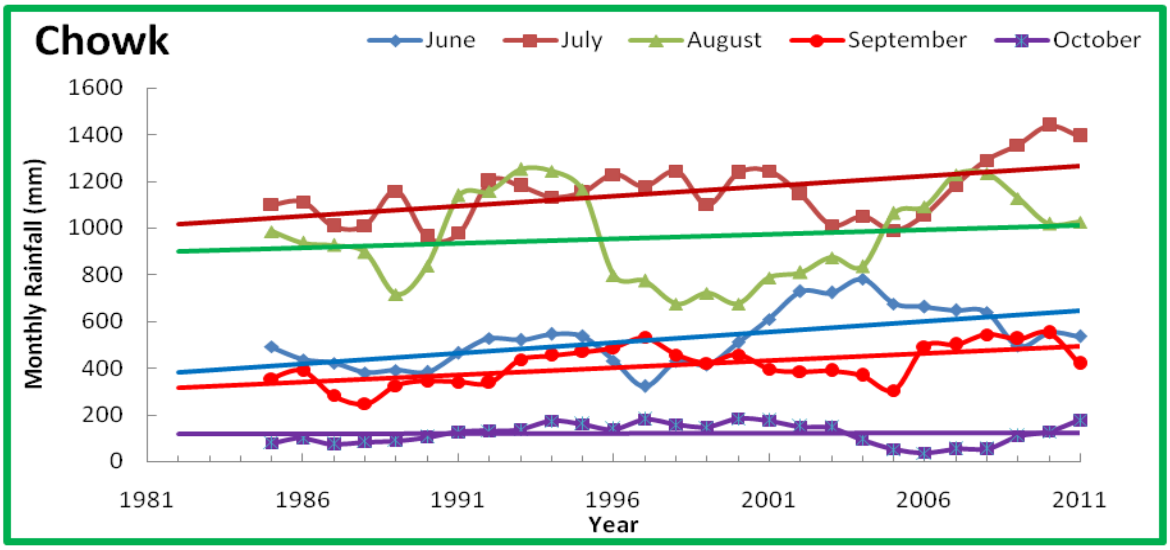


Figure 4.16 Monthly rainfall trends at Chowk

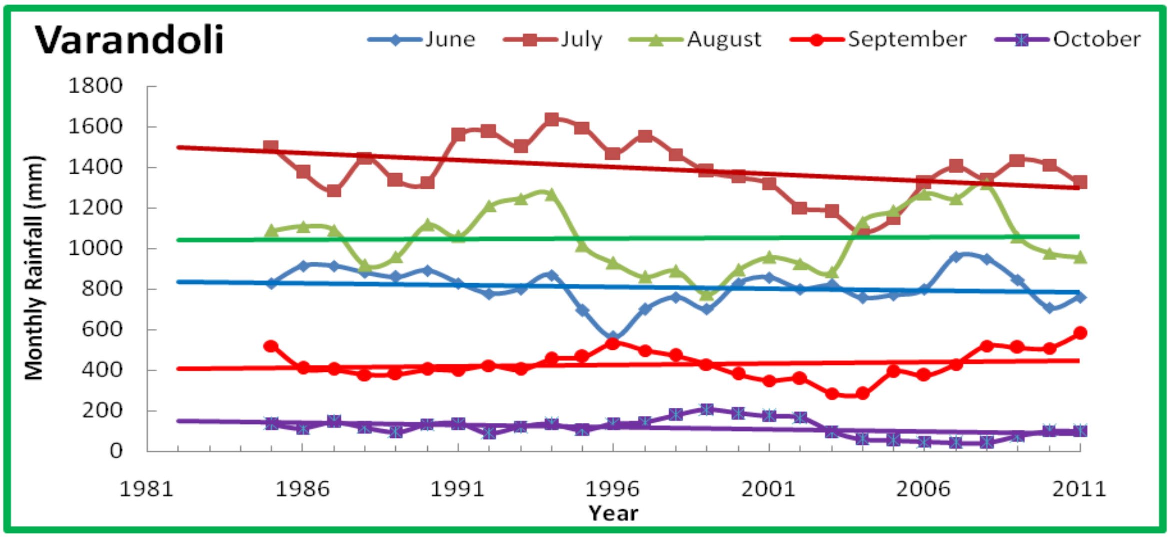


Figure 4.117 Monthly rainfall trends at Varandoli

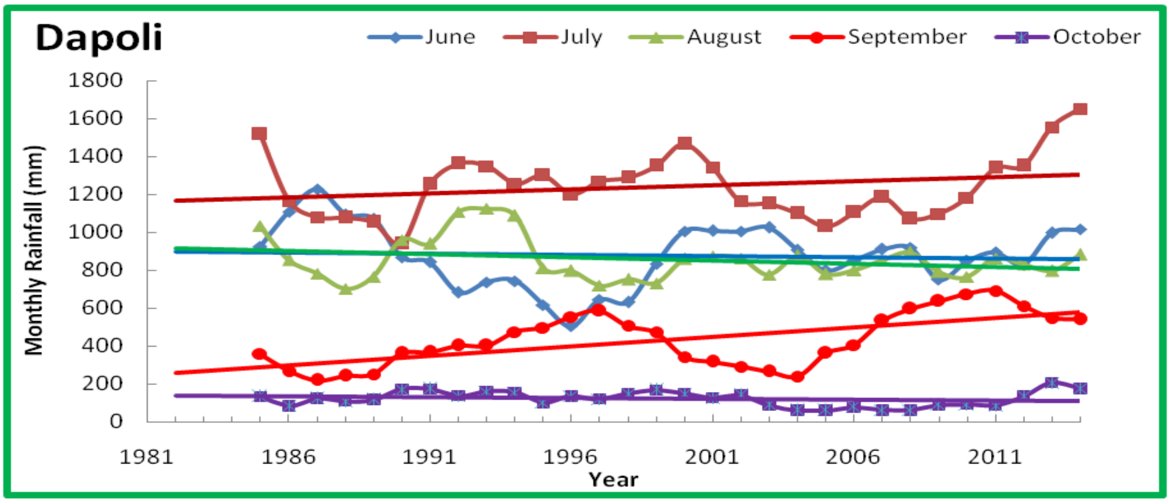


Figure 4.18 Monthly rainfall trends at Dapoli

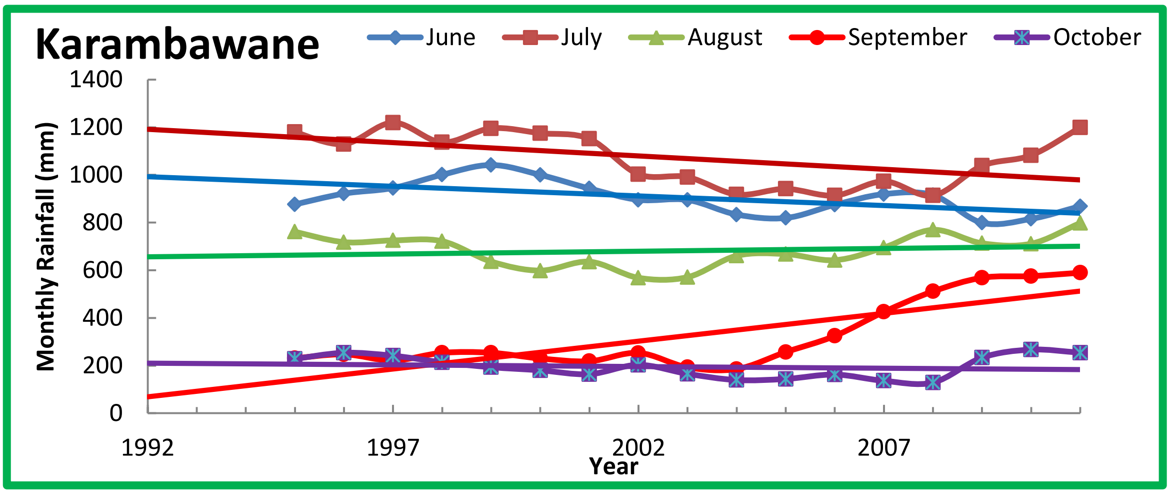


Figure 4.19 Monthly rainfall trends at Karambwane

Mulde station is situated in the southern part of Konkan region and showed decreasing trend in June and increasing trend in September which is shown in Figure 4.20. Vengurla showed increasing rainfall trend in July, September and October month which is shown in Figure 4.21. Maximum rate of increasing rainfall was observed in September month whereas maximum decreasing trend was observed in June month at Vengurla station. The decline in monthly rainfall was observed in June and August months at Vengurla station. Amboli station receives maximum rainfall in Konkan as well as in Maharashtra state and showed increasing trend in all months except August which is shown in Figure 4.22. Amboli station observed significant increasing rainfall trend only in month of September.

Monthly rainfall in July showed decreasing trend whereas June, August and September month showed increasing trend in Palghar district. Thane district exhibited increasing trend in June August and September months. Raigad district showed increasing trend only in September month at selected stations and remaining month exhibited both increasing and decreasing trend at various study stations. Ratnagiri district showed increasing trend only in September month at both study stations. Sindhudurg district showed significant increasing trend in July and September month whereas June month showed decreasing trend at all selected station in the district.

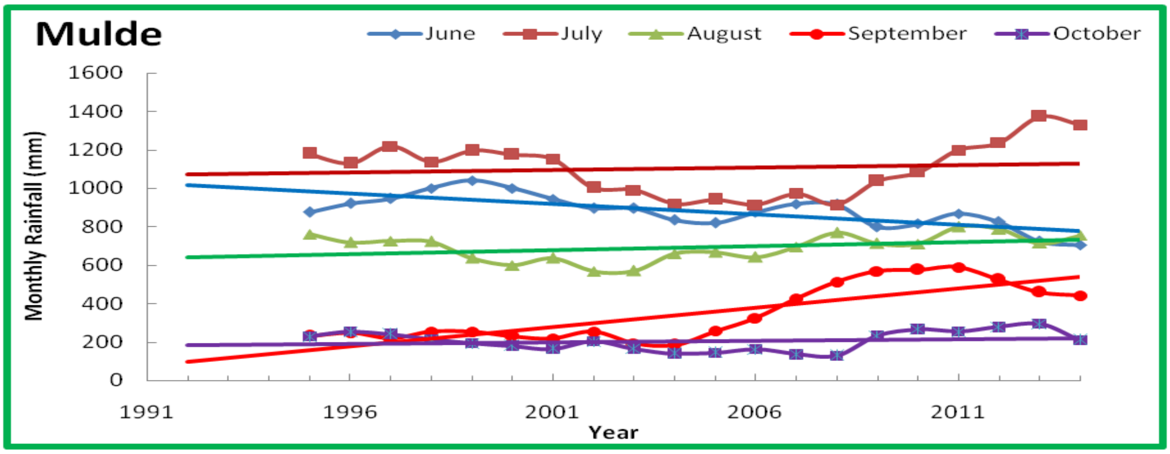


Figure 4.20 Monthly rainfall trends at Mulde.

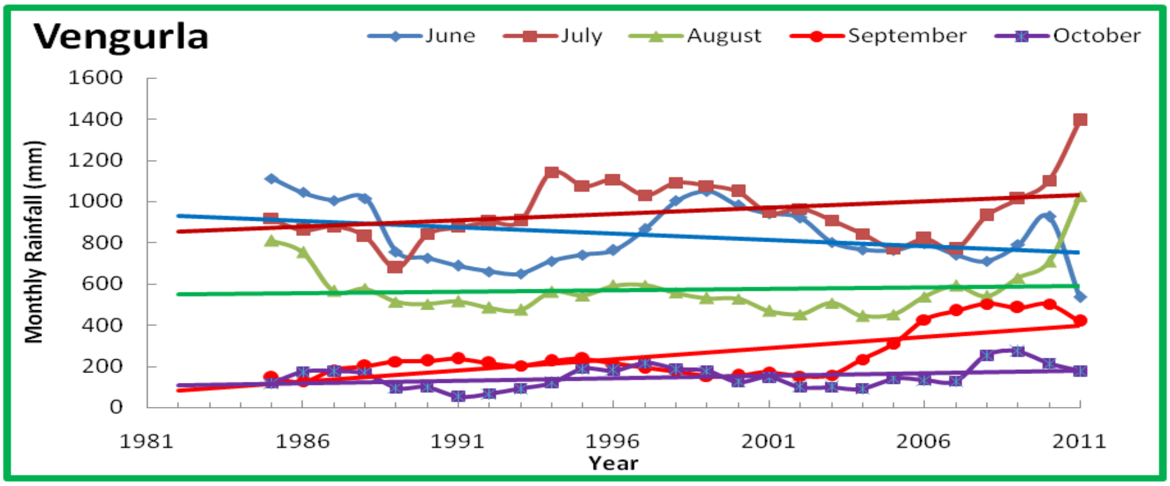


Figure 4.21 Monthly rainfall trend at Vengurla

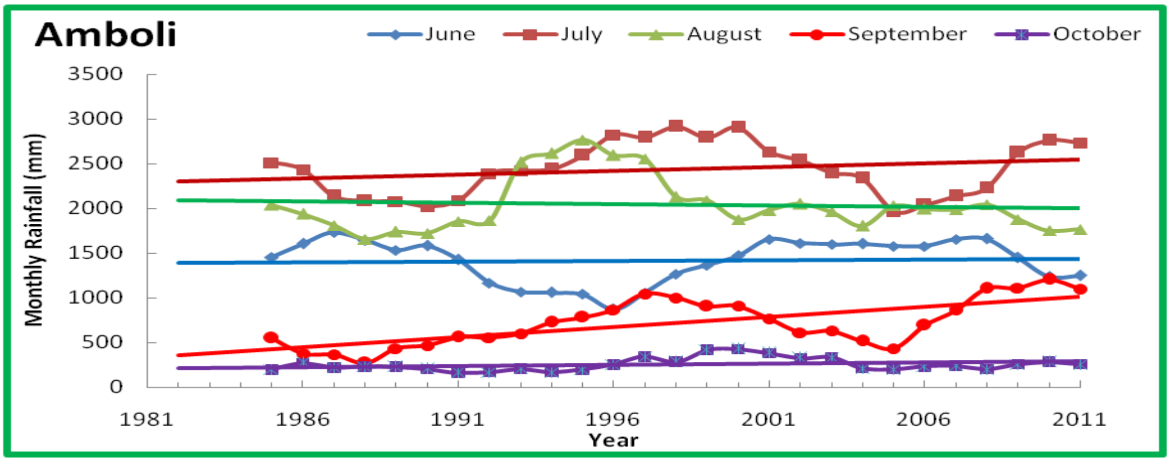


Figure 4.22 Monthly rainfall trend at Amboli

4.2.5 Regression method
4.2.5.1 Annual Rainfall

Regression method was used for the trend analysis of annual rainfall of eleven selected stations in the Konkan region. Regression constants a and b were therefore extracted from these equations. The regression parameters which are reported in the form of graph shows that the constant a, which is a reflection of the trend and b is the interceptor constant. Annual rainfall of Jamsar station was analysed and results are presented in Figure 4.23 which reveals that annual rainfall had increasing trend. Savarkhand station evinced increasing trend of annual rainfall. Khapari station showed lowest increasing trend of annual rainfall in the Konkan region whereas highest increasing trend were observed at Karambwane station and shown in Figure 4.25 and 4.30, respectively. Chowk, Mulde, Vengurla and Amboli station showed overall increasing trend of more than 10 mm/year which is shown in Figure 4.27, 4.31, 4.32 and 4.33, respectively whereas; Dapoli station showed overall 6.16 mm/year increasing trend and is shown in Figure 4.29 for the given period. Decreasing trend of annual rainfall was observed at Karjat and Varandoli station which is shown in Figure 4.26 and 4.28, respectively. Palghar, Thane, Ratnagiri and Sindhudurg district showed increasing trend of annual rainfall whereas Raigad district showed increasing as well as decreasing trend at various stations.

4.2.5.2 Monthly rainfall

Jamsar station reveals that July month showed decreasing trend of 10.41 mm per year whereas August month showed increasing trend of 12.73 mm per year. June and September month showed weak trend and October having very negligible positive trend at Jamsar which is presented in Figure 4.23.Figure 4.24 showed overall increasing trend of average monthly rainfall at Savarkhand station in June (4.6 mm/year), August (12.73 mm/year) and September (7.16 mm/year) month. Monthly rainfall in July (10.41 mm/year) and October (0.24 mm/year) exhibited decreasing trend at Savarkhand. Monthly rainfall condition of the Khapari station which is situated in northern part of Konkan region is shown in Figure 4.25.Monthly rainfall at Khapari reveals that August (10.28 mm/year) month showed significant increasing trend whereas June, September and October showed increasing trend but weak which is less than 3 mm per year. Only July (0.21 mm/year) exhibited very negligible decreasing trend of monthly rainfall at Khapari.

Karjat station showed increasing trend of monthly rainfall in July (4.56 mm/year) and September (4.99 mm/year) months. June (6.03 mm/year), August (17.78 mm/year) and October (2.54 mm/year) months showed decreasing trend at Karjat station which is shown

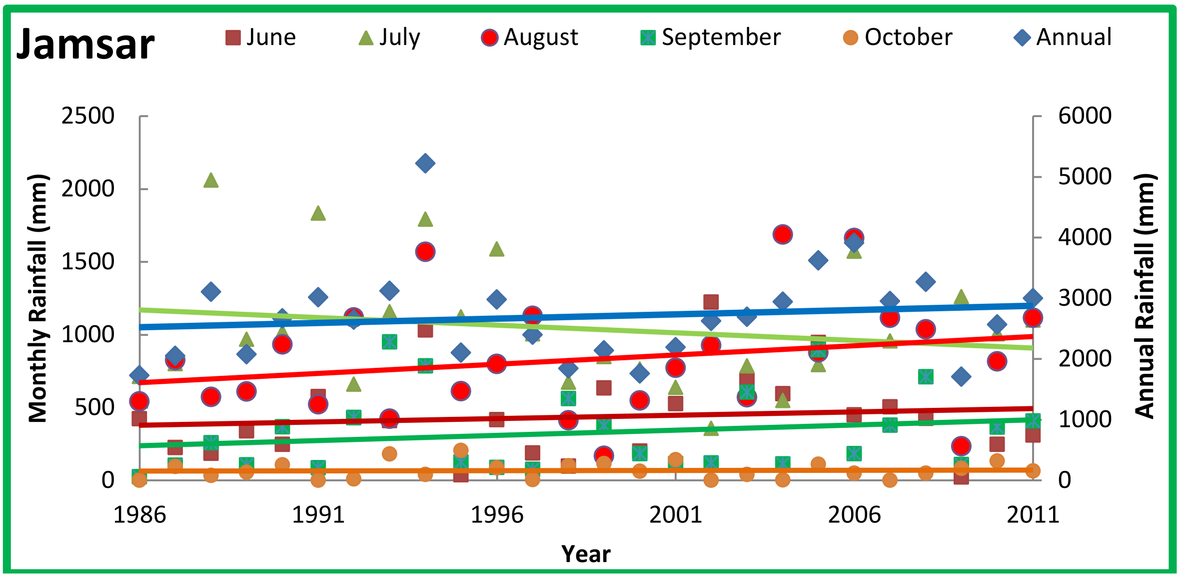


Fig. 4.23 Annual and monthly rainfall trends by using regression method at Jamsar.

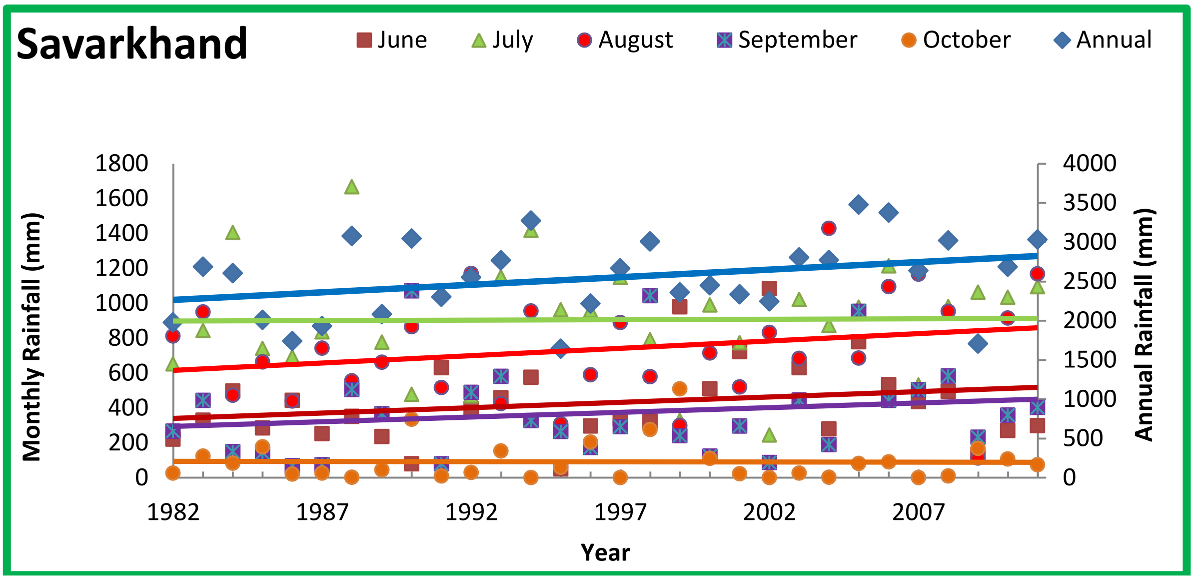


Fig. 4.24 Annual and monthly rainfall trends by using regression method at Savarkhand.

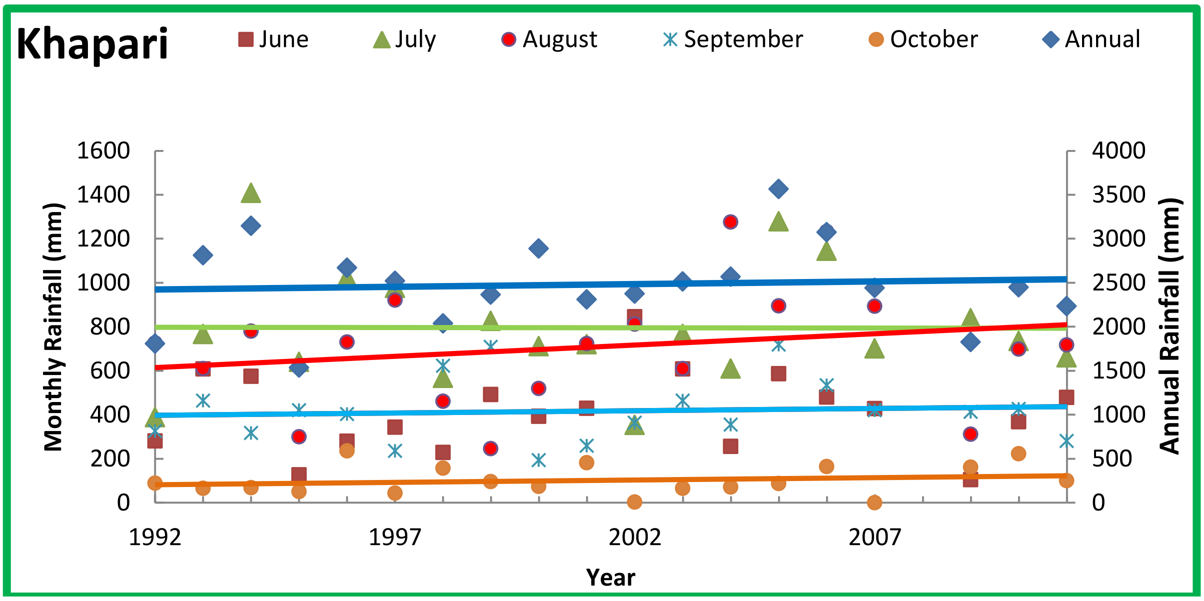


Fig. 4.25 Annual and monthly rainfall trends by using regression method at Khapari.

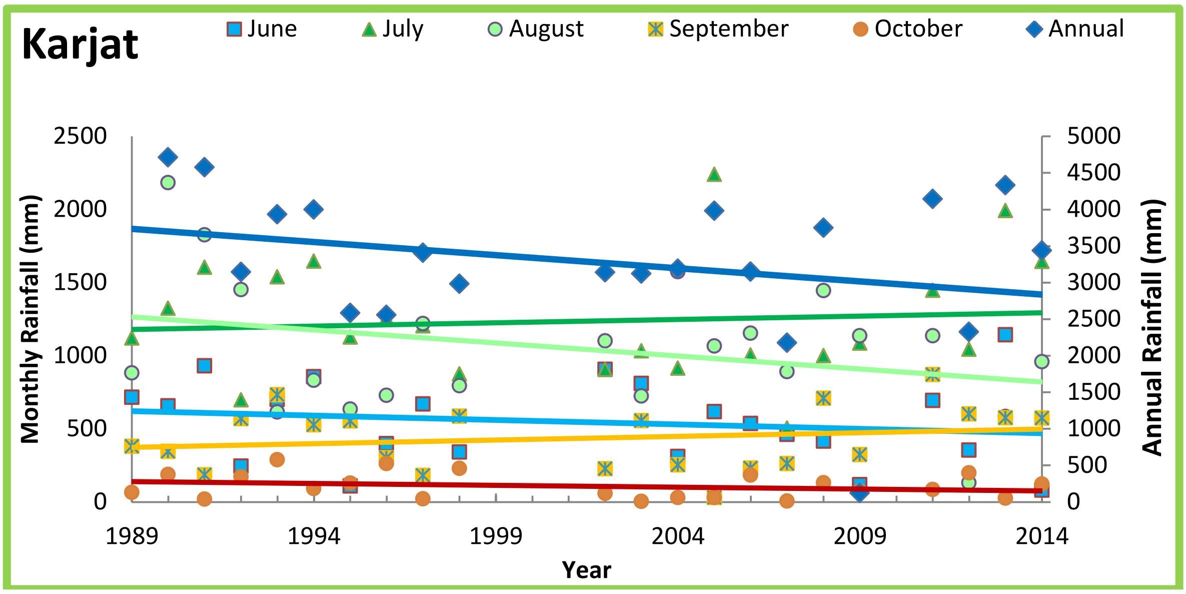


Fig. 4.26 Annual and monthly rainfall trends by using regression method at Karjat.

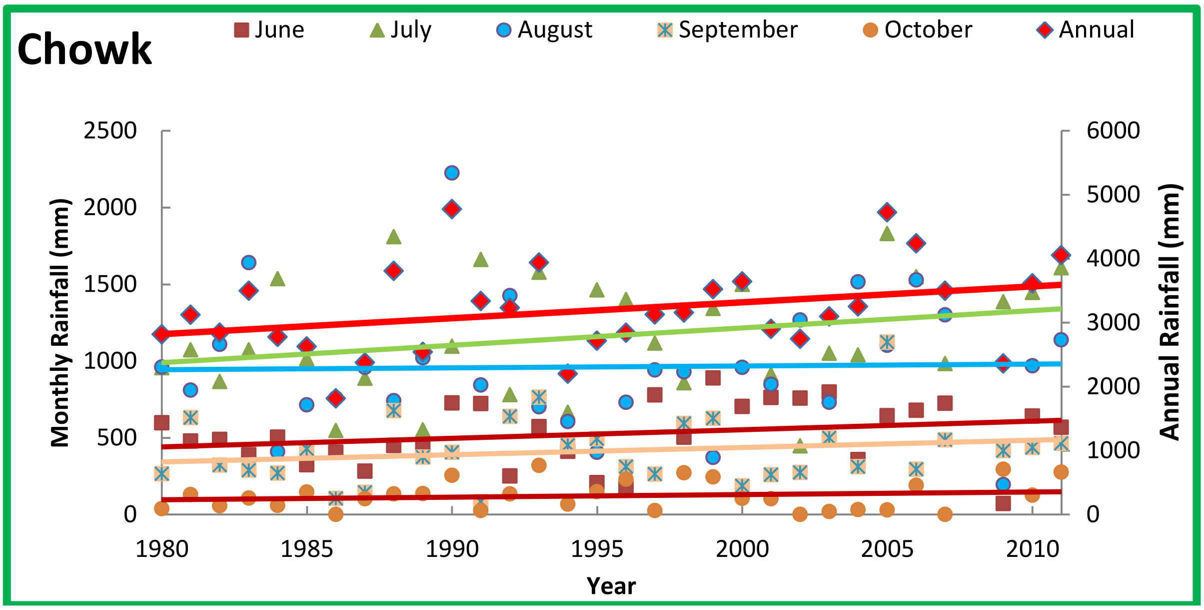


Fig. 4.27 Annual and monthly rainfall trends by using regression method at Chowk.

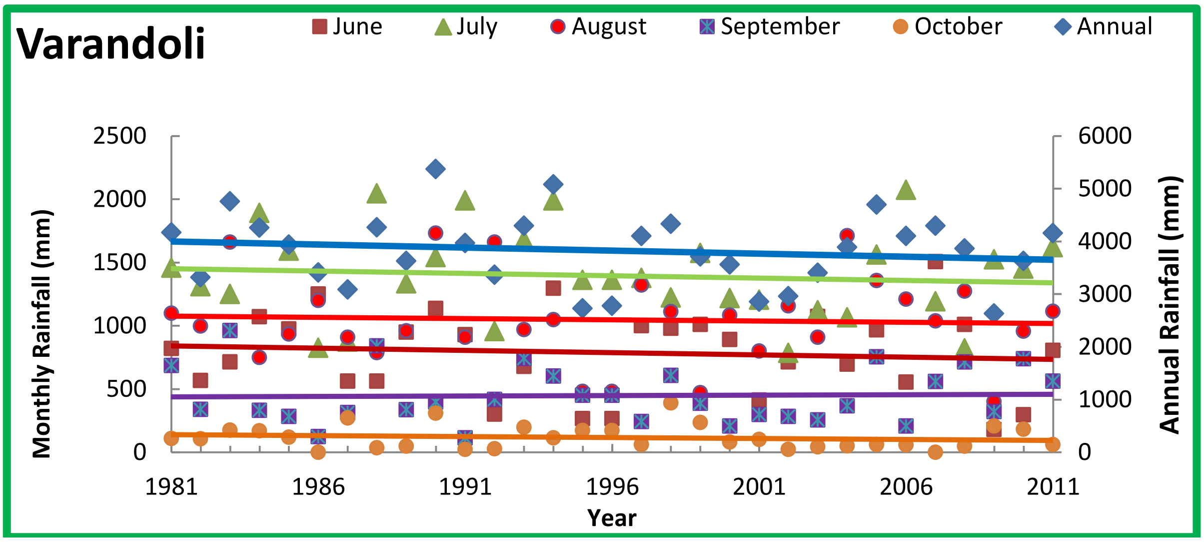


Fig. 4.28 Annual and monthly rainfall trends by using regression method at Varandoli.

in Figure 4.25. Chowk station of Konkan region showed significant increasing trend in all monsoon months which is shown in Figure 4.26. Chowk station showed increasing trend in all monsoon months whereas showed maximum increasing rate in July month which is presented in Figure 4.27. All months except September at Varandoli station showed decreasing trend which is shown in Figure 4.28. Decreasing rate of monthly rainfall was 3.57 mm/year in June, 3.72 mm/year in July, 1.98 mm/year in August and 1.5 mm/year in October at Varandoli station. Only September month showed very negligible increasing trend at Varandoli and rate of increasing rainfall was 0.66 mm/year.

Regression statistic of monthly rainfall at Dapoli is presented in Figure 4.29 which indicates that monthly rainfall in June (3.17 mm/year), July (2.85 mm/year) and September (6.68 mm/year) showed increasing trend whereas August (5.93 mm/year) and October (0.25 mm/year) month exhibited decreasing trend at Dapoli. The rate of increasing and decreasing rainfall at Dapoli was less than 7 mm for considered time period. Karambawane station which is situated in southern part of Konkan and monthly rainfall condition were presented in Figure 4.30. All months showed increasing trend at Karambawane which was 17.61 mm in June, 2.98 mm in July, 9.61 mm in August, 24.61 mm in September and 0.03 mm in October.

Monthly rainfall of Mulde station is shown in Figure 4.31 which evince that monthly rainfall were increasing in July (13.18 mm/year), August (0.86 mm/year), September (15.37 mm/year) and October (0.63 mm/year). Rainfall in June month exhibited decreasing trend of 10.96 mm/year at Mulde station. Vengurla station of Konkan region showed increasing trend in July (4.58 mm/year), September (10.51 mm/year) and October (3.5 mm/year) month however rainfall in June (4.35 mm/year) and August (5.94 mm/year) month showed decreasing trend at Vengurla station which is presented in Figure 4.32. Monthly rainfall condition at Amboli station is shown in Figure 4.33.Increasing trend were exhibited in July (7.95 mm/year), September (18.46 mm/year) and October (3.08 mm/year) whereas decreasing trend evinced in June (1.6 mm/year) and August (8.47 mm/year) at Amboli station.

Annual and monthly rainfall variation was increased in both north and south part of the study region and middle part of Konkan region showed more uniform rainfall pattern as compared other part for considered time period. Varandoli station showed decreasing trend in maximum number of months followed by Karjat and decreasing trend wasn’t exhibited in any month at Chowk and Karambawane station. Annual increasing trend evinced in south Konkan however north Konkan observed both increasing and decreasing trend in annual rainfall. The same results were presented by Guhathakurta Pulak. and Rajeevan (2008) regarding annual rainfall trend using linear regression test method.

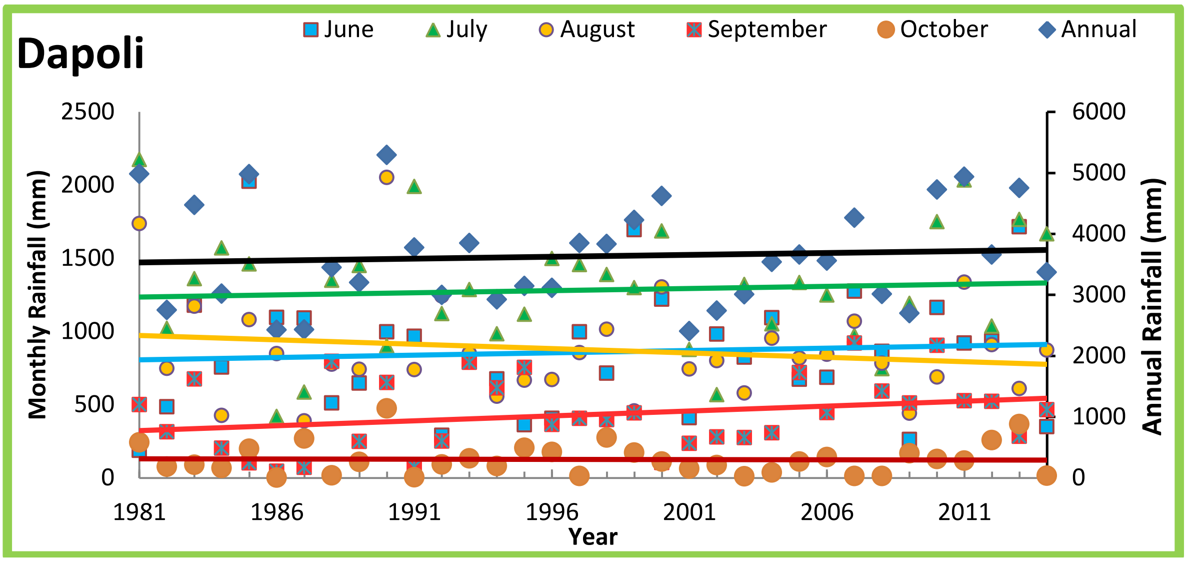


Fig. 4.29 Annual and monthly rainfall trends by using regression method at Dapoli.

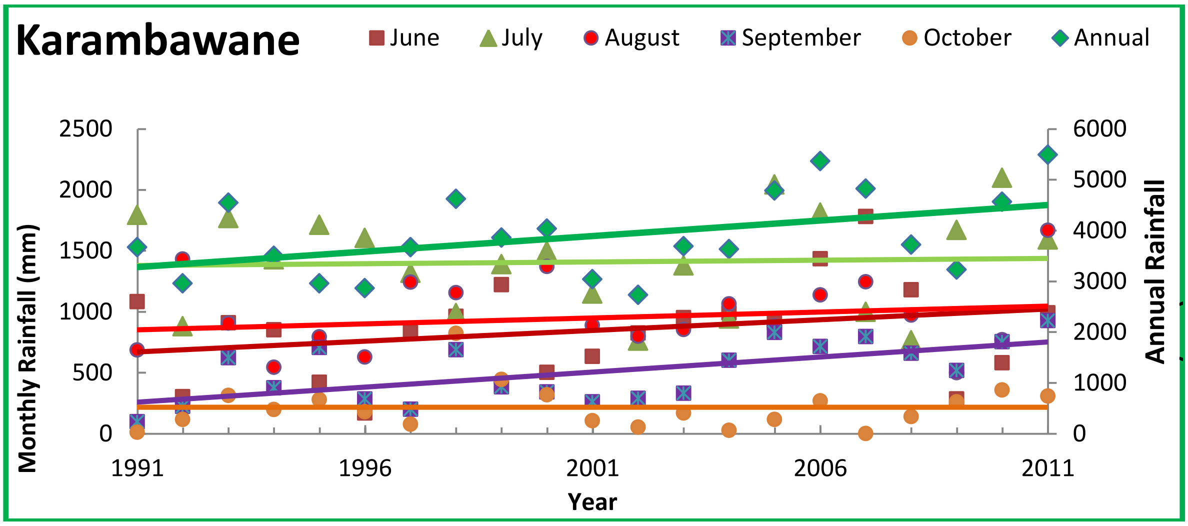


Fig. 4.30 Annual and monthly rainfall trends by using regression method at Karambawane.

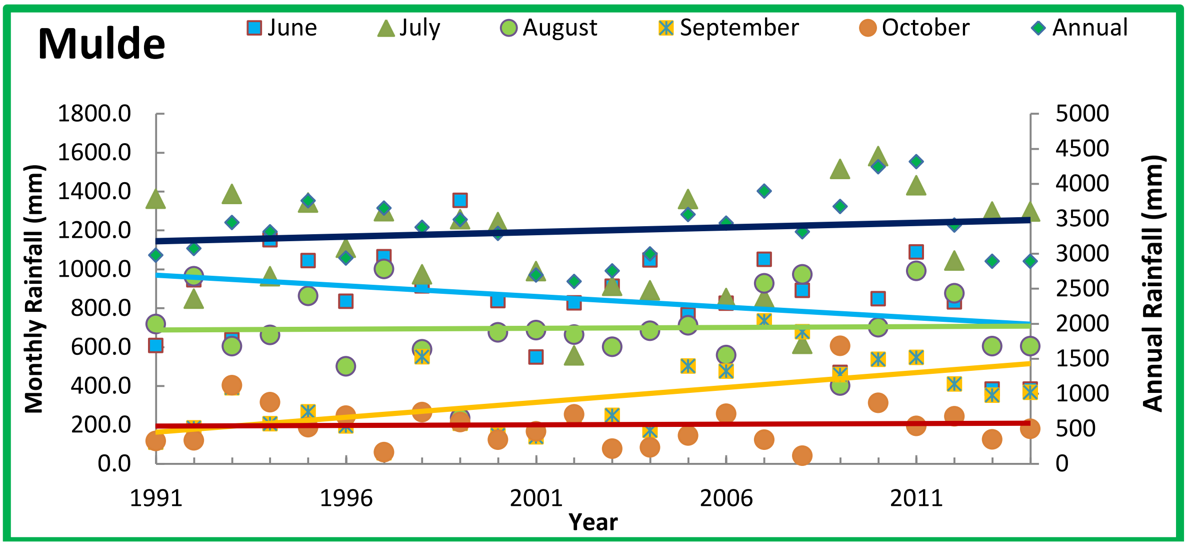


Fig. 4.31 Annual and monthly rainfall trends by using regression method at Mulde.

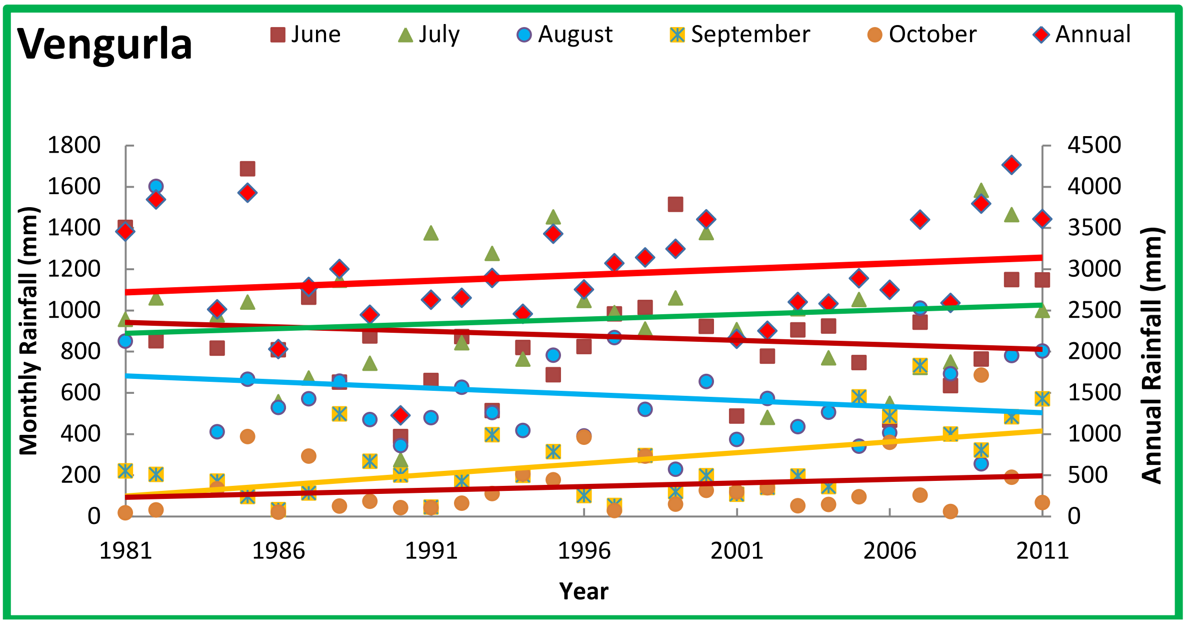


Fig. 4.32 Annual and monthly rainfall trends by using regression method at Vengurla.

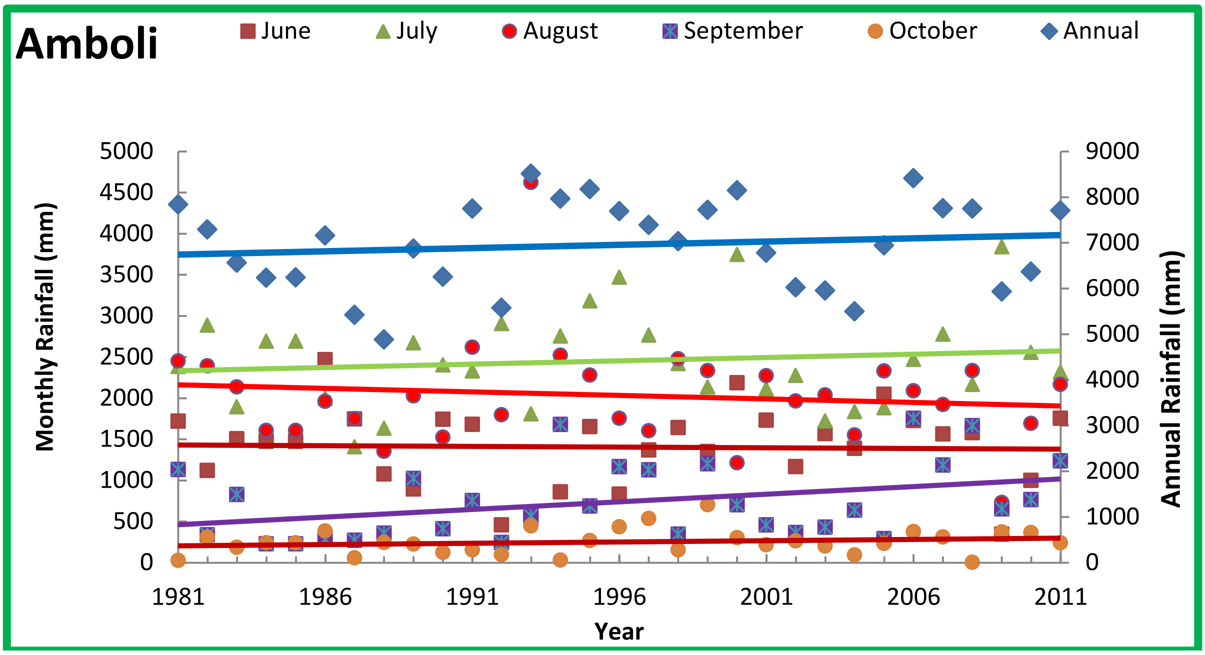


Fig. 4.33 Annual and monthly rainfall trends by using regression method at Amboli.

4.3 Comparison of rainfall trends

4.3.1Trends of annual rainfall

Various trend analysis methods were compared for annual basis and results are presented in fig. 4.34. Mann Kendall method did not show any trend of annual rainfall all over the Konkan region. Whereas Sen's Slope, Moving average and Regression method showed increasing trend of annual rainfall in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed increasing as well as decreasing trend at various stations. Turning point test evinced decreasing trend in Raigad and Sindhudurg district whereas Palghar, Thane and Ratnagiri district didn't showed any trend.

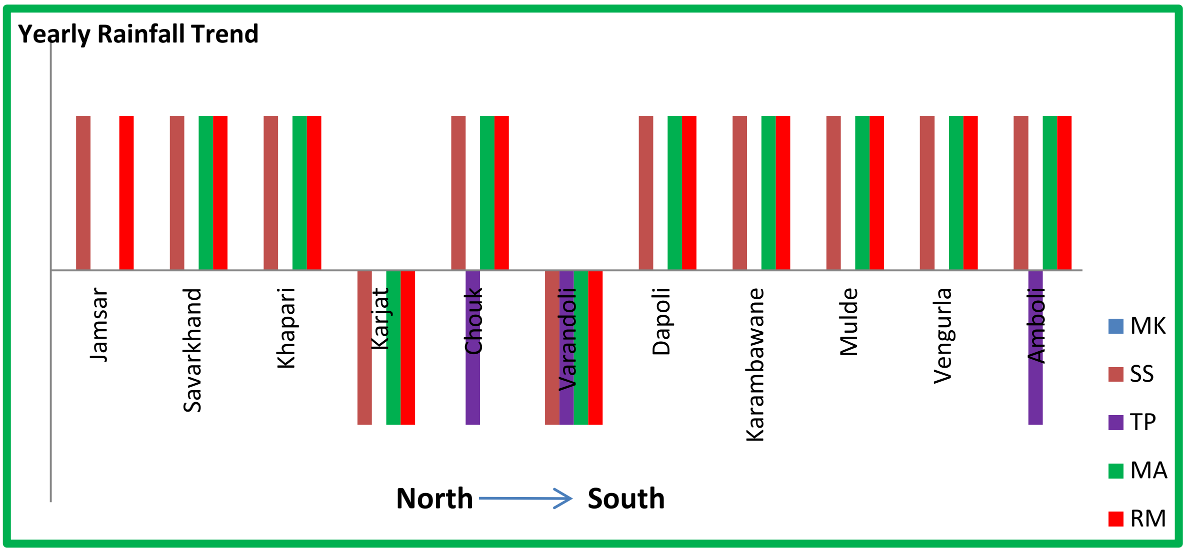


Fig. 4.34 Method-wise trend of annual rainfall at selected stations

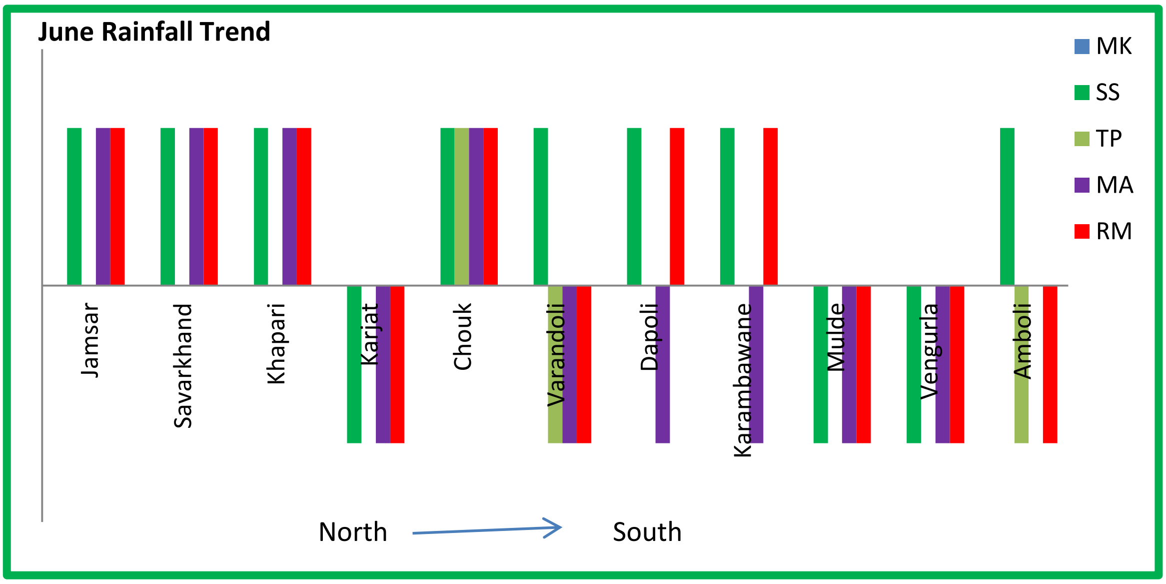


Fig. 4.35 Method-wise trend of June month rainfall at selected stations

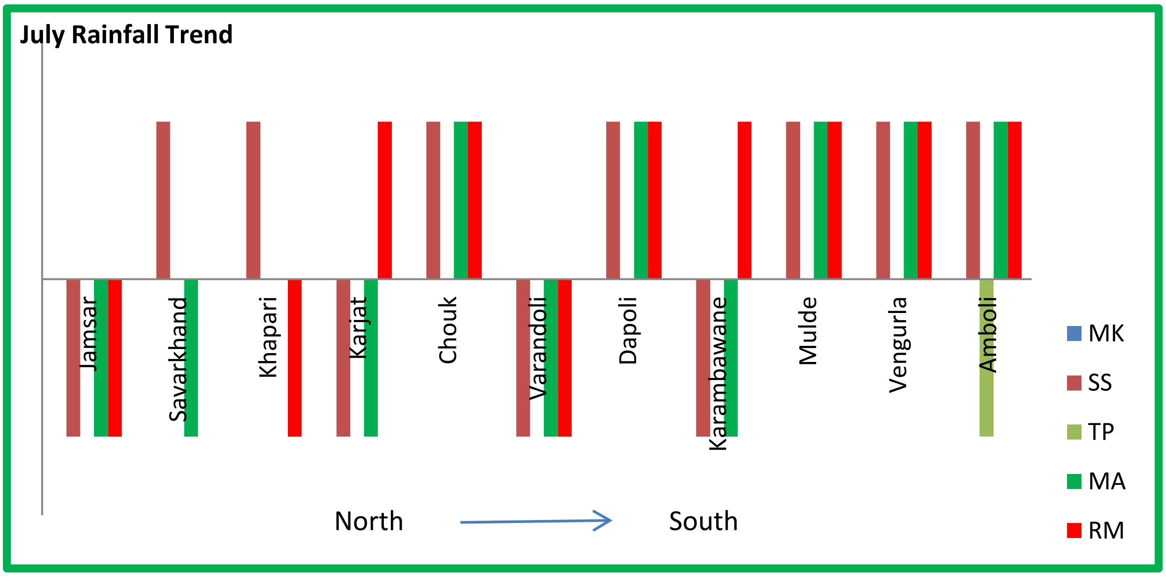


Fig. 4.36 Method-wise trend of July month rainfall at selected stations

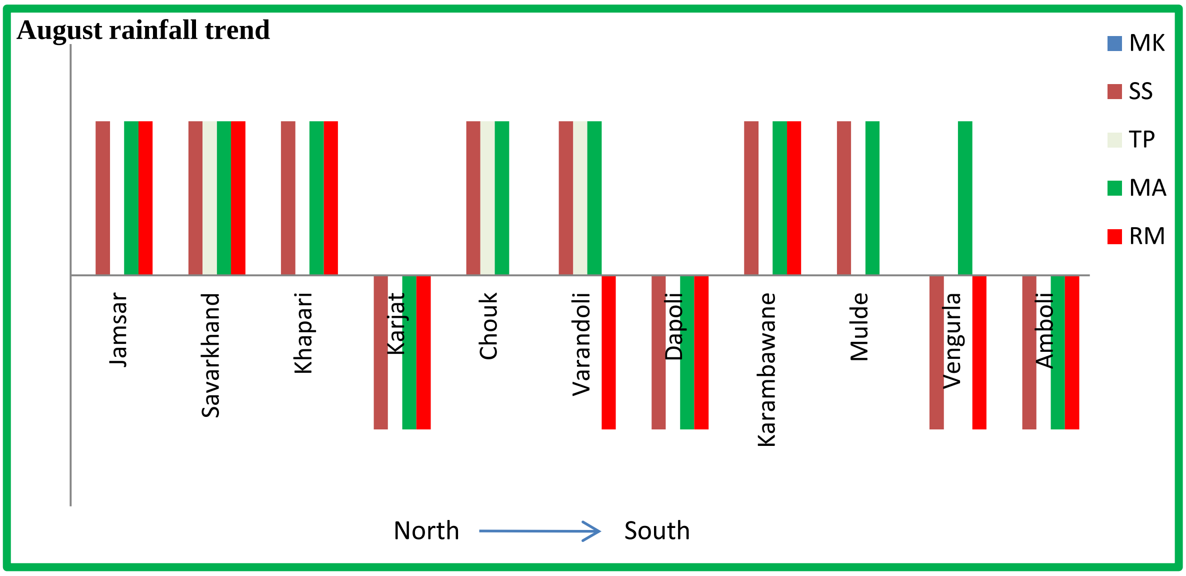


Fig. 4.37 Method-wise trend of August month rainfall at selected stations

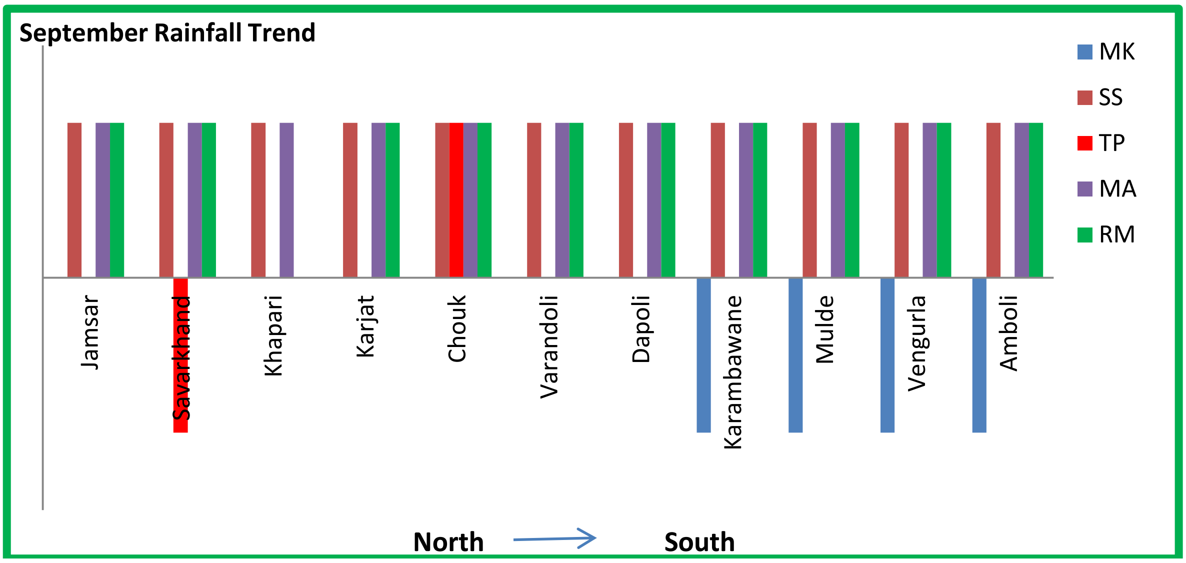


Fig. 4.38 Method-wise trend of September month rainfall at selected stations

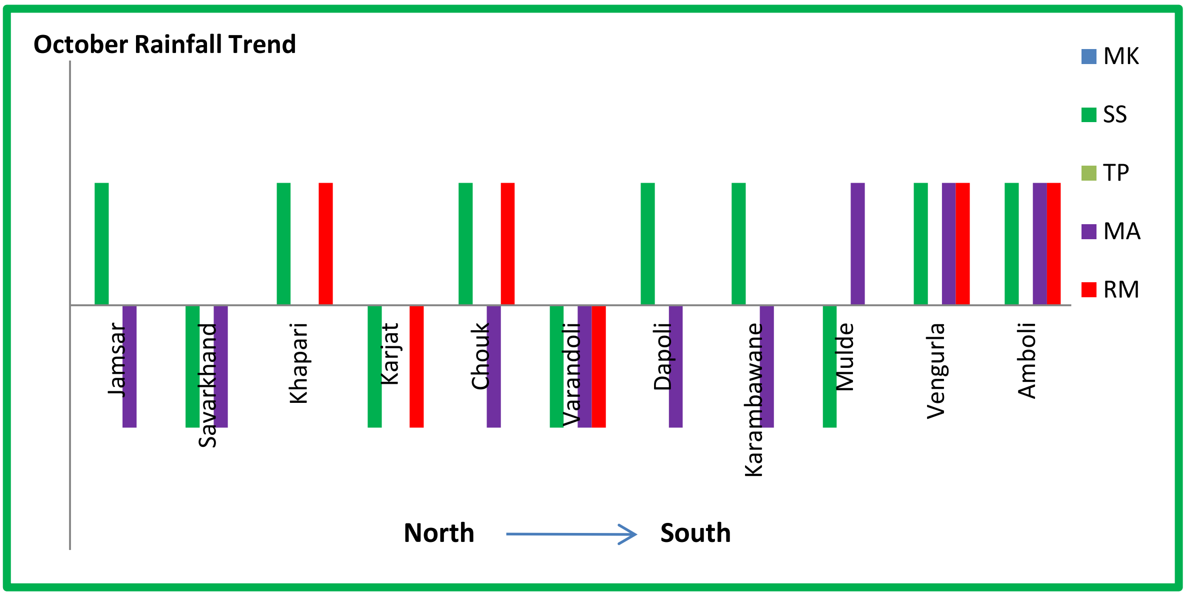


Fig. 4.39 Method-wise trend of October month rainfall at selected stations

4.3.2 Trends of monthly rainfall

4.3.2.1 Rainfall Trend for June

Monthly rainfall of June month was statistically analysed by using five different methods and results are presented in fig. 4.35. Results showed that Mann Kendall method did not exhibited any trend of June month rainfall throughout the Konkan region. Sen's Slope, Moving average and Regression method showed increasing trend in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed both increasing and decreasing trend of June month rainfall at different stations. Turning point test showed decreasing trend in Sindhudurg district whereas Palghar, Thane and Ratnagiri district didn't show any trend of monthly rainfall in the month of June.

4.3.2.2 Rainfall trend for July

Results of monthly rainfall of July are shown in fig. 4.35.Mann Kendall method did not evinced any trend of July month rainfall all over the Konkan region. Sen's Slope method showed increasing trend of monthly rainfall of July in Thane and Sindhudurg district, whereas Palghar, Raigad and Ratnagiri showed both increasing as well as decreasing trend at different stations of July month rainfall. Turning point test showed decreasing in Sindhudurg district whereas other region didn't exhibit any trend of monthly rainfall of July. Moving average method showed decreasing trend in Palghar district and increasing trend in Sindhudurg district whereas Raigad and Ratnagiri exhibited both increasing as well as decreasing trend at different stations. Thane district didn't exhibit any trend in July month. Regression method showed decreasing trend in Palghar and Thane district whereas increasing trend in Ratnagiri and Sindhudurg at different stations in the month of July. Raigad district showed both increasing and decreasing trend at different stations in July month.

4.3.2.3 Rainfall trend for August

Mann Kendall method has not show any significant trend of August month rainfall all over the Konkan region which is shown in fig. 4.37. Sen's Slope and Moving average method showed similar trend of increasing rainfall for August month in Palghar and Thane district whereas Raigad, Ratnagiri and Sindhudurg district exhibited both increasing as well as decreasing trend at different stations. Turning point test showed increasing trend in Palghar and Raigad district which are situated in northern part of the study region whereas south part of Konkan region didn't evinced any trend for August month rainfall. Regression method showed increasing trend in Palghar and Thane district whereas; decreasing trend in Raigad and Sindhudurg district and Ratnagiri exhibited both increasing as well as decreasing trend for different stations in August month rainfall. Mann Kendall and Turning point test showed similar results for the south Konkan region. Results also showed that most of the methods showed increasing trend in north Konkan whereas South Konkan showed decreasing trend of rainfall in August month. .

4.3.2.4 Rainfall trend for September

September month rainfall was analysed for selected study station by using five different methods and results are presented in fig. 4.38. Mann Kendall method showed increasing trend for September month rainfall in Ratnagiri and Sindhudurg district at different stations whereas; Palghar, Thane and Raigad did not show any trend of Rainfall in the month of September. Sen's slope and Moving average methods exhibited increasing trend for September month all over the Konkan region. Turning point test showed the trend only in Palghar and Raigad district at different stations having decreasing and increasing trend, respectively. Regression method showed increasing trend in Palghar, Raigad, Ratnagiri and Sindhudurg district whereas Thane district didn't exhibit any trend in September month.

4.3.2.5 Rainfall trend for October

Rainfall received in the month of October is less as compared to other monsoon months and trend observed in the month were estimated by using five different methods and results are presented in fig. 4.39. Mann Kendall method and Turning point test didn't show any significant trend of October month rainfall in the Konkan region. Sen's slope method evinced only increasing trend in Thane and Ratnagiri district whereas Palghar, Raigad and Sindhudurg district exhibited both increasing as well as decreasing trend at different stations of rainfall in October month. Moving average method exhibited decreasing trend in Palghar, Raigad and Ratnagiri district whereas; Sindhudurg showed increasing trend and thane district did not exhibit any trend in October month. Regression method showed increasing trend in Thane and Sindhudurg district and both increasing as well as decreasing trend at different stations in Raigad district whereas; Palghar and Ratnagiri did not show any trend in October month.

4.3.3 Weekly rainfall trend

Weekly rainfall of selected stations was analysed by using Mann Kendall and Sen's slope method and Results were presented in Table 4.24. Mann Kendall method showed only decreasing trend of weekly rainfall for 28th and 33rd SMW in Palghar district whereas; Sindhudurg district showed only increasing trend at all stations in different SMW. Raigad and Ratnagiri showed both increasing as well as decreasing trend in various SMW. Mann Kendall method did not show any trend of weekly rainfall in Thane district throughout the monsoon season. Sen's slope method exhibited either increasing or decreasing trend in

Palhgar district from 24th to 39th SMW. Except 22nd, 42nd and 43rd SMW all remaining weeks exhibited either increasing or decreasing trend in Thane, Raigad and Ratnagiri district. Sen's slope method evinced either increasing or decreasing trend at different SMW at various stations of Sindhudurg district.

Map of annual rainfall trend of Konkan region

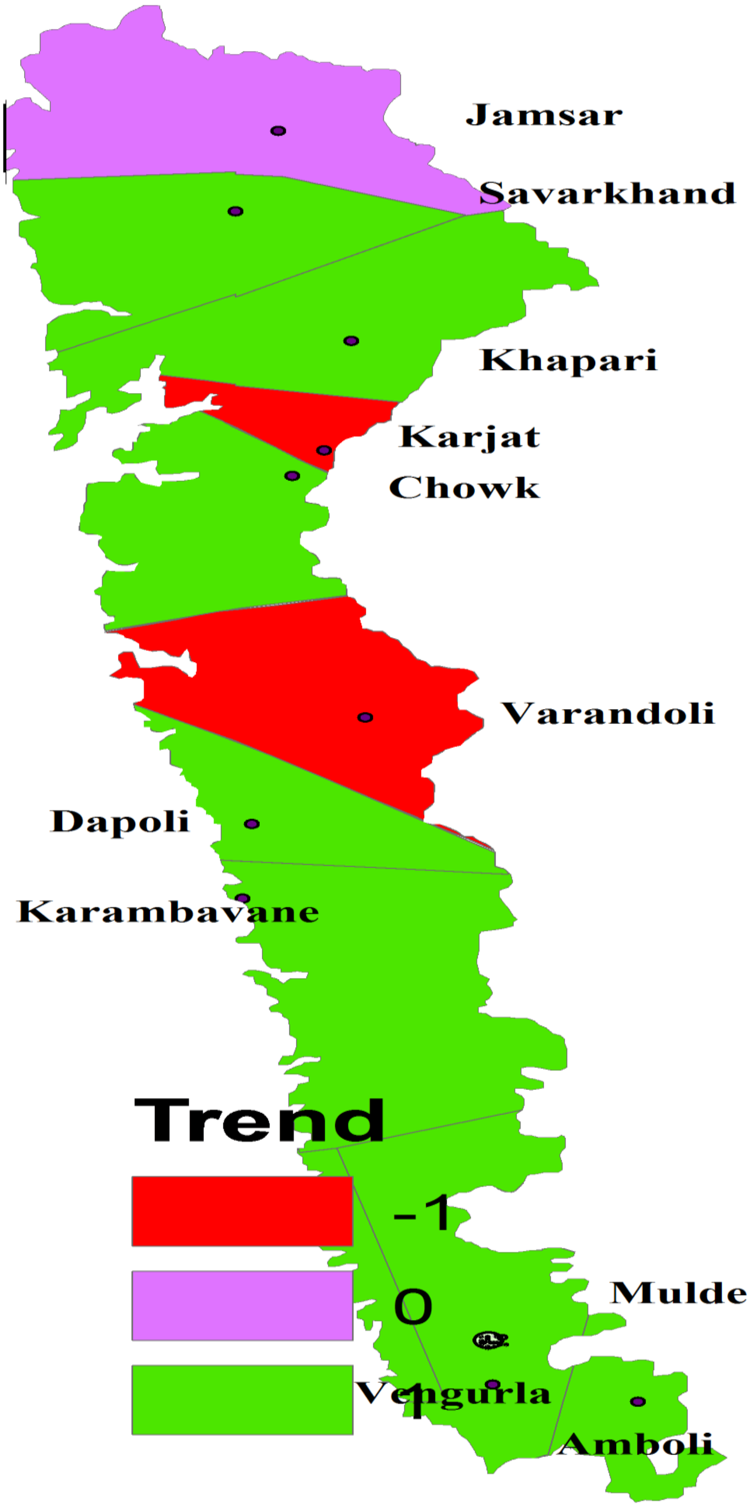


Table 4.20 Method-wise Weekly rainfall trend at selected stations

MW	Jamsar		Savarkhand		Khapari		Karjat		Chowk		Varandoli		Dapoli		Karambwane		Mulde		Vengurla		Amboli	
	MK	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**	**MK**	**SS**
22	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	↑ET	NT	↑ET	NT	NT	NT	NT
23	NT	NT	NT	↑ET	NT	↓ET	NT	NT	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET
24	NT	↓ET	NT	↓ET	NT	↓ET	NT	NT	NT	↑ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET
25	NT	↑ET	NT	↑ET	NT	↓ET	NT	NT	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET
26	NT	↑ET	NT	↑ET	NT	↑ET	NT	NT	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	1.1	NT	↑ET
27	NT	↑ET	NT	↑ET	NT	↑ET	NT	NT	↑ET	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	↑ET	↑ET
28	↓ET	↓ET	↓ET	↓ET	NT	↓ET	NT	NT	NT	↓ET	↓ET	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET
29	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	NT	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET
30	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET
31	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET
32	NT	↓ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET
33	↓ET	↓ET	↓ET	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET
34	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↑ET
35	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↑ET	↑ET	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	↑ET	↑ET
36	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	NT	NT	↑ET	NT	↑ET	↑ET	↑ET	↑ET	↑ET	NT	↑ET
37	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	↑ET	↑ET	↑ET	↑ET	↑ET	↑ET	NT	↑ET
38	NT	↑ET	NT	NT	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↑ET	↑ET	↑ET	NT	↑ET	NT	↓ET
39	NT	↓ET	NT	NT	NT	↑ET	NT	↓ET	NT	NT	NT	↓ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET
40	NT	NT	NT	NT	NT	↑ET	NT	NT	NT	NT	NT	NT	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	NT
41	NT	NT	NT	NT	NT	↑ET	NT	NT	↑ET	↑ET	NT	↑ET	NT	NT	NT	NT	NT	↓ET	NT	NT	NT	1.1
42	NT	NT	NT	NT	NT	NT	↓ET	NT	NT	NT	NT	NT	NT	NT	↓ET	↓ET	NT	↓ET	NT	NT	NT	NT
43	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	↑ET	NT	NT	NT	NT

Note: MK – Mann-Kendall test; SS – Sen's Slope test; NT – No Trend; ↑ET – Exist Increasing Trend; ↓ET – Exist Decreasing Trend

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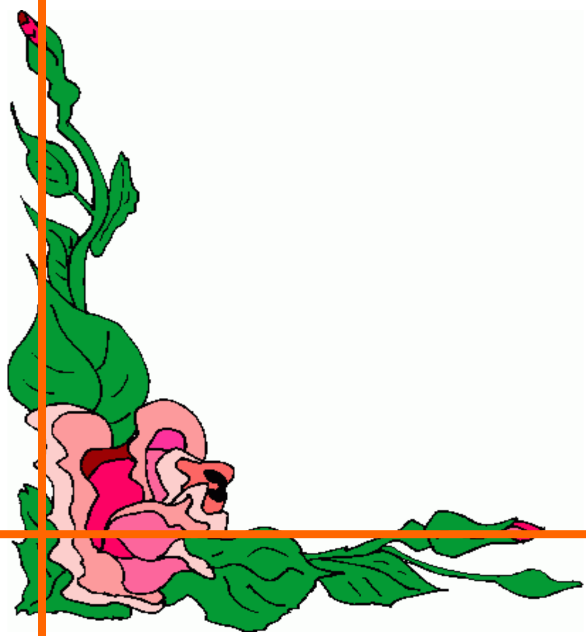
Introduction

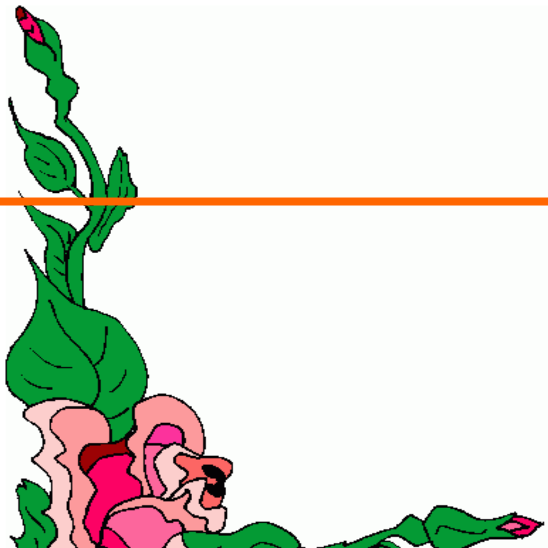
Review of Literature

Material and Methods



Results and Discussion

Summary and Conclusions



Bibliography

Appendices

V. SUMMARY AND CONCLUSIONS

The Konkan region receives the heavy rainfall but differs from other tropical regions because of the strong influence of the Arabian Sea and the Sahyadri hilly ranges. Rainfall is one of the substantial weather indicators of climate change (Mirza and Hossian, 2004). Rising temperatures across the globe would likely results in changes in precipitation and atmospheric moisture through a more active hydrological cycle, leading to increases in water holding capacity throughout the atmosphere at a rate of about 7 per cent per °C (IPCC 2007). The present study was undertaken for Konkan region of Maharashtra which is coastal part of Maharashtra covering total geographical area of 3.09 Mha. The region receives 46 per cent of total precipitation of the state on just 10 per cent of total area of the Maharashtra state. The Konkan region has hilly topography with highly drainable lateritic and non-lateritic soils. Due to porous nature of geological strata water holding capacity of soil is less which cause the most of rainfall drains away fastly in rainy season to adjacent Arabian Sea. Even though area having heavy rainfall, it faces water scarcity in summer season.`Daily rainfall data of Jamsar, Savarkhand, Khapari, Karjat, Chowk, Varandoli, Dapoli, Karambavane, Mulde, Vengurla and Amboli, stations. The daily data was converted into weekly, monthly and annual rainfall. Trends of monthly and annual rainfall were estimated by using Mann Kendall, Sen's Slope, Turning point test, Moving average and Regression methods whereas trends of weekly rainfall was calculated with the help of Mann Kendall and Sen's Slope method. Summary of results is as follows.

5.1 Summary:

Average annual rainfall for available data at Jamsar (2702 mm), Savarkhand (2547 mm), Khapari (2478 mm), Karjat (2801 mm), Chowk (3197 mm), Varandoli (3824 mm), Dapoli (3635 mm), Karambawane (3893 mm), Mulde (3330 mm), Vengurla (2922 mm) and Amboli (6981 mm).All station received more than 400 mm rainfall in June, 900 mm in July except Khapari, 700 mm in August, 300 mm in September, except Vengurla and less than 200 mm rainfall in October month, except Karambwane, Mulde and Amboli. The average weekly rainfall increased continuously from week 22nd to 26th SMW except Dapoli station. Maximum rainfall received in week number 30th at Jamsar, Savarkhand, Karjat, Karambawane and Vengurla station whereas Amboli, Mulde Varandoli, chowk received highest rainfall in 28th SMW and Khapari in 29th SMW.

According to Mann Kendall method annual as well as June, July, August and October month rainfall did not show any trend all over the Konkan region where as September month rainfall exhibited increasing trend in Ratnagiri and Sindhudurg district and Palghar, Thane, Raigad district did not showed any trend. Mann Kendall method also showed only decreasing trend of weekly rainfall in few SMW in Palghar district whereas only increasing trend in Sindhudurg district and Raigad, Ratnagiri district showed both increasing as well as decreasing trend in various SMW. Mann Kendall method did not exist any trend of weekly rainfall in Thane district throughout the monsoon season.

Sen's Slope method showed increasing trend of annual rainfall in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed increasing as well as decreasing trend at various stations. Sen's Slope method also showed increasing trend of June month rainfall in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed both increasing and decreasing trend. Increasing trend of July monthly rainfall was showed in Thane and Sindhudurg district whereas Palghar, Raigad and Ratnagiri district showed both increasing as well as decreasing trend of July moth rainfall. August month rainfall exhibited increasing trend in Palghar and Thane district whereas Raigad, Ratnagiri and Sindhudurg district exhibited both increasing as well as decreasing trend. Increasing trend was exhibited in September month rainfall all over the Konkan region. October month evinced only increasing trend in Thane and Ratnagiri district whereas Palghar, Raigad and Sindhudurg district exhibited both increasing as well as decreasing trend. Either increasing or decreasing trend were exhibited in Palhgar district from 24^{th} to 39^{th} SMW. Except 22^{nd}, 42^{nd} and 43^{rd} SMW all remaining weeks exhibited either increasing or decreasing trend in Thane, Raigad and Ratnagiri district. Sindhudurg district showed either increasing or decreasing trend in all SMW.

Turning point test evinced decreasing trend of annual rainfall in Raigad and Sindhudurg district whereas Palghar, Thane and Ratnagiri district didn't show any trend. Decreasing trend was showed in June month rainfall in Sindhudurg district and both increasing as well as decreasing trend in Raigad district whereas Palghar, Thane and Ratnagiri district didn't show any trend. Turning point test showed decreasing trendof July month rainfall in Sindhudurg district whereas other district didn't exist any trend. Increasing trend of August month rainfall was showed in Palghar and Raigad district which are situated in north and middle part of the study region whereas south part of Konkan region didn't evince any trend. September month rainfall was existed only in Palghar and Raigad district had decreasing and increasing trend, respectively. Turning point test didn't show any significant trend of October month rainfall in the Konkan region.

Moving average method showed increasing trend of annual rainfall in Palghar, Thane, Ratnagiri and Sindhudurg district however Raigad district showed both increasing as well as decreasing trend. Increasing trend of June month rainfall was showed in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed both increasing and decreasing trend. Decreasing trend of July month rainfall showed in Palghar district and increasing trend in Sindhudurg district whereas Raigad and Ratnagiri exhibited both increasing as well as decreasing trend and Thane didn't exhibit any trend. Increasing trend of August month rainfall was showed in Palghar and Thane district whereas Raigad, Ratnagiri and Sindhudurg district exhibited both increasing as well as decreasing trend. Moving average methods exhibited increasing trend of September month rainfall all over the Konkan region. Decreasing trend of October month rainfall was exhibited in Palghar, Raigad and Ratnagiri district whereas Sindhudurg showed increasing trend and Thane district did not exhibit any trend.

Regression method showed increasing trend of annual rainfall in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed increasing as well as decreasing trend at various stations. Regression method also showed increasing trend of June month rainfall in Palghar, Thane, Ratnagiri and Sindhudurg district whereas Raigad district showed both increasing and decreasing trend. Decreasing trend of July month rainfall was showed in Palghar and Thane district whereas increasing trend in Ratnagiri and Sindhudurg district. Raigad district showed both increasing and decreasing trend. August month rainfall exhibited increasing trend in Palghar and Thane district whereas decreasing trend Raigad and Sindhudurg district and Ratnagiri exhibited both increasing as well as decreasing trend. Increasing trend of September month rainfall was showed in Palghar, Raigad, Ratnagiri and Sindhudurg district whereas Thane didn't exhibit any trend. Regression method showed increasing trend of October month rainfall in Thane and Sindhudurg district and both increasing as well as decreasing trend in Raigad district where as Palghar and Ratnagiri did not show any trend.

5.2 Conclusions

- ❖ Annual rainfall exhibited increasing trend in Palghar, Thane, Ratnagiri, and Sindhudurg district whereas Raigad district showed decreasing trend.
- ❖ North end and South Konkan were showed increasing trend of annual rainfall.
- ❖ June month rainfall showed increasing trend in Palghar (0.64%), Thane (0.52 %) and Ratnagiri (0.65%) district whereas Raigad (-0.19%) and Sindhudurg (-0.26%) district exhibited decreasing trend.

- ❖ July month rainfall showed decreasing trend in Palghar (-0.08 %), Thane (-0.22%) and Raigad (-0.02 %) district whereas Ratnagiri (0.03 %) and Sindhudurg (0.20 %) district showed increasing trend.
- ❖ August month rainfall exhibited increasing trend in Palghar (0.87 %) and Thane (0.61%) district whereas Raigad (-0.26 %), Ratnagiri (-0.20 %) and Sindhudurg (-0.17%) district showed decreasing trend.
- ❖ September month rainfall evinced increasing trend of Palghar (1.12%), Thane (0.5%), Raigad (0.39%), Ratnagiri (2.19 %) and Sindhudurg (2.32%).
- ❖ October month rainfall showed decreasing trend in and Raigad (-0.66%) whereas Palghar (0.09%), Thane (0.63%), Ratnagiri (0.15%) and Sindhudurg (0.64%) district showed increasing trend.
- ❖ Decreasing trend was observed in more number of weeks in north Konkan whereas south Konkan showed increasing trend in most of the weeks.

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Final Thesis Seminar

on

Trend analysis of rainfall in Konkan region of Maharashtra.

By

Ms. Mandale Varsha Prakash

Reg. No. ENDPM/2014/82

Under Guidance of

Prof. dilip MAHALE

Professor and Head, Department of SWCE.

Department of Soil and Water Conservation Engineering

CONTENTS OF SEMINAR

- Introduction
- Objectives
- Review of Literature
- Material and Methods
- Results and discussion
- Conclusion

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INTRODUCTION

- Water resource has become a prime concern for any development and planning including food production, flood control and effective water resource management.
- According to IPCC 2007, global surface temperature is increasing at a rate of 0.74 ± 0.18°C over 1906-2005.
- It has also been revealed that by the middle of 21st century, there will be 10-30 per cent decrease in annual average runoff and availability of freshwater projected by IPCC (IPCC, 2007).

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- About 16.5 per cent of world population is living in India on 2.5 per cent of world's total land having only 4 per cent water resources.
- If we see the Konkan region, availability of Water resources is 46 % of state on only 10 % geographical area of state.
- Average annual rainfall of Konkan region varies from 2500 to 4500 mm.
- Demand and supply gap of water is increasing continuously and per capita availability of water is decreasing. (Anonymous, 2012).

- Changes in climate over the Indian peninsular region, particularly the South West monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country (Datta, 2013).
- The more accurate information about rainfall and their trends are needed for the formulation of weather model, which will help to improve productivity and quality of crop yield and sustainability of water resource management practices.
- Considering above points, present study was done to find out the trends of rainfall at different stations of Konkan region of Maharashtra.

OBJECTIVES

- Analysis of variations in weekly, monthly and annual rainfall data.
- Detection of the trend in the weekly, monthly and annual rainfall data.
- Analysis of the rainfall trend using different methods.

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REVIEW OF LITERATURES

Parthasarathy and Dhar (1975)	conducted trend analysis of annual rainfall of India. They processed the annual rainfall of 60 year period from 1901 to 1960. They analyzed the rainfall data by using statistical methods such as Mann-Kendall rank statistics, Student's t-test and low-pass filter. They found that the mean values of the annual rainfalls for the 30 years period from 1931 to 1960 showed a significant increase of about 5 per cent.
Helsel and Hirsch (2002)	Developed a statistical methods for trend analysis build on regression and hypothesis testing. The explanatory variable of interest is usually time, though spatial or directional trends. Detection of both sudden and gradual trends over time with and without adjustment for the effects of confounding variables had employed. Various tests were classified, and their strengths and weaknesses were compared.

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Bihrat and Mehmetcik (2003)	detected the existence of a trend in a hydrological time series by statistical tests. The power of the parametric t-test for trend detection was estimated by Monte Carlo simulation for various probability distributions and compared with the power of the non-parametric Mann-Kendall test. Annual stream flow records in various regions of Turkey were analyzed by the two tests to compare their powers in detecting a trend. Results indicated that t-test had less power than the non-parametric Mann-Kendall test when the probability distribution was skewed.
Goswami (2006)	studied increasing trend of extreme rain events over India in a warming environment. He reported significant rising trends in frequency and magnitude of extreme rain events over India during the monsoon seasons from 1951 to 2000. However, there was significant decreasing trend in the frequency of moderate rainfall events as a result the seasonal mean rainfall did not show any significant trend.

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Krishnakumar *et al.*, (2008)	studied the monthly, seasonal and annual rainfall trends in twentieth century over Kerala, India during the period 1871 to 2005. They collected monthly rainfall data from the daily weather reports published by the IMD, Trivandrum. They checked the temporal changes in rainfall data by using Mann-Kendall rank statistics and linear trend. Rainfall during winter and summer seasons showed insignificant increasing trend.
Patra (2008)	studied rainfall trends in twentieth century (1871–2006) over Orissa State, India. He classified the temporal variation in monthly, seasonal and annual rainfall over the state during the period 1871 to 2006. Long term changes in rainfall characteristics were determined by both parametric and non-parametric tests. The analysis revealed a long term insignificant decline trend of annual, as well as, monsoon rainfall, whereas increasing trend in post-monsoon season over the state of Orissa. Rainfall during winter and summer seasons showed an increasing trend. Statistically, monsoon rainfall could be considered as very dependable, as the coefficient of variation was 14.2 per cent. However, there was decreasing monthly rainfall trend in June, July and September, whereas increasing trend in August. This trend was more predominant in last 10 years.

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Singh *et al.*, (2010)	studied trend in temporal variation of rainfall over India. Monthly, seasonal and annual trends of rainfall had been studied using monthly data series of 135 years (1871–2005) for 30 sub-divisions (sub-regions) in India. Half of the sub-divisions showed an increasing trend in annual rainfall. During June and July, the number of sub-divisions showed increasing rainfall. In August, the number of sub-divisions was showing an increasing trend, whereas in September, the situation was opposite. Annual and monsoon rainfall had decreased, while pre-monsoon, post-monsoon and winter rainfall had increased at the national scale. Rainfall in June, July and September had decreased, whereas in August it had increased, at the national scale.
Thakur (2010)	examined daily data of rainfall, maximum and minimum ambient temperature, relative humidity, sunshine hours and evaporation at Dapoli and Wakawali stations for predicting impact of climate change. Results revealed the linearly rising trend in daily data of rainfall, maximum and minimum ambient temperature, relative humidity, sunshine hours and evaporation at Dapoli and Wakawali stations for predicting impact of climate change. Rainfall, bright sunshine hours and wind velocity showed decreasing trend and evaporation had increasing trend for both the stations.

Choudhury et al. (2012)	studied Trend Analysis of Long Term Weather Variables in Meghalaya, North-East India. Long time (1983-2010) weather variables had been analyzed to detect trend changes using non-parametric Mann Kendall test. Results revealed that total annual rainfall trend increased non-significantly at the rate of 3.72 mm year-1. Contribution of monsoon months declined marginally at the rate of 1.70 mm while pre -monsoon and post- monsoon months increased non-significantly at an annual rate of 3.18 mm and 1.16 mm, respectively.
Kazimierz and Leszek (2012)	Studied Long-term Changes in Runoff from a Small Agricultural Catchment located in central Poland. Analyzed a 48-year precipitation and runoff from a small agricultural catchment. They evaluated the trend of three annual hydro-meteorological parameters, i.e. precipitation, runoff and runoff coefficient, the Mann-Kendall test was applied. It indicated no trend in respect of precipitation, and decreasing trends of runoff and runoff coefficient at a 95% level of significance. Lin-ear approximation of the annual runoff values indicated a decrease in runoff of ca. 1.2 mm per year for the analysed period.

Jain and Kumar (2012)	carried out the trend analysis of rainfall and temperature data for India. They conducted Regression analysis with time as the independent variable and rainfall/temperature as the dependent variables. They observed that six river basins had shown increasing trend in annual rainfall in the 0.27–10.16 mm/yr range, whereas 15 river basins had shown decreasing annual rainfall in the 0.45–4.93 mm/yr range. Further, four river basins had shown increasing trend in rainy days and 15 river basins had shown the opposite trend.
Mondal *et al* (2012)	studied the monthly and annual trends of Birupa river basin of north eastern part of Cuttack district, Orissa for the duration of 40 years from 1970 to 2010. They processed daily rainfall data to find the monthly and annual trends using Mann-Kendall test, Modified Mann-Kendall test, together with Sen's slope estimator, to check the magnitude of slope. They found the maximum annual rainfall in year 1983 of 2810 mm and minimum annual rainfall in year 1996 of 1118 mm. Z statistic of Mann-Kendall test revealed that there was a rising trend of rainfall in the months of August, July and September and falling trend of rainfall in December, January and February.

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Nagh *et al.*, (2012)	conducted rainfall trend analysis using 50 years historical data in newly developed Bernam catchment in Peninsular Malaysia for the years 1948 to 2002. They converted a daily point rainfall data into a catchment rainfall data, using Thiessen Polygon method. They observed the spatial and temporal variability of rainfall. Different statistical parameters such as mean, range, standard deviation, standard error, coefficient of variation were calculated for rainfall, in order to observe the deviation from long term means as monthly and seasonal basis. They found that wet months in study catchment occurred during inter monsoon instead of monsoon themselves.
Sing and Darroch (2012)	carried out the trend analysis of global radiation (1960-2003), transmissivity (1960-2003) and bright sunshine hours (1973-2003) over Nagpur during pre-monsoon (March to May) and monsoon seasons (June-September). They used Mann-Kendall Test to test the significance of reported trend. They concluded that global radiation had a statistically significant declining trend in both pre-monsoon and monsoon seasons. Bright sunshine hours were also found to be statistically significant for pre monsoon but no trend was observed for the monsoon. Transmissivity had also declined significantly in pre-monsoon and monsoon

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Gaikwad (2013)	studied the trends of different meteorology parameters on the basis of temporal, spatial and half decadal for Harnai, Dapoli and Wakawali stations in Dapoli tahsil of Ratnagiri district of Maharashtra state, India. Evapo-transpiration for all the three stations was estimated by using Penman-Monteith (PM-56) and Hargreaves-Samani methods as per the data available. The analysis showed that reference evapo-transpiration had linearly decreasing trend at Dapoli (3.2 mm per year) and Wakawali (14.53 mm per year), however it had an increasing trend at Harnai (0.45 mm per year). The results also revealed that reference evapo-transpiration was increasing as the distance from sea shore increased.
Jadhav and Shardul (2014)	determined the trends of different meteorological parameters in the Konkan region. The meteorological data were analyzed for Dapoli, Palghar and Wakawali stations. Trends were estimated with the help of Moving average and Regression analysis. The results revealed that rainfall and reference evapo-transpiration for all the three stations had decreasing trend. Average annual temperature had increasing trend and relative humidity decreasing trend at Dapoli, Palghar and Wakawali stations. Wind speed showed increasing trend for Dapoli and decreasing trend at Wakawali station.

Critique

Spatial and temporal variation of meteorological parameters has prime importance in crop and water resource planning. Different tests are available for the analysis of variation depending on; the parameters to be analyzed, data availability, type of data, number of stations to be analyzed and purpose of analysis. Above cited literature indicated that some tests were used to know the nature of trend some were used to estimate magnitude of trends of meteorological parameters at various stations in single study. Hence in the proposed study trend analysis was done with the help of Mann Kendall, Sen's Slope test , Turning point test, moving average method and regression analysis.

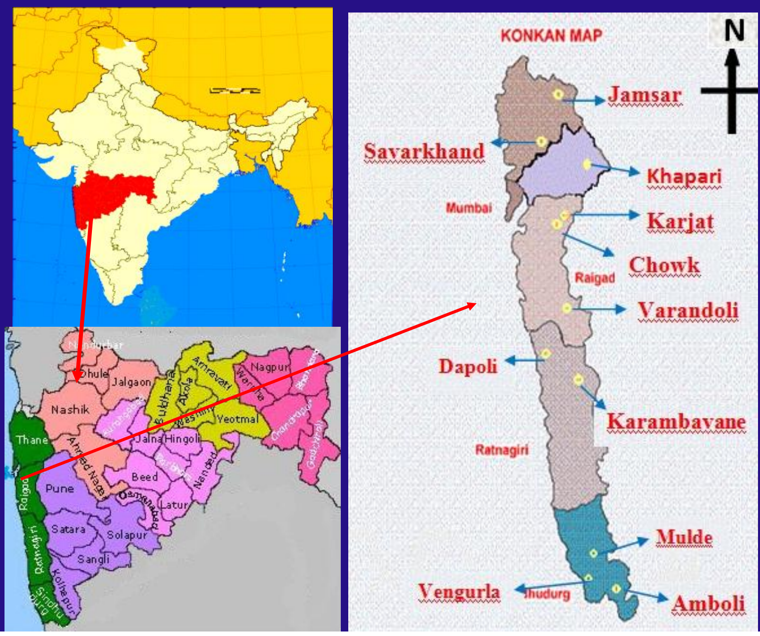
MATERIAL AND METHODS

STUDY AREA:

The Konkan region of Maharashtra having Palghar, Thane, Raigad, Ratnagiri and Sindhudurga districts.

- Latitude: 15^0 6’ N to 20° 22’ N
- Longitude: 72^0 39’ E to 73°48’ E
- Total geographical area of Konkan region is 3.09 Mha.
- The average annual rainfall of Konkan region varies between 2500-4500 mm.

Location map of stations under study



Geographical location of rainfall stations

District	Station	Taluka	Latitude	Longitude
Palghar	Jamsar	Jawhar	19°90 ' N	73°23 ' E
	Savarkhand	Wada	19°65 ' N	73°14 ' E
Thane	Khapari	Murbad	19°26 ' N	73°38 ' E
Raigad	Karjat	Karjat	18°91 ' N	73°32 ' E
	Chowk	Karjat	18°83 ' N	73°28 ' E
	Varandoli	Mahad	18°08 ' N	73°42 ' E
Ratnagiri	Dapoli	Dapoli	17°75 ' N	73°18 ' E
	Karambavane	Chiplun	17°53 ' N	73°18 ' E
Sindhudurg	Amboli	Sawantwadi	15°96 ' N	73°99 ' E
	Mulde	Kudal	16°01 ' N	73°70 ' E
	Vengurla	Vengurla	15°43' N	73°42' E

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Availability of data for study stations

Station	Period (year)		No. of years data available	Missing data	Source
	From	To			
Jamsar	1986	2011	**26**	-	Unit of Hydrology Deptt., Nasik
Savarkhand	1991	2011	**21**	-	Unit of Hydrology Deptt., Nasik
Khapari	1992	2011	**20**	-	Unit of Hydrology Deptt., Nasik
Karjat	1989	2014	**21**	1989,1999, 2000, 2001, 2009	Dr. BSKKV, Dapoli
Chowk	1980	2011	**30**	2008	Unit of Hydrology Deptt., Nasik
Varandoli	1981	2011	**30**	-	Unit of Hydrology Deptt., Nasik
Dapoli	1981	2014	**34**	-	Dr. BSKKV, Dapoli
Karambavane	1991	2011	**21**	-	Unit of Hydrology Deptt., Nasik
Amboli	1981	2011	**31**	-	Unit of Hydrology Deptt., Nasik
Mulde	1991	2014	**24**	-	Dr. BSKKV, Dapoli
Vengurla	1981	2011	**30**	1983	Dr. BSKKV, Dapoli

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Variation of Rainfall

➢Mean

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$$

Where,

$\bar{X}$ = Mean

X_i = Variables

N = Total number of variables

➢Standard Deviation

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})^2}$$

Where,

σ = Standard deviation

$\bar{X}$ = Mean

X_i =Variables

N = Total number of variables

➢**Coefficient of variation**

$$CV = \frac{\sigma}{\overline{X}} X\ 100$$

Where,

CV = Coefficient of variation

$\overline{X}$ = Mean

σ = Standard deviation

Trend Analysis of Rainfall

- ➢**Mann-Kendall Test (M-K)**
- ➢**Sen´s slope estimator**
- ➢**Turning Point Test**
- ➢**Moving Average method**
- ➢**Regression Method**

Mann-Kendall test (M-K)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\,(x_j - x_k)$$

$$Sign\,(x_j - x_k) = \begin{cases} 1 & if \quad x_j - x_k > 0 \\ 0 & if \quad x_j - x_k = 0 \\ -1 & if \quad x_j - x_k < 0 \end{cases}$$

Where

x_1, x_2, … x_n - n data points.
x_j - data point at time j.
x_k - data point at time k.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right]$$

Where,

q - Number of tied groups,
t_p - Number of data values in the p^{th} group.

The standard test statistic Z was computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if \quad S < 0 \end{cases}$$

- **A positive/negative value of Z indicates an upward /downward trend.**

Significance Levels of M-K Test

Critical values for Z statistic and their significance levels are presented in the Following table

Confidence Level	Critical Value of Z	Notation
90%	1.64	*
95%	1.96	**
99%	2.54	***

Sen's slope estimator

$$f(t) = Q_t + B$$

Where,

Qt - Slope

B - Constant.

Slopes of all data pairs was calculated

$$Q_i = \frac{x_j - x_k}{j-k}, i = 1,2,3 \dots N, j > k$$

➢ **If there was n values x_j in the time series then N = n(n-1)/2 slope estimates Q_t. Slope is the median of these N values of Q_t.**

Example of Sen's Slope methos

Year	Rainfall				
2000	X_1	-	-	-	-
2001	X_2	$\frac{x_2 - x_1}{2001 - 2000}$	-	-	-
2002	X_3	$\frac{x_3 - x_1}{2002 - 2000}$	$\frac{x_3 - x_2}{2002 - 2001}$	-	-
2003	X_4	$\frac{x_4 - x_1}{2003 - 2000}$	$\frac{x_4 - x_2}{2003 - 2001}$	$\frac{x_4 - x_3}{2003 - 2002}$	-
2004	X_5	$\frac{x_5 - x_1}{2004 - 2000}$	$\frac{x_4 - x_2}{2004 - 2001}$	$\frac{x_5 - x_3}{2004 - 2002}$	$\frac{x_5 - x_4}{2004 - 2003}$

- The N values of Q_t was ranked from the smallest to the largest and the Sen's estimator is,

$$Qt = \begin{cases} Q_{\frac{N+1}{2}} & if\ N\ is\ odd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) & if\ N\ is\ even \end{cases}$$

- MAKESENS Excel template was used for trend analysis

Turning Point test

(i)	$x_{i-1} > x_i > x_i+1$	Not a turning point
(ii)	$x_{i-1} > x_{i+1} > x_i$	Turning point
(iii)	$x_i > x_{i-1} > x_{i+1}$	Turning point
(iv)	$x_i > x_{i+1} > x_{i-1}$	Turning point
(v)	$x_{i+1} > x_{i-1} > x_i$	Turning point
(vi)	$x_{i+1} > x_i > x_{i-1}$	Not a turning point

- **In an observed sequence, t = 1, 2, 3, 4............N, a turning point P occurs at time t = i, if is either greater than and or less than the two adjacent values.**

- The expected number of turning points in the given data series was calculated by following formula;

$$E(p) = \frac{2}{3}(N-2)$$

- The variance of the expected number of turning points were calculated by the following formula;

$$Var(p) = \frac{16N-29}{90}$$

- The standard measure of the turning point test, Z (test statistic) was calculated by using following equation;

$$Z = \frac{p-E(p)}{[var(p)]^{\frac{1}{2}}}$$

Where,

N=data size

p=actual number of turning points

If its value of |Z| ≥1.96 at 5 per cent level of significance the trend is present in the given series and at 99 per cent significance level, the trend is present when |Z| ≥ 2.575.

■ Moving Average method

$$Y_{i+1/2(n-1)} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

where

$Y_{i+1/2(n-1)}$ = moving average,

X_i = Rainfall

n = moving average order.

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■ Regression Method

➢ Linear regression equations were used for the trend analysis of rainfall of selected stations in the Konkan region.

$$Y = a + bx$$

Where,

Y= value obtained by substituting in above equation corresponding to X

x = independent variable

a, b = Constants.

➢ The regression parameters which are reported in the form of graph show that the constant a, which is a reflection of the trend and b is the interceptor constant.

$$a = \bar{y} - b\bar{x} \qquad b = \frac{\sum(y-\bar{y})(x-\bar{x})}{\sum(x-\bar{x})^2}$$

Where,

$\sum(y-\bar{y})/(x-\bar{x})$ Sum of deviation of x and y from respective means

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RESULTS AND DISCUSSION

Annual rainfall variation at selected study stations

Name of Station	Availability of data	Average Rainfall (mm)	Min. Rainfall (mm)	Max. Rainfall (mm)	SD (mm)	CV (per cent)	District-wise	
							SD (mm)	CV (Per cent)
Jamsar	1986-2011	2702	1703	5216	778	29	639	25
Savarkhand	1982-2011	2547	1641	3473	499	20		
Khapari	1991-2011	2478	1535	3564	480	19	480	19
Karjat	1989-2014	2801	1324	4709	1457	52	945	31
Chowk	1980-2010	3197	1814	4775	693	22		
Varandoli	1981-2011	3824	2627	5370	684	18		
Dapoli	1981-2014	3635	2403	5291	832	23	828	22
Karambawane	1991-2011	3893	2731	5489	823	21		
Mulde	1991-2014	3330	2600	4314	454	14	696	17
Vengurla	1981-2011	2922	1224	4261	648	22		
Amboli	1981-2010	6981	4873	8504	987	14		
Average	-	3482	-	-	758	23	-	-

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Rainfall variation at selected stations in the month of June

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise	
						SD (mm)	CV (per cent)
Jamsar	436.67	22.60	1223.00	293.95	67.32	267.05	61.62
Savarkhand	429.41	49.60	1082.40	240.15	55.93		
Khapari	415.86	103.50	845.00	184.57	44.38	184.57	44.38
Karjat	547.09	78.50	1141.50	290.29	53.06	277.21	44.97
Chowk	525.66	70.80	889.50	207.29	39.43		
Varandoli	787.45	179.40	1505.80	334.06	42.42		
Dapoli	859.06	186.60	2025.30	426.93	49.70	409.89	48
Karambawane	848.51	168.80	1781.60	392.84	46.30		
Mulde	843.38	381.80	1353.80	244.09	28.94	341.85	32.39
Vengurla	875.47	387.00	1685.00	293.39	33.51		
Amboli	1406.20	341.70	2464.00	488.07	34.71		
Average	725	-	-	309	25		

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Variation of rainfall in the month of July

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise SD (mm)	District-wise CV (per cent)
Jamsar	1040.08	355.90	2059.40	422.36	40.61	369.84	37.80
Savarkhand	905.21	243.60	1665.60	317.33	35.00		
Khapari	795.11	352.88	1408.60	272.55	34.28	272.55	34.28
Karjat	1235.62	503.90	2238.70	413.96	33.50	385.62	30.74
Chowk	1161.45	446.50	1829.80	379.48	32.67		
Varandoli	1395.09	782.60	2073.60	363.42	26.05		
Dapoli	1283.90	419.00	2172.60	413.29	32.19	409.98	30.52
Karambawane	1409.25	761.40	2097.60	406.68	28.86		
Mulde	1123.40	555.00	1580.80	278.60	24.80	391.62	26.98
Vengurla	959.12	274.00	1580.78	309.02	32.22		
Amboli	2454.08	1406.10	3839.00	587.26	23.93		
Average	1251	-	-	379	31	-	-

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Variation of rainfall in the month of August

Name of Station	Average Rainfall	Min. Rainfall	Max. Rainfall	SD (mm)	CV (per cent)	District-wise SD (mm)	District-wise CV (per cent)
Jamsar	829.59	165.90	1686.60	400.01	48.22	349.76	44.4
Savarkhand	738.19	111.50	1428.40	299.51	40.58		
Khapari	708.05	244.70	1275.84	277.35	39.17	77.35	39.17
Karjat	1047.12	130.20	2181.00	454.64	43.42	407.39	40.07
Chowk	962.25	194.70	2223.60	417.93	43.43		
Varandoli	1047.39	399.20	1731.80	349.60	33.38		
Dapoli	874.55	386.60	2051.00	354.13	40.49	339.47	37.33
Karambwane	950.51	420.30	1668.40	324.81	34.17		
Mulde	698.78	233.70	1000.20	192.11	27.49	368.49	34.94
Vengurla	590.33	227.40	1599.30	269.69	45.68		
Amboli	2033.6	728.20	4619.00	643.67	31.65		
Average	952.76	-	-	362.13	38.88	-	-

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Variation of rainfall in the month of September

Name of Station	Average Rainfall (mm)	Min. Rainfall (mm)	Max. Rainfall (mm)	SD (mm)	CV (per cent)	District-wise SD (mm)	District-wise CV (per cent)
Jamsar	327.13	24.6	949.4	272.94	83.44	270.60	77.74
Savarkhand	372.40	67.80	1069.26	268.26	72.03		
Khapari	416.62	192.36	717.73	146.88	35.26	146.88	35.26
Karjat	434.2	27.9	869.2	215.75	49.69	217.28	50.30
Chowk	415.07	82.7	1122.6	215.46	51.91		
Varandoli	447.46	114	962.1	220.62	49.31		
Dapoli	433.96	43.2	919.4	245.71	56.62	244.15	52.29
Karambawane	505.92	99.4	928.6	242.59	47.95		
Mulde	339.03	54.5	733.1	187.67	55.36	275.97	62.22
Vengurla	261.16	32	731.4	180.71	69.19		
Amboli	740	227	1752	459.52	62.1		
Average	426.63	-	-	241.46	51.53		

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Variation of rainfall in the month of October

Name of Station	Average Rainfall (mm)	Min. Rainfall (mm)	Max. Rainfall (mm)	SD (mm)	CV (per cent)	District-wise SD (mm)	District-wise CV (per cent)
Jamsar	67.17	0	204	57.46	85.55	86.74	105.95
Savarkhand	91.83	0	508.40	116.02	126.35		
Khapari	101.32	0	235	67.19	66.32	67.19	66.32
Karjat	108.58	3	288.2	86.97	80.1	92.71	80.06
Chowk	122.23	0	318.3	95.69	78.28		
Varandoli	116.74	0	389.2	95.48	81.79		
Dapoli	125.73	0.5	472.8	110.52	87.9	148.03	86.52
Karambwane	217.93	0	822.8	185.53	85.13		
Mulde	201.4	604.8	40	124.42	61.77	143.31	75.40
Vengurla	146.75	685	16.6	150.34	102.44		
Amboli	250.35	0	701	155.16	61.98		
Average	140.91	-	-	113.16	83.41		

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Monthly rainfall contribution to total annual rainfall.

Name of station	Yearly	June (%)	July (%)	August (%)	September (%)	October (%)
Jamsar	2702	16	38	31	12	2
Savarkhand	2547	17	36	29	15	4
Khapari	2478	17	32	26	17	4
Karjat	2801	15	35	32	12	4
Chowk	3197	16	36	30	13	4
Varandoli	3824	21	36	27	12	3
Dapoli	3635	24	35	24	12	3
Karambawane	3893	22	36	22	13	6
Mulde	3330	25	34	21	10	6
Vengurla	2922	30	33	20	9	5
Amboli	6981	20	35	29	11	4

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Monthly and annual rainfall variation in Konkan Region

Name of Station	June (Per cent)	July (Per cent)	August (Per cent)	September (Per cent)	October (Per cent)	Annual (Per cent)
Jamsar	67.32	40.61	48.22	83.44	85.55	29
Savarkhand	55.93	35	40.58	72.03	126.35	20
Khapari	44.38	34.28	39.17	35.26	66.32	19
Karjat	53.06	33.5	43.42	49.69	80.1	52
Chowk	39.43	32.67	43.43	51.91	78.28	22
Varandoli	42.42	26.05	33.38	49.31	81.79	18
Dapoli	49.7	32.19	40.49	56.62	87.9	23
Karambawane	46.3	28.86	34.17	47.95	85.13	21
Mulde	28.94	24.8	27.49	55.36	61.77	14
Vengurla	33.51	32.22	45.68	69.19	102.44	22
Amboli	34.71	23.93	31.65	62.1	61.98	14

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Average weekly rainfall at selected stations

Week	Jamsar	Savarkhand	Khapari	Karjat	Chowk	Varandoli	Dapoli	Karambbawane	Mulde	Vengurla	Amboli
22	24	23	30	10	31	61	30	75	61	60	118
23	68	83	44	61	76	150	125	212	113	148	268
24	127	139	112	127	156	222	262	216	246	248	432
25	151	143	153	147	175	239	254	226	224	205	421
26	229	175	159	216	266	333	233	321	246	233	548
27	169	163	152	200	183	243	299	297	244	209	460
28	252	239	150	222	302	375	272	314	266	174	637
29	266	203	224	269	248	336	287	323	242	205	590
30	272	255	221	361	266	318	293	347	244	241	544
31	233	181	220	276	251	275	257	275	219	175	546
32	226	187	142	238	233	292	246	207	172	134	531
33	128	125	122	266	190	180	176	154	136	121	381
34	149	147	146	188	166	186	137	222	117	93	373
35	98	104	138	169	151	154	212	199	181	136	266
36	71	82	97	175	89	92	138	100	105	72	168
37	74	102	93	81	72	89	91	96	62	43	156
38	82	81	81	58	92	101	91	105	66	60	154
39	27	32	58	61	60	65	59	76	64	41	112
40	19	33	39	45	45	51	60	77	94	80	87
41	16	11	17	32	21	16	41	57	50	28	51
42	15	19	14	11	14	11	15	19	41	18	30
43	3	10	2	9	1	5	9	15	18	12	11
Avg.	123	115	110	146	140	172	163	179	146	124	313

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Trend analysis of Rainfall
Annual and Monthly Mann Kendall trend statistics

Name of the station	Yearly Trend	Monthly Trend (Z Statistic)				
	Z Statistics	June	July	August	September	October
Jamsar	1.15	0.66	-0.42	1.23	1.5	0.46
Savarkhand	1.89	1.07	0.85	1.39	1.14	-0.32
Khapari	0.69	0.45	0.52	0.39	0.91	0.26
Karjat	-0.23	-0.82	-0.33	-0.94	0.94	-0.91
Chowk	1.87	0.79	0.89	0.21	0.57	0.1
Varandoli	-0.58	-0.53	-0.63	0.29	0.22	-0.75
Dapoli	0.62	0.5	0.12	-0.21	1.66	0.09
Karambawane	1.96 **	1.24	-0.15	0.63	2.87 ***	0.21
Mulde	0.72	-1.34	0	0.15	2.51 **	0
Vengurla	1.29	-0.04	0.46	-0.64	2.5 **	1.27
Amboli	0.18	0.02	0.39	-0.53	2.36 **	0.9

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

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Weekly Mann Kendall trend statistics

Week	Jamsar	Savarkhand	Khapari	Karjat	Chowk	Varandoli	Dapoli	Karambawane	Mulde	Vengurla	Amboli
22	-0.47	0.774	-0.13	0.84	0.84	0.28	1.10	1.29	0.50	-0.07	-0.15
23	-0.56	0.553	-0.10	0.26	-0.37	-0.80	0.86	-1.03	0.92	-0.49	-0.34
24	-0.57	-1.231	-0.19	0.25	0.07	-1.27	0.44	0.21	-0.55	-1.19	-0.87
25	0.57	1.463	-0.84	0.02	0.54	-0.02	-0.03	1.48	-0.65	-1.05	0.66
26	1.19	1.124	1.23	-0.02	0.68	0.53	-0.74	0.88	-0.65	0.41	0.29
27	0.26	1.570	0.45	0.07	1.97 **	0.97	0.74	0.39	0.00	-0.41	2.26 **
28	- 2.27**	-2.319 **	-0.52	0.00	-1.02	-2.02 **	0.40	-1.60	-0.60	-0.20	-0.76
29	-0.71	-0.571	0.19	-0.52	-0.25	-0.80	0.00	0.00	0.25	-0.24	-0.80
30	1.06	1.677 *	0.97	-0.57	1.16	0.76	0.95	1.06	-0.55	-1.12	0.49
31	1.54	1.070	1.88	1.38	0.92	0.22	0.21	1.48	0.40	-0.87	0.73
32	-0.09	-0.963	-0.45	0.02	-1.36	-0.63	-0.62	0.15	0.40	-1.39	-1.43
33	-2.69 ***	-2.141 **	-1.23	-1.71	-1.05	-1.51	-1.85	-0.60	-0.55	-1.26	-0.70
34	0.31	0.928	0.71	-1.85	1.80	1.72	-0.39	-0.63	-1.24	-1.51	1.04
35	1.70	1.267	0.97	-0.63	1.63	1.39	1.96	1.30	0.65	0.70	2.67 ***
36	0.48	0.250	0.45	-0.21	0.39	0.00	0.85	1.66	2.23 **	2.09 **	1.24
37	1.58	1.552	1.04	0.99	1.10	0.92	0.68	2.18 **	1.96	2.06 **	1.58
38	0.35	-0.107	0.26	1.24	-0.24	-0.87	1.68	1.09	2.31 **	1.08	-1.05
39	-1.63	-0.018	0.26	-1.59	0.00	-1.04	-0.48	0.24	0.72	0.32	1.09
40	1.54	0.245	1.30	-0.31	0.05	0.09	0.67	0.52	-0.40	-0.44	0.05
41	0.42	0.774	0.66	0.00	2.32 **	1.72	0.31	0.24	-1.29	0.02	1.70
42	-0.14	0.553	-0.17	-2.20 **	-1.00	-1.56	0.33	-2.03 **	-1.50	1.11	-0.21
43	0.71	-1.231	-0.23	-1.13	0.95	-1.64	-0.03	0.34	0.93	-0.13	-1.07

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

Department of Soil and Water Conservation Engineering

Sen's Slope Test

Annual and monthly trend statistic

Name of Station	Yearly Trend	Monthly Trend (Qt)				
	(Qt)	June	July	August	September	October
Jamsar	20.54	3.3	-3.18	14.49	5.41	0.51
Savarkhand	22.88	4.73	6.42	10.16	5.05	-0.14
Khapari	12.14	6.11	7.32	6.8	5.47	0.56
Karjat	-15.1	-12.98	-9.72	-16.7	4.38	-2.67
Chowk	26.91	5.06	8.29	1.27	1.96	0.18
Varandoli	-7.33	-4.4	-4.59	0.87	1.18	-1.48
Dapoli	11.6	4.63	2.23	-1.52	7.49	0.18
Karambawane	60.81	17.02	-4.29	12.29	26.74	1.61
Mulde	13.21	-9.24	0.14	0.39	13.58	-0.09
Vengurla	17.17	-1	1.57	-3.68	9.64	1.98
Amboli	4.41	0.32	3.84	-5	16.99	3.31

Department of Soil and Water Conservation Engineering

Weekly trend statistic of Sen's Slope test

Week	Jamsar	Savarkhand	Khapari	Karjat	Chowk	Varandoli	Dapoli	Karambawane	Mulde	Vengurla	Amboli
22	0.00	0.000	0.00	0.00	0.00	0.00	0.00	1.24	0.35	0.00	0.00
23	0.00	0.640	-0.19	-0.37	-0.15	-2.55	0.94	-5.49	1.49	-1.06	-1.35
24	-0.82	-2.900	-1.23	-1.24	0.14	-3.78	1.77	2.12	-2.43	-4.60	-4.28
25	1.70	2.000	-2.43	-2.39	1.20	-0.17	-0.08	7.33	-2.89	-2.31	1.43
26	6.85	3.364	6.14	0.88	2.63	2.61	-2.15	8.66	-3.52	1.09	2.37
27	0.98	4.018	2.46	-4.63	4.02	3.03	2.41	2.78	0.10	-1.17	12.14
28	-8.36	-8.533	-1.18	-4.43	-5.40	-11.43	1.29	-14.23	-2.62	-0.45	-4.46
29	-3.62	-0.971	3.42	-5.16	-0.68	-1.87	0.05	-0.27	0.95	-0.95	-4.70
30	6.10	7.800	7.61	-2.67	4.86	2.98	2.58	12.06	-1.36	-5.01	3.59
31	4.61	3.533	12.49	6.70	2.80	1.60	1.12	11.65	1.36	-2.38	4.56
32	-1.11	-2.142	-1.70	0.00	-3.35	-1.88	-0.72	0.80	1.08	-1.79	-7.55
33	-6.07	-3.888	-1.95	-7.62	-2.29	-4.10	-3.01	-1.97	-1.22	-2.40	-2.01
34	1.20	1.371	1.28	-8.28	3.91	3.92	-0.43	-4.55	-2.36	-1.49	2.61
35	3.52	1.704	3.25	-1.91	3.83	3.00	6.60	5.47	3.52	0.56	10.60
36	0.71	0.300	1.60	-0.23	0.58	0.00	1.92	4.40	5.22	2.46	3.00
37	2.27	1.350	1.93	1.00	1.06	0.78	0.85	6.72	2.10	1.12	3.73
38	0.07	-0.036	0.95	1.13	-0.40	-0.89	1.49	3.09	1.80	0.23	-1.86
39	-1.20	0.000	0.44	-1.60	0.00	-1.01	-0.15	0.30	0.97	0.09	1.58
40	0.04	0.000	2.97	0.00	0.00	0.00	0.26	1.09	-0.71	-0.16	0.00
41	0.00	0.000	0.19	0.00	0.40	0.15	0.02	0.00	-1.31	0.00	1.10
42	0.00	0.640	0.00	0.00	0.00	0.00	0.00	-1.54	-1.34	0.04	0.00
43	0.00	-2.900	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00

▪ Turning point test

Annual rainfall trend statistic

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	15	26	16.00	-0.53	0.94	No Trend
Savarkhand	18	30	18.67	0.18	-1.88	No Trend
Khapari	10	19	11.33	-1.78	0.38	No Trend
Karjat	13	19	11.33	-1.78	-0.47	No Trend
Chowk	14	32	19.33	0.33	-7.50 ***	Exist Trend
Varandoli	15	31	19.33	0.36	-6.09 ***	Exist Trend
Dapoli	24	34	21.33	0.89	1.50	No Trend
Karambawane	11	21	12.67	-1.42	-0.07	No Trend
Mulde	13	24	14.67	-0.89	0.94	No Trend
Vengurla	19	31	19.33	0.36	-0.47	No Trend
Amboli	15	30	18.67	0.18	-10.31 ***	Exist Trend

Note: * - 90 % confidence level, ** - 95% Confidence level, * - 99% Confidence level**

Department of Soil and Water Conservation Engineering

June month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	16	26	16.00	-0.53	0.00	No Trend
Savarkhand	19	30	18.66	0.178	0.94	No Trend
Khapari	10	18	10.67	-1.96	0.17	No Trend
Karjat	14	19	11.33	-1.78	-0.75	No Trend
Chowk	22	31	19.33	0.36	3.75**	Exist Trend
Varandoli	17	31	19.33	0.36	-3.28**	Exist Trend
Dapoli	20	34	21.33	0.89	-0.75	No Trend
Karambawane	10	21	12.67	-1.42	0.94	No Trend
Mulde	13	24	14.67	-0.89	0.94	No Trend
Vengurla	17	29	18.00	0.00	0.00	No Trend
Amboli	17	31	19.33	0.36	-3.28**	Exist Trend

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

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July month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	16	26	16.00	-0.53	0.00	No Trend
Savarkhand	18	30	18.66	0.18	-1.86	No Trend
Khapari	12	18	10.67	-1.96	-0.34	No Trend
Karjat	13	19	11.33	-1.78	-0.47	No Trend
Chowk	18	31	19.33	0.36	-1.88	No Trend
Varandoli	18	31	19.33	0.36	-1.88	No Trend
Dapoli	20	34	21.33	0.89	-0.75	No Trend
Karambawane	12	21	12.67	-1.42	0.23	No Trend
Mulde	15	24	14.67	-0.89	-0.19	No Trend
Vengurla	19	29	18.00	0.00	0.00	No Trend
Amboli	17	31	19.33	0.36	-3.28 ***	Exist Trend

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

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August month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Trend
Jamsar	16	26	16.00	-0.53	0.00	No Trend
Savarkhand	22	30	18.66	0.18	9.38 ***	Exist Trend
Khapari	11	18	10.67	-1.96	-0.09	No Trend
Karjat	14	19	11.33	-1.78	-0.75	No Trend
Chowk	21	31	19.33	0.36	2.34 **	Exist Trend
Varandoli	21	31	19.33	0.36	2.34 **	Exist Trend
Dapoli	23	34	21.33	0.89	0.94	No Trend
Karambawane	12	21	12.67	-1.42	0.23	No Trend
Mulde	13	24	14.67	-0.89	0.94	No Trend
Vengurla	20	29	18.00	0.00	0.00	No Trend
Amboli	19	31	19.33	0.36	-0.47	No Trend

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

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September month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Condition
Jamsar	14	26	16.00	-0.53	1.88	No Trend
Savarkhand	17	30	18.66	0.18	-4.68 ***	Exist Trend
Khapari	11	18	10.67	-1.96	-0.09	No Trend
Karjat	12	19	11.33	-1.78	-0.19	No Trend
Chowk	21	31	19.33	0.36	2.34 **	Exist Trend
Varandoli	18	31	19.33	0.36	-1.88	No Trend
Dapoli	23	34	21.33	0.89	0.94	No Trend
Karambawane	11	21	12.67	-1.42	0.59	No Trend
Mulde	14	24	14.67	-0.89	0.38	No Trend
Vengurla	16	29	18.00	0.00	0.00	No Trend
Amboli	18	31	19.33	0.36	-1.88	No Trend

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

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October month trend statistic of Turning point test

Name of Stations	P	N	E(p)	V(p)	Z	Trend
Jamsar	17	26	16.00	-0.53	-0.94	No Trend
Savarkhand	19	30	18.66	0.18	0.94	No Trend
Khapari	12	18	10.67	-1.96	-0.34	No Trend
Karjat	16	19	11.33	-1.78	-1.31	No Trend
Chowk	20	31	19.33	0.36	0.94	No Trend
Varandoli	19	31	19.33	0.36	-0.47	No Trend
Dapoli	22	34	21.33	0.89	0.38	No Trend
Karambawane	12	21	12.67	-1.42	0.23	No Trend
Mulde	14	24	14.67	-0.89	0.38	No Trend
Vengurla	18	29	18.00	0.00	0.00	No Trend
Amboli	19	31	19.33	0.36	-0.47	No Trend

Note: * - 90 % confidence level, ** - 95% Confidence level, *** - 99% Confidence level

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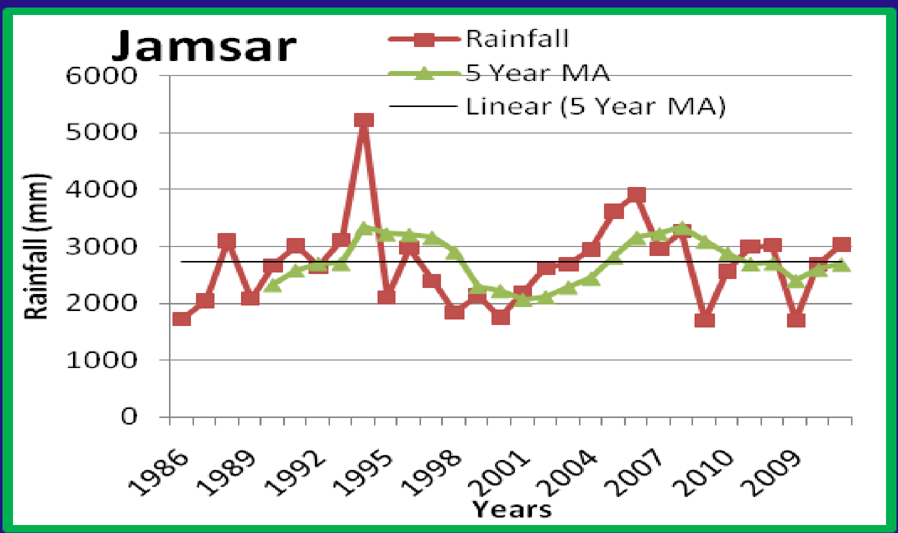
MOVING AVERAGE METHOD



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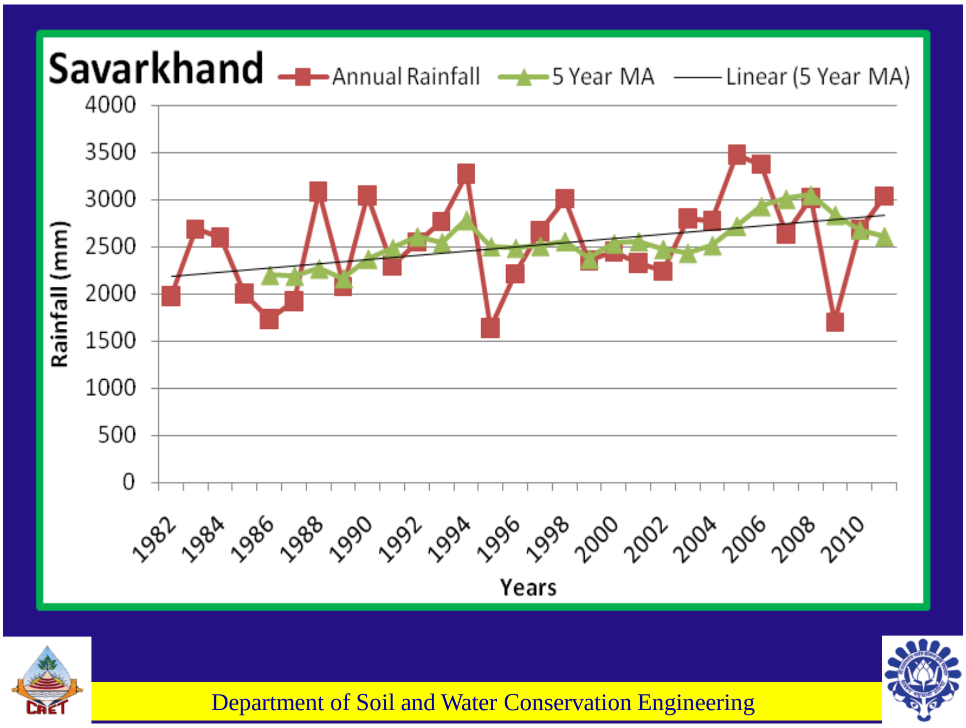
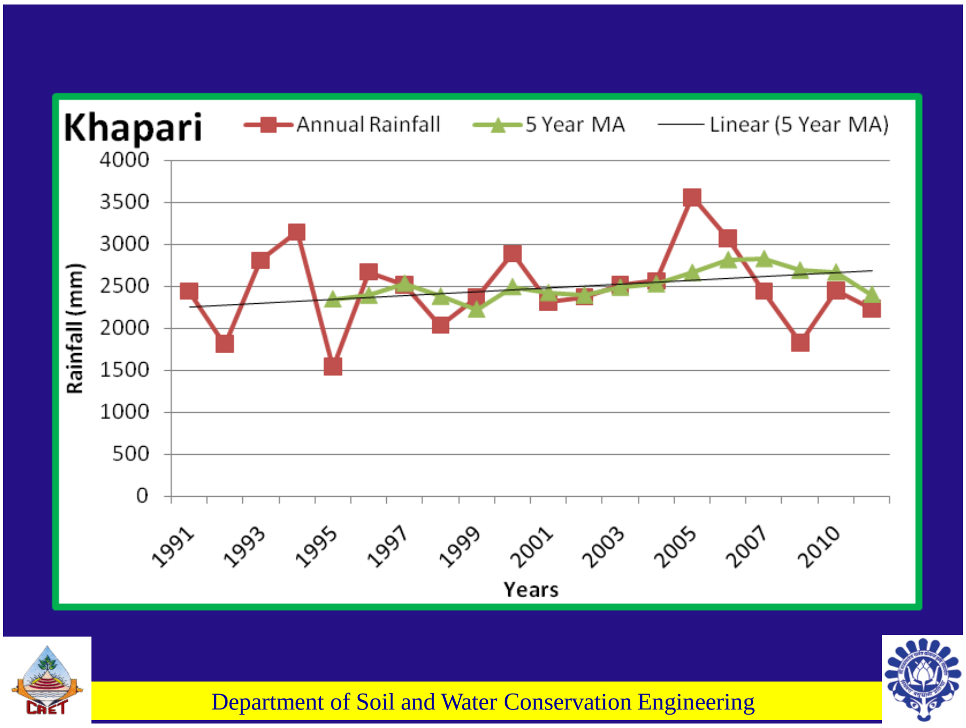
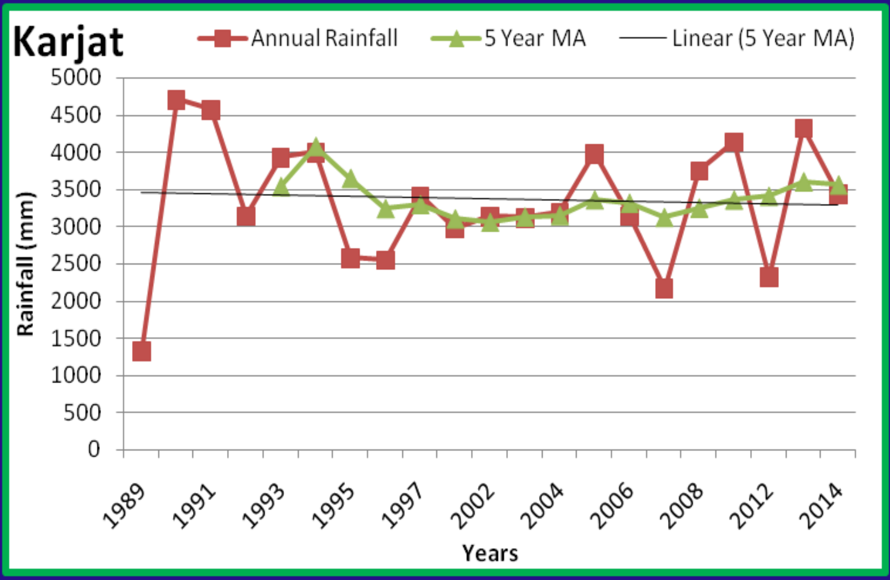

Savarkhand
Annual Rainfall
5 Year MA
Linear (5 Year MA)
Rainfall (mm)
4000
3500
3000
2500
2000
1500
1000
500
0
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Years
Department of Soil and Water Conservation Engineering


Khapari
Annual Rainfall
5 Year MA
Linear (5 Year MA)
Rainfall (mm)
4000
3500
3000
2500
2000
1500
1000
500
0
1991
1993
1995
1997
1999
2001
2003
2005
2007
2010
Years
Department of Soil and Water Conservation Engineering



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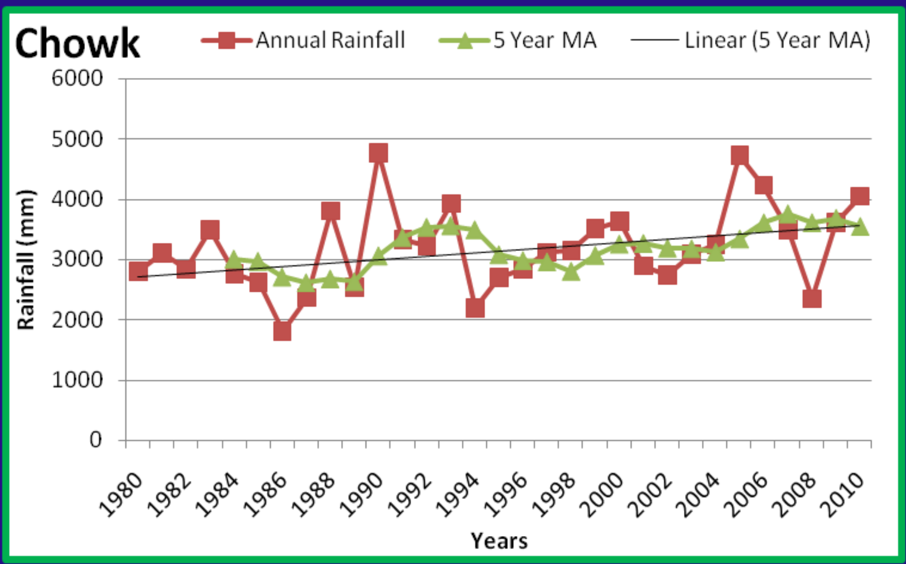

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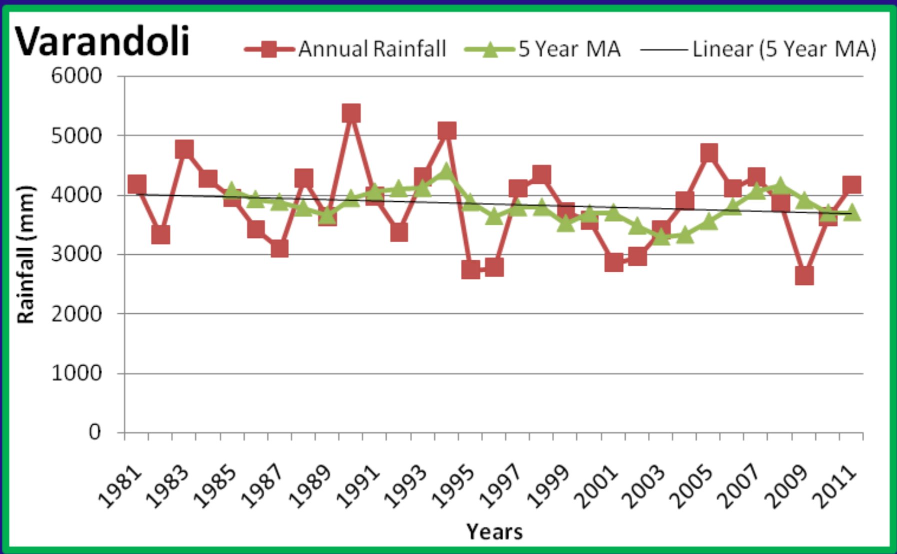
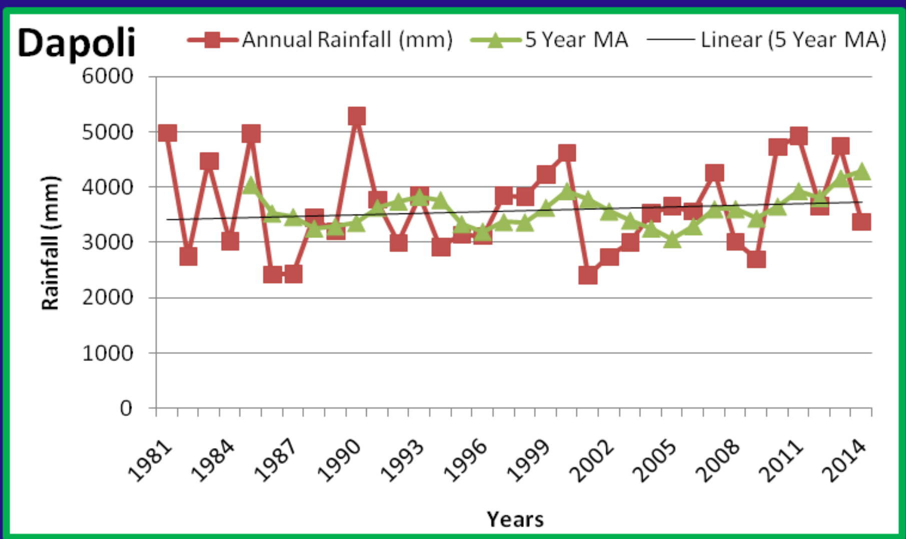


Department of Soil and Water Conservation Engineering



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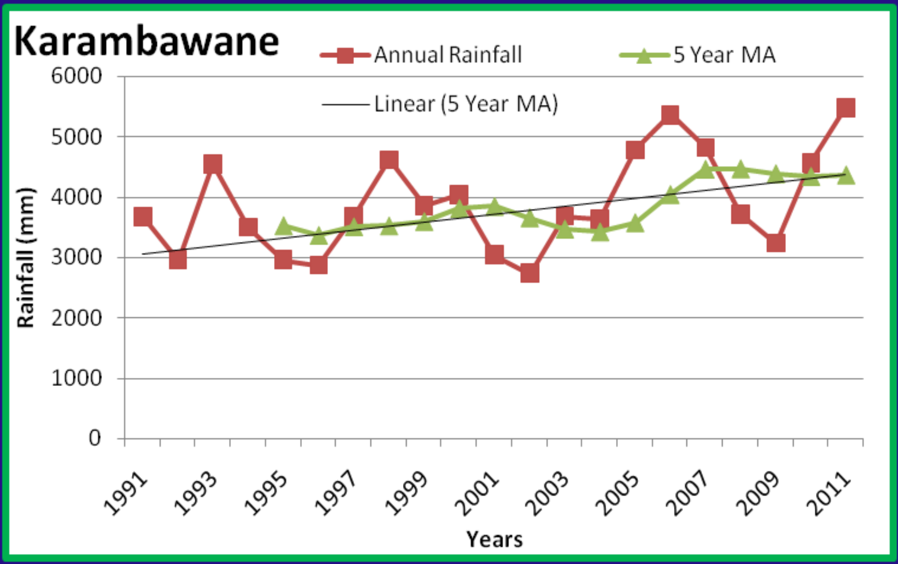

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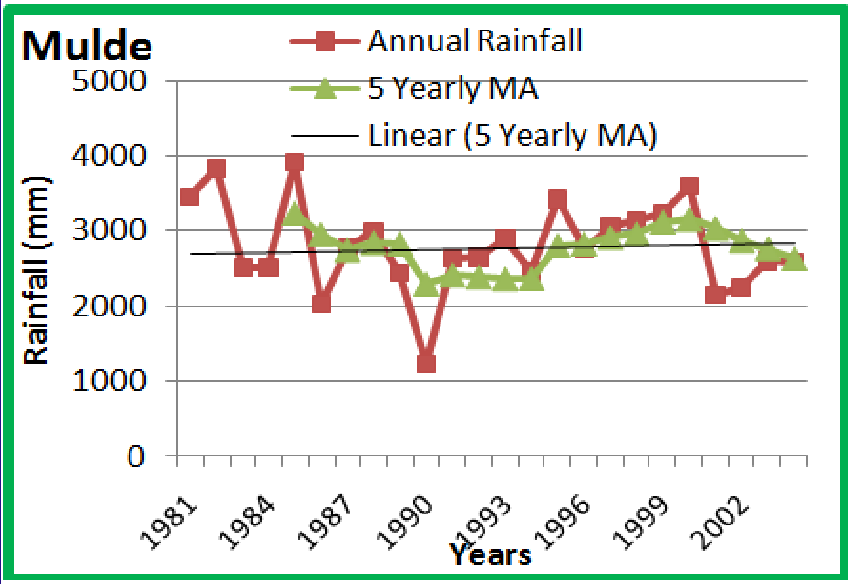

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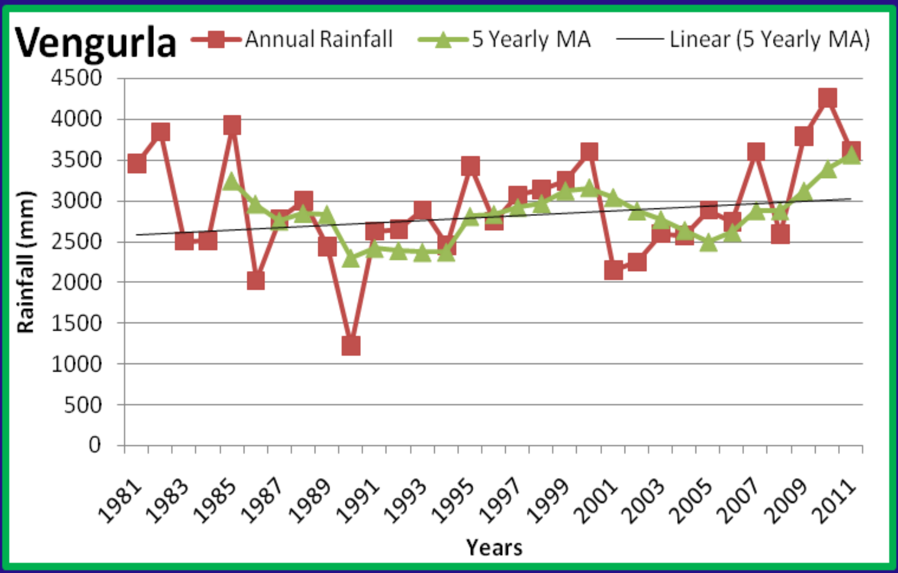

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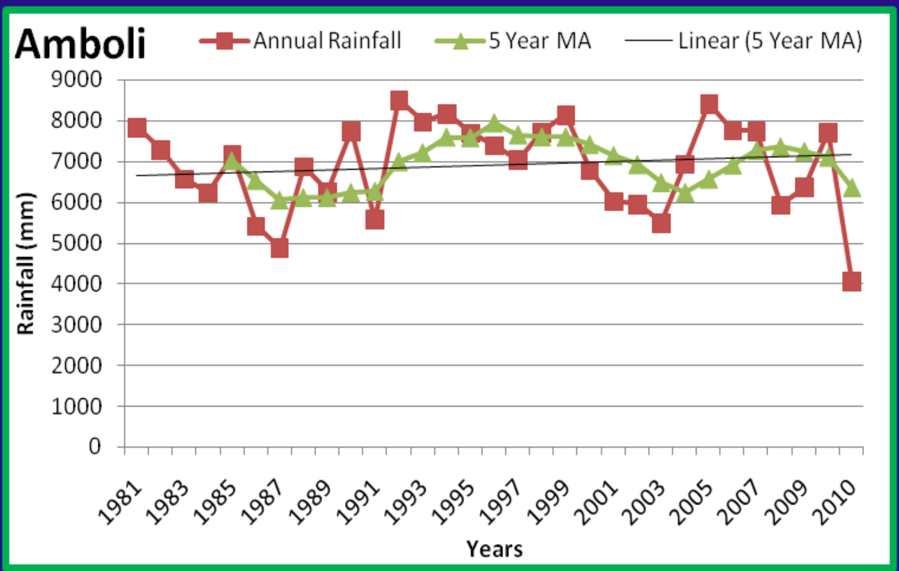

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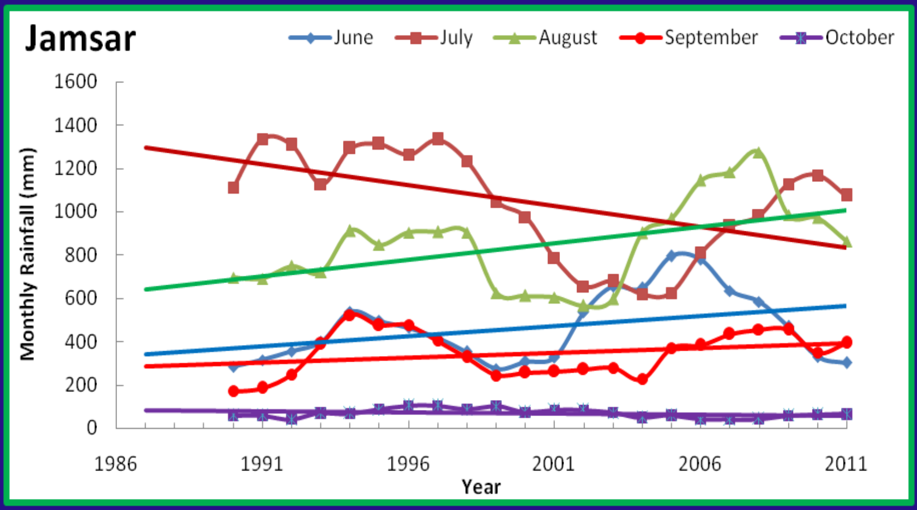
Monthly rainfall trends at Jamsar



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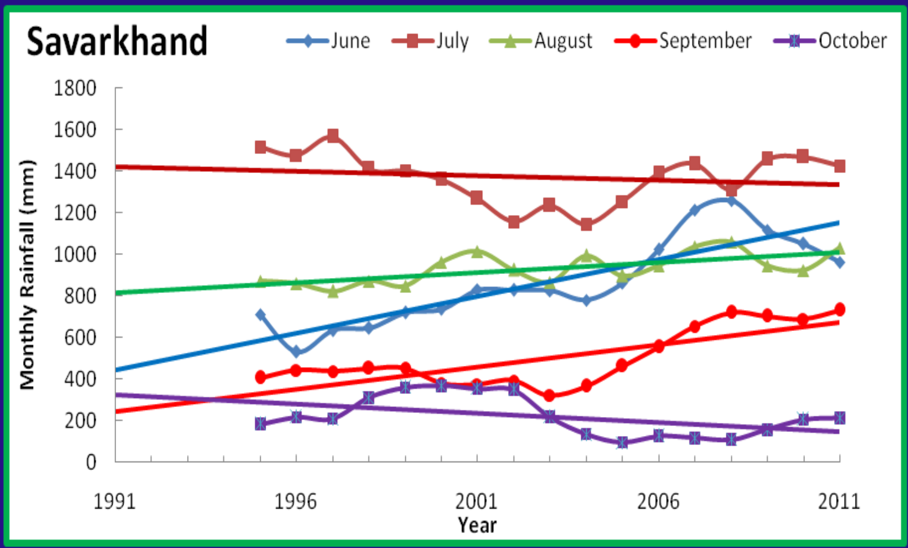
Monthly rainfall trends at Savarkhand



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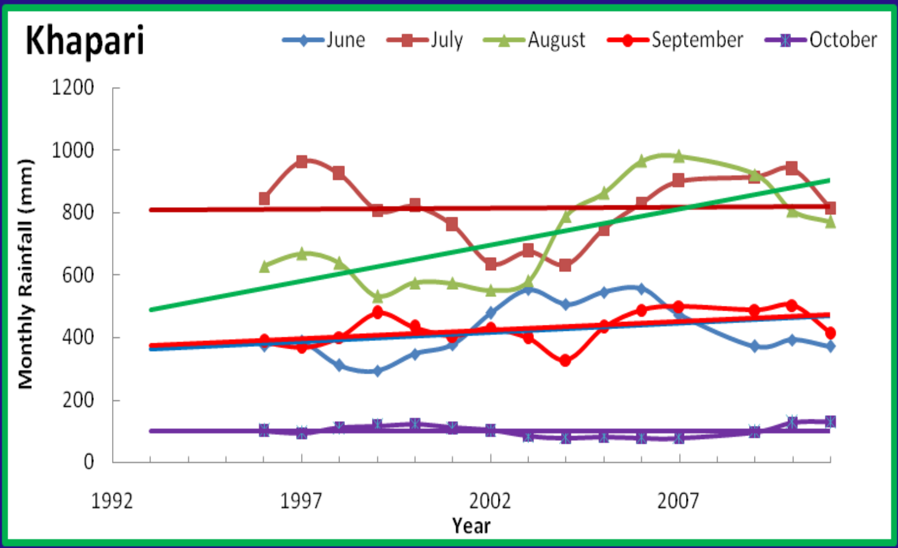
Monthly rainfall trends at Khapari



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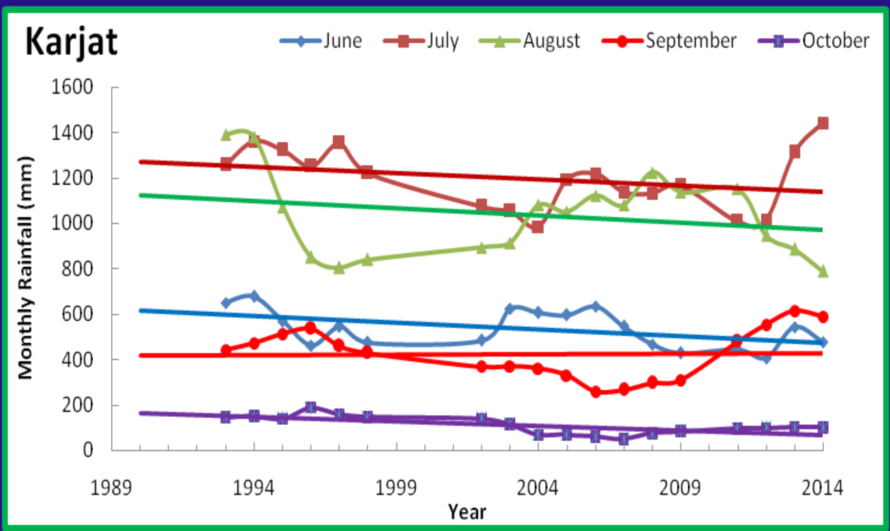
Monthly rainfall trends at Karjat



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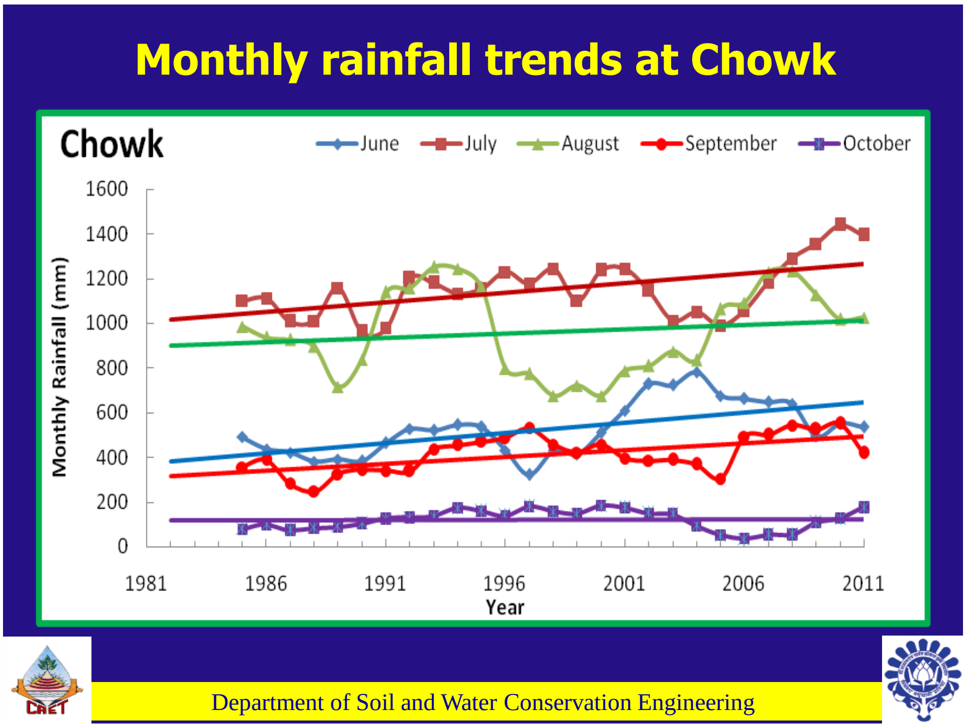
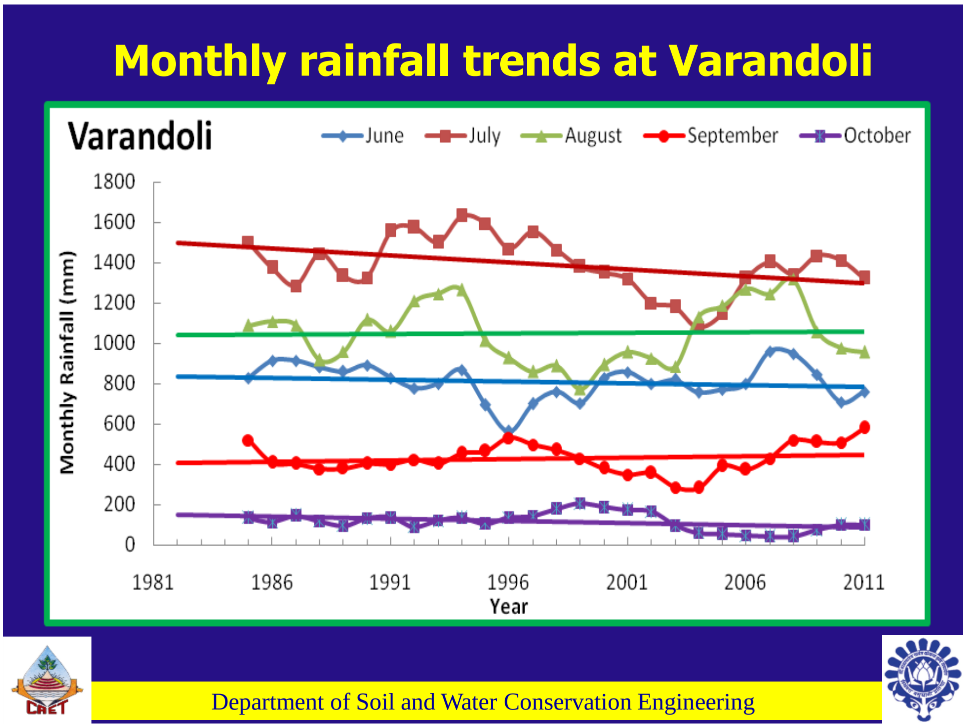
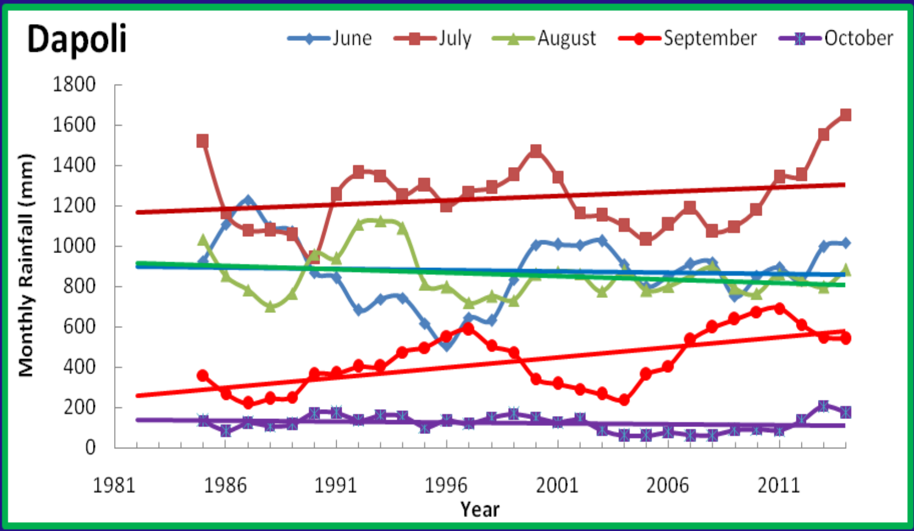

Monthly rainfall trends at Chowk
Chowk
June
July
August
September
October
Monthly Rainfall (mm)
Year
Department of Soil and Water Conservation Engineering


Monthly rainfall trends at Varandoli
Varandoli
June
July
August
September
October
Monthly Rainfall (mm)
Year
Department of Soil and Water Conservation Engineering

Monthly rainfall trends at Dapoli



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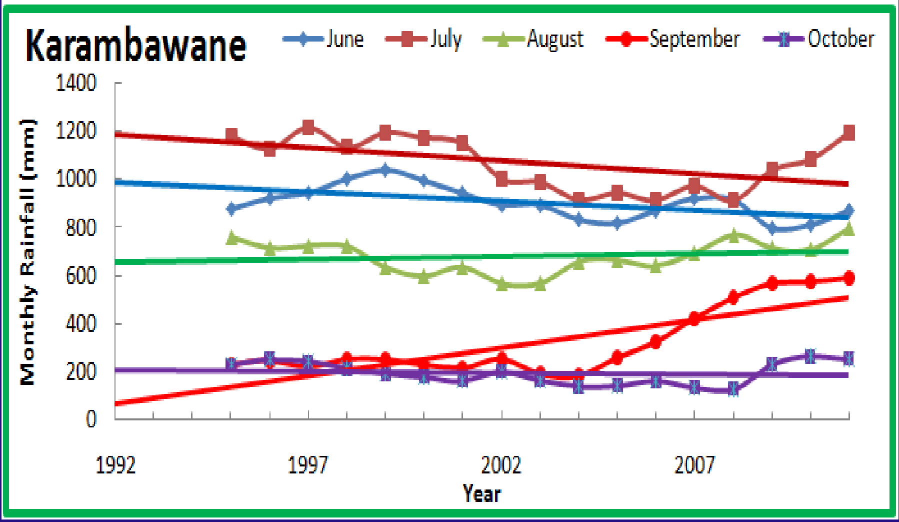
Monthly rainfall trends at Karambwane



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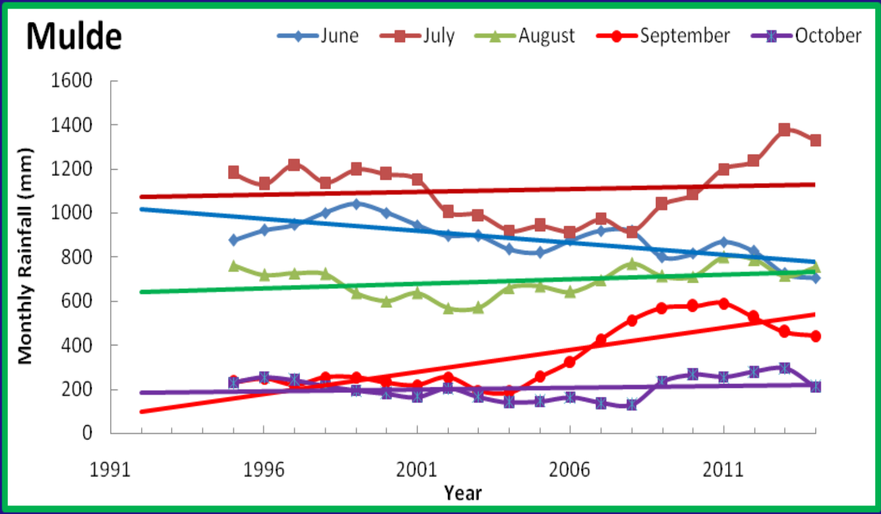
Monthly rainfall trends at Mulde



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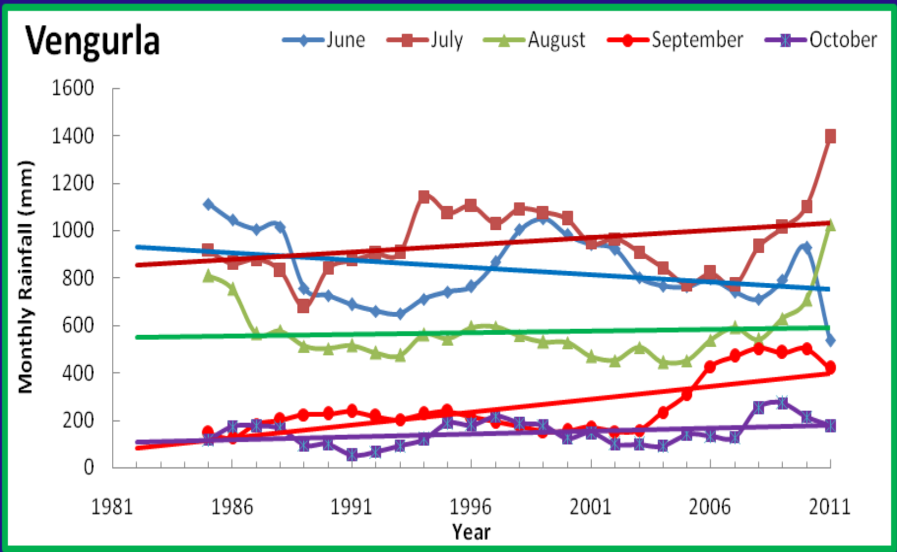
Monthly rainfall trends at Vengurla



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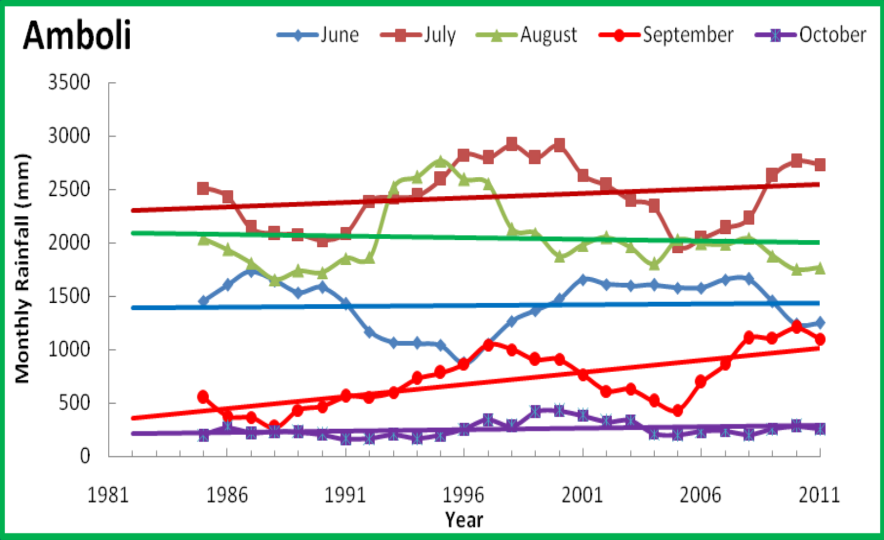
Monthly rainfall trends at Amboli



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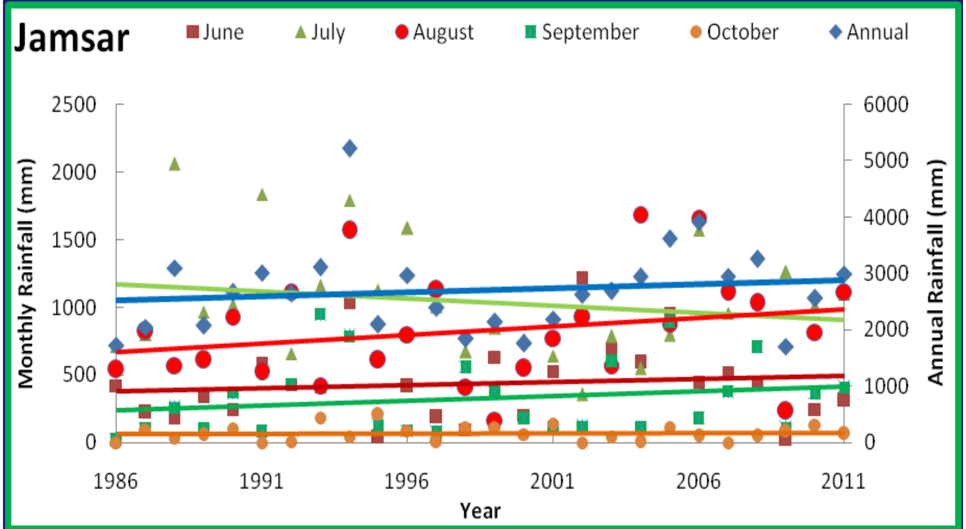
REGRESSION METHOD



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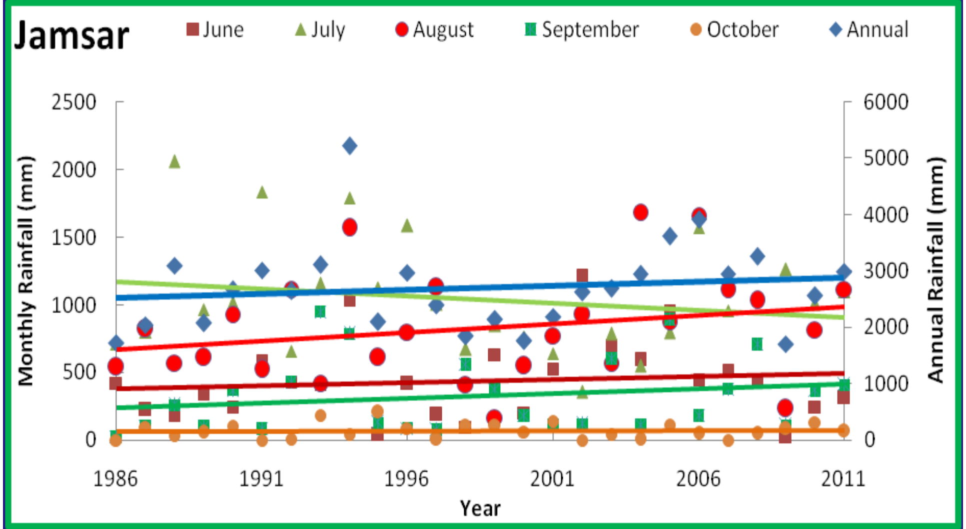
REGRESSION METHOD



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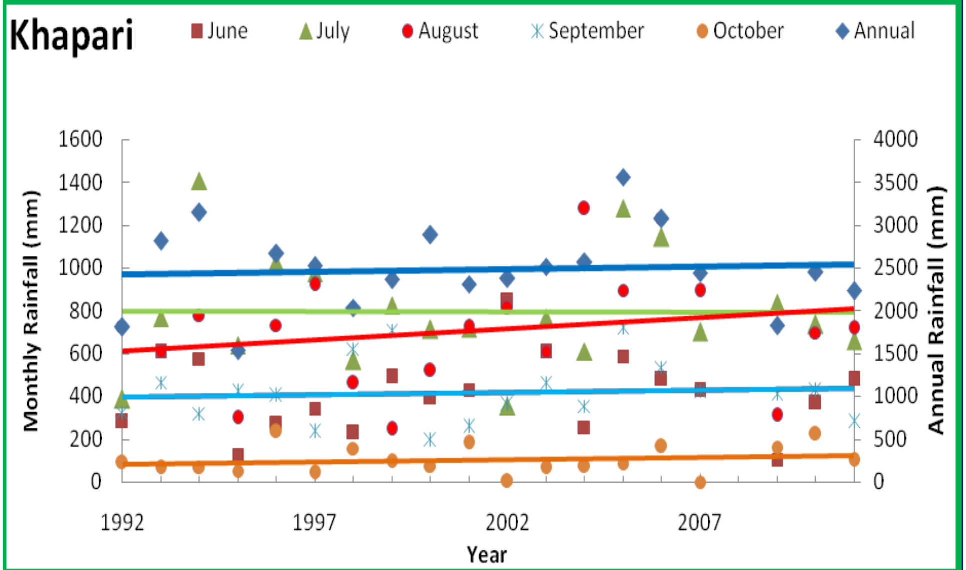

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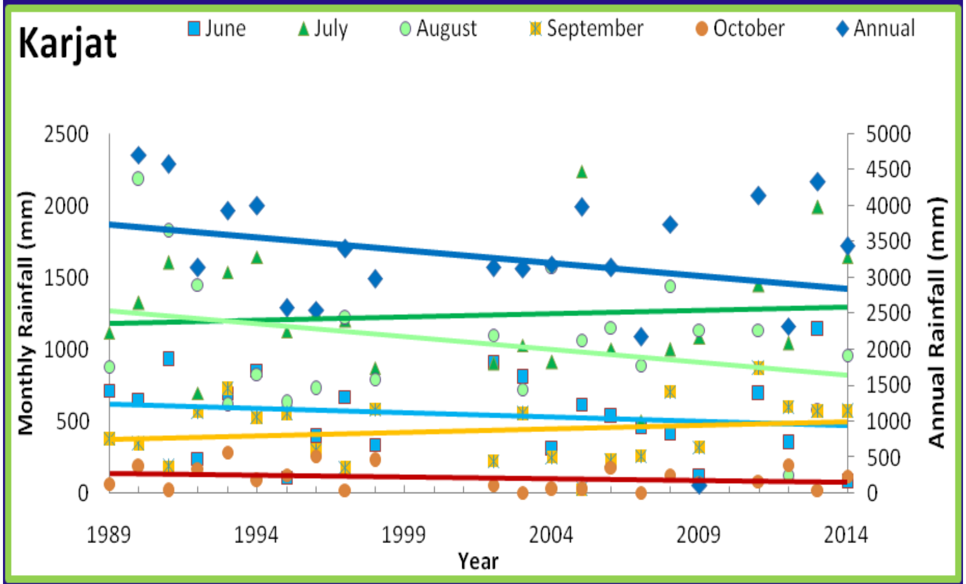

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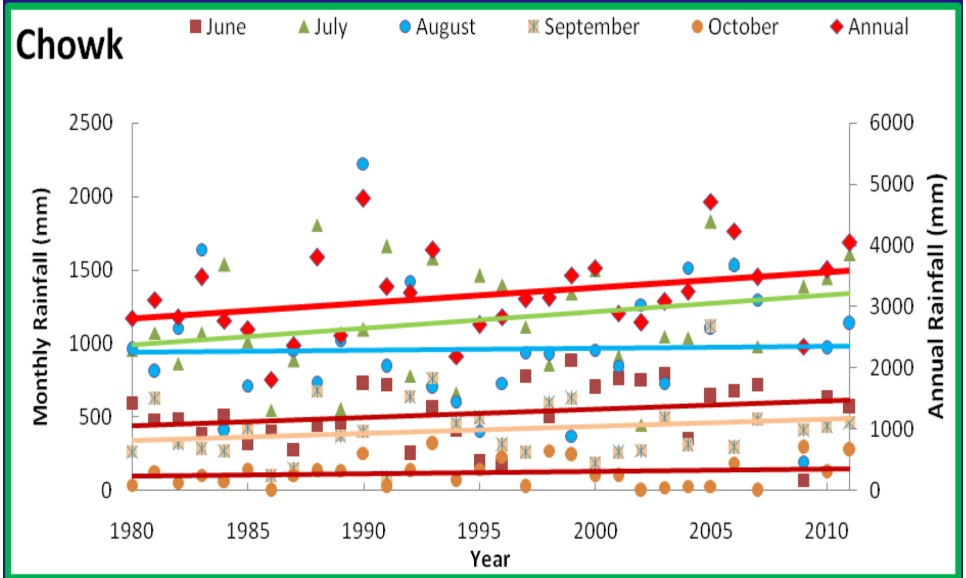

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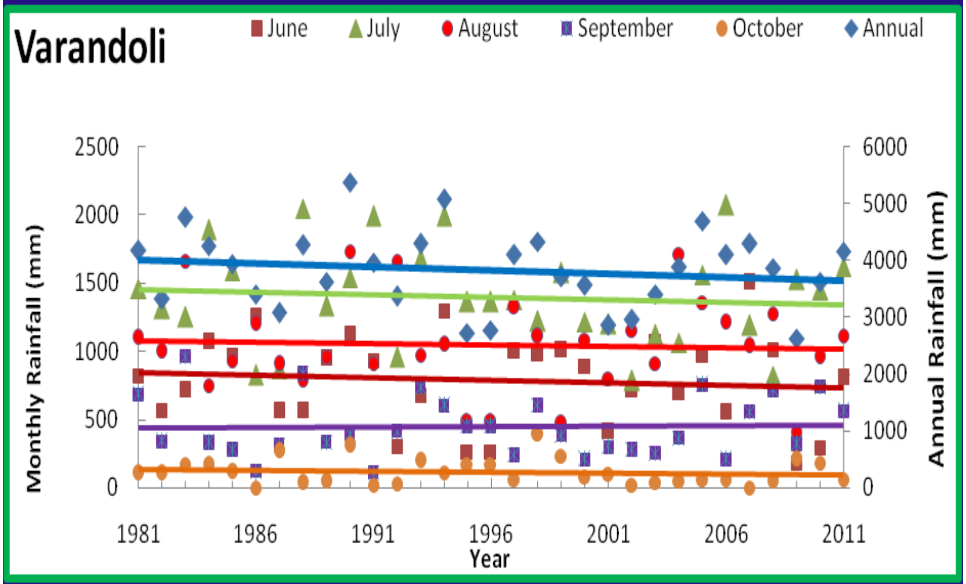

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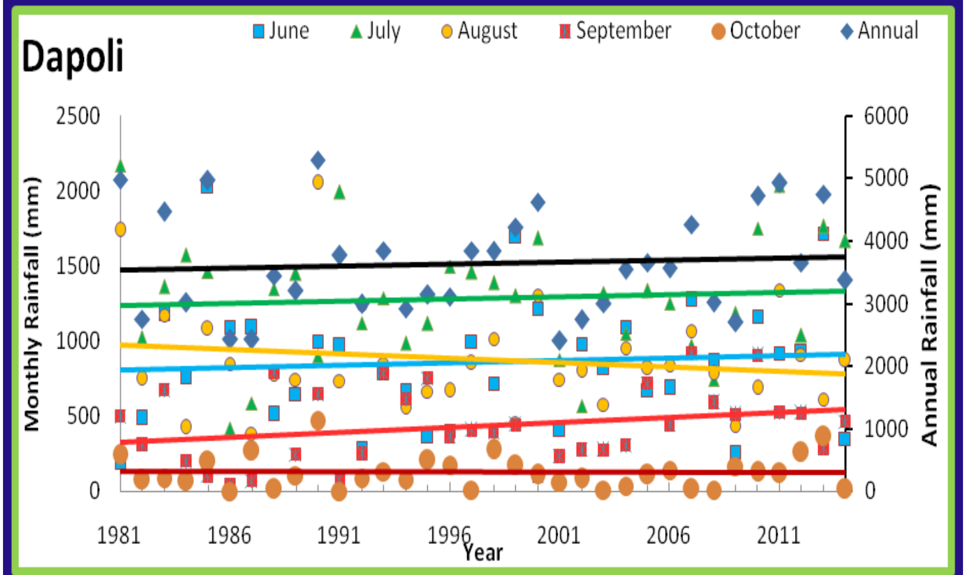

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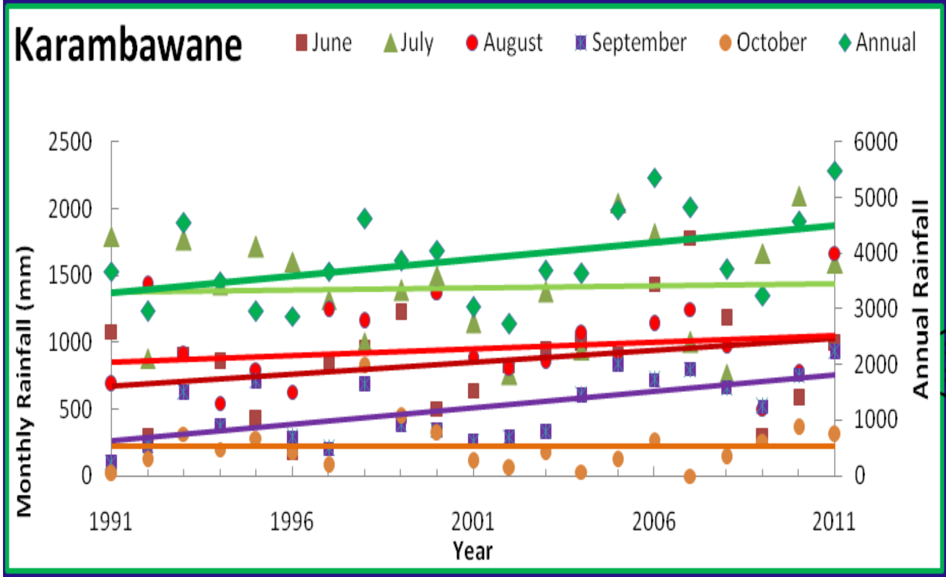

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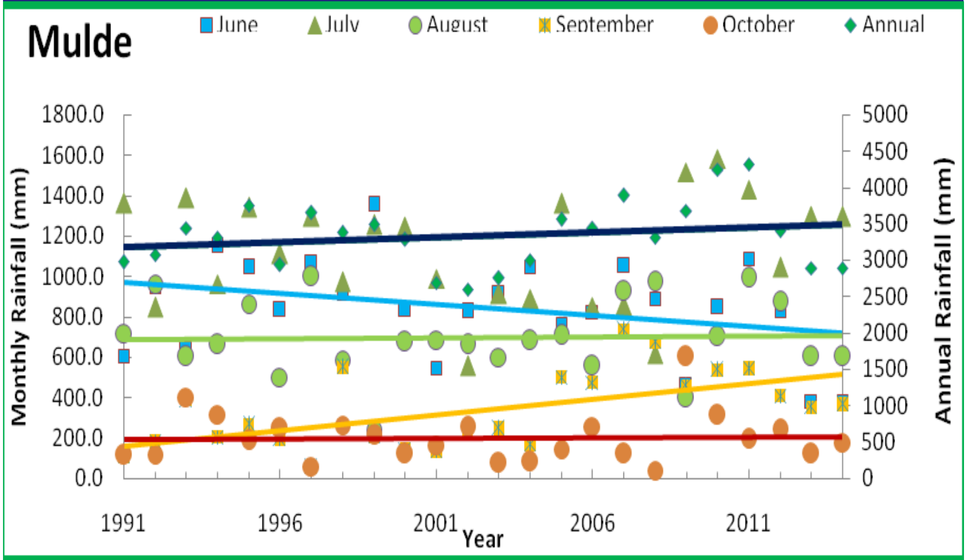

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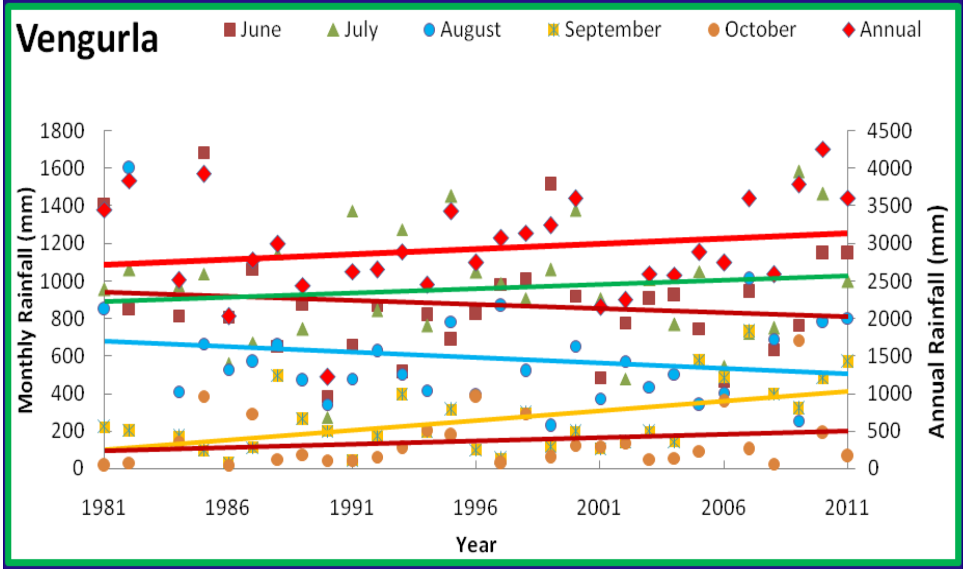

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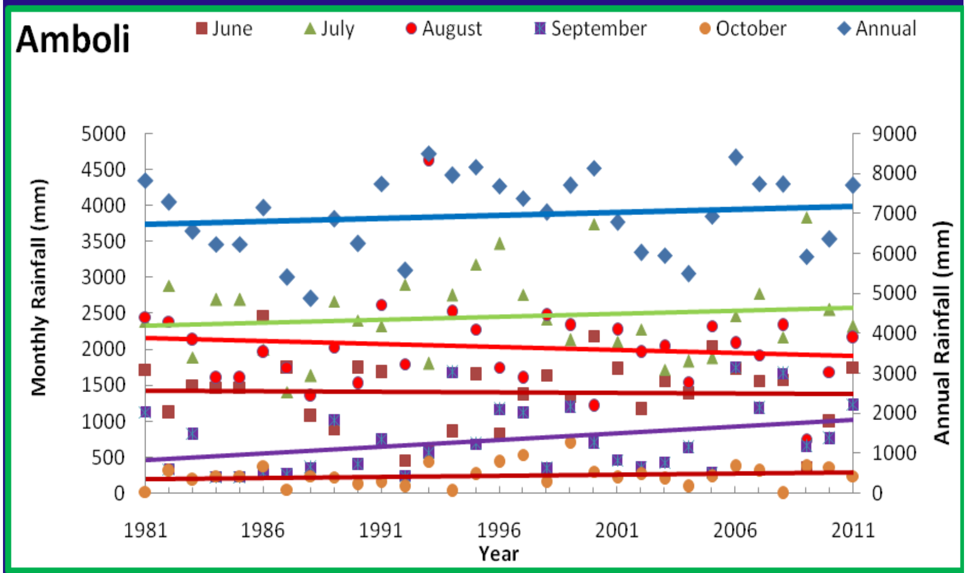

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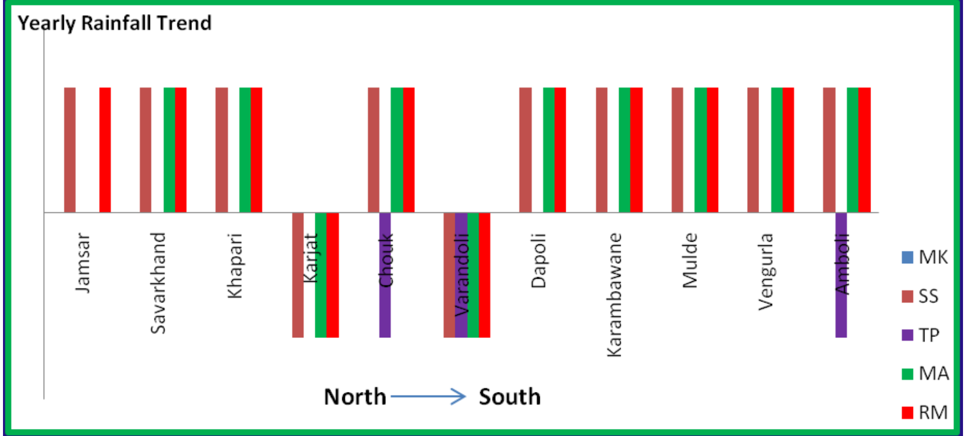
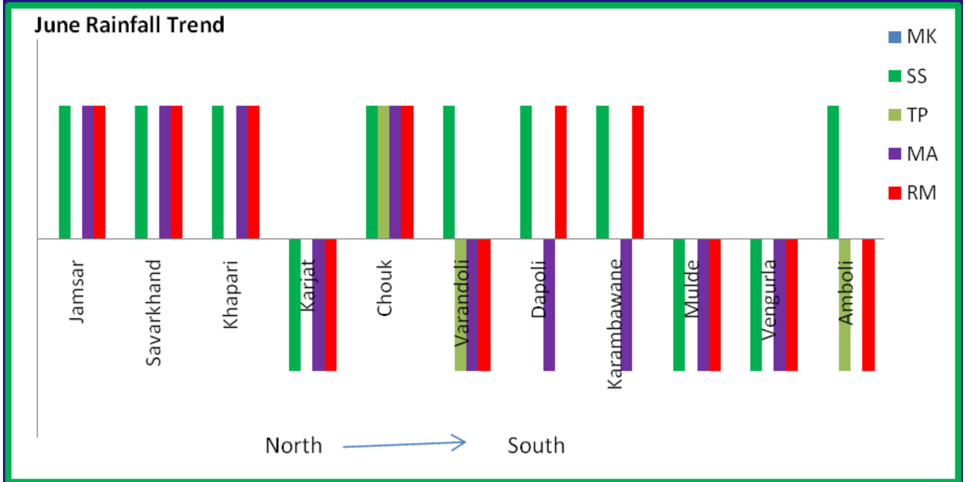
COMPARISON OF TRENDS

- **Annual Rainfall Trend**

- **Five methods of trend detection were compared station-wise and results of annual rainfall trends are presented in graph.**



Rainfall Trend of June month



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Rainfall Trend of July month

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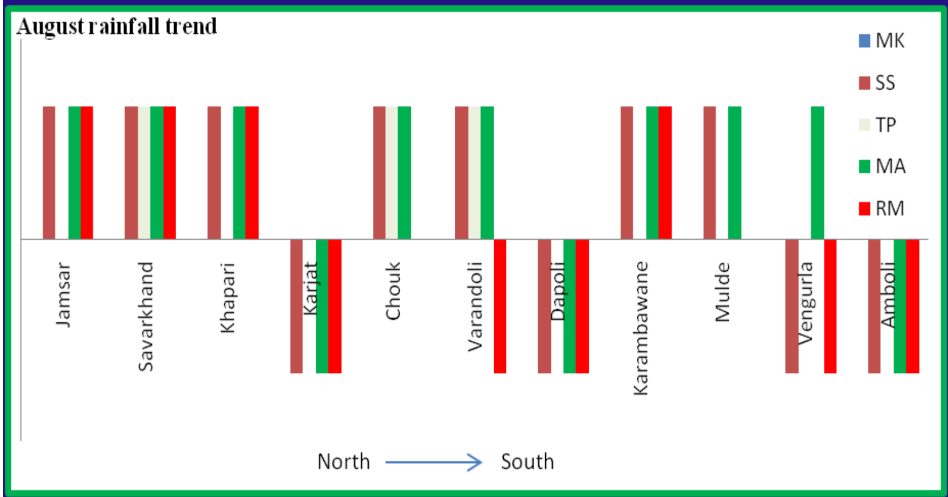
Rainfall Trend of August month



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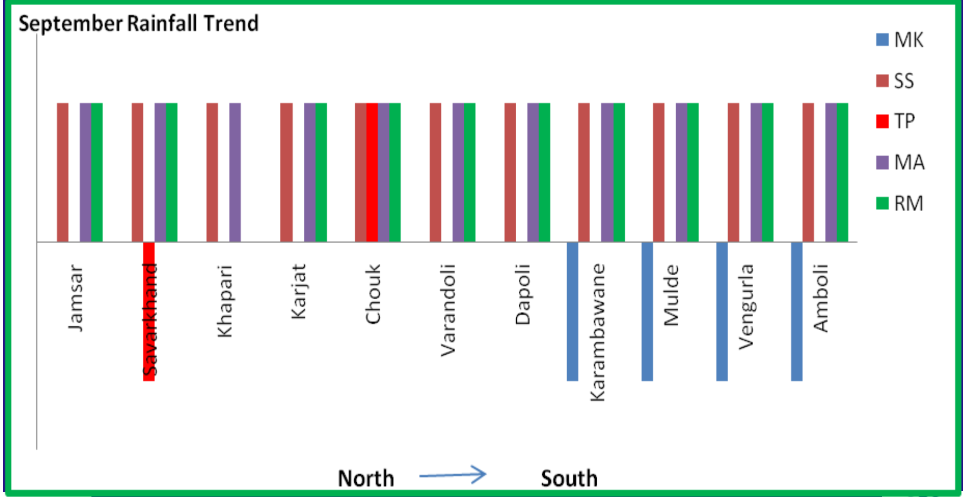
Rainfall Trend of September month



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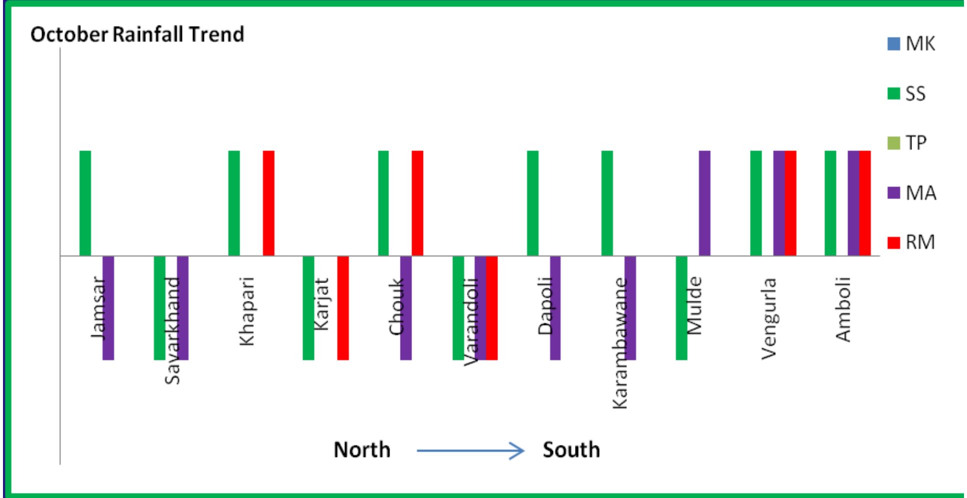
Rainfall Trend of October month



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Weekly Rainfall Trend

MW	Jamsar		Savarkhand		Khapari		Karjat		Chowk		Varandoli		Dapoli		Karambwane		Mulde		Vengurla		Amboli	
	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS	MK	SS
22	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	↑ET	NT	↑ET	NT	NT	NT	NT
23	NT	NT	NT	↑ET	NT	↓ET	NT	NT	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET
24	NT	↓ET	NT	↓ET	NT	↓ET	NT	NT	NT	↑ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET
25	NT	↑ET	NT	↑ET	NT	↓ET	NT	NT	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET
26	NT	↑ET	NT	↑ET	NT	↑ET	NT	NT	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	NT	NT	↑ET
27	NT	↑ET	NT	↑ET	NT	↑ET	NT	NT	↑ET	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	↑ET	↑ET
28	↓ET	↓ET	↓ET	↓ET	NT	↓ET	NT	NT	NT	↓ET	↓ET	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET
29	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	NT	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET
30	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET
31	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET
32	NT	↓ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET
33	↓ET	↓ET	↓ET	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET	NT	↓ET
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36	NT	↑ET	NT	↑ET	NT	↑ET	NT	↓ET	NT	↑ET	NT	NT	NT	↑ET	NT	↑ET	↑ET	↑ET	↑ET	↑ET	NT	↑ET
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38	NT	↑ET	NT	NT	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	↑ET	NT	↑ET	↑ET	↑ET	NT	↑ET	NT	↓ET
39	NT	↓ET	NT	NT	NT	↑ET	NT	↓ET	NT	NT	NT	↓ET	NT	↓ET	NT	↑ET	NT	↑ET	NT	↑ET	NT	↑ET
40	NT	NT	NT	NT	NT	↑ET	NT	NT	NT	NT	NT	NT	NT	↑ET	NT	↑ET	NT	↓ET	NT	↓ET	NT	NT
41	NT	NT	NT	NT	NT	↑ET	NT	NT	↑ET	↑ET	NT	↑ET	NT	NT	NT	NT	NT	↓ET	NT	NT	NT	NT
42	NT	NT	NT	NT	NT	NT	↓ET	NT	NT	NT	NT	NT	NT	NT	↓ET	↓ET	NT	↓ET	NT	NT	NT	NT
43	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	↑ET	NT	NT	NT	NT

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CONCLUSIONS

- Annual rainfall exhibited increasing trend in Palghar, Thane, Ratnagiri, and Sindhudurg district whereas Raigad district showed decreasing trend.

- June month rainfall showed increasing trend in Palghar (0.64%), Thane (0.52 %) and Ratnagiri (0.65%) district whereas Raigad (-0.19%) and Sindhudurg (-0.26%) district exhibited decreasing trend.

- July month rainfall showed decreasing trend in Palghar (-0.08 %), Thane (-0.22%) and Raigad (-0.02 %) district whereas Ratnagiri (0.03 %) and Sindhudurg (0.20 %) district showed increasing trend.

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THANK YOU