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Regression analysis between mean daily intensity, rainy days and seasonal rainfall in normal, excess and deficient years: A case study

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सार – यह शोध पत्र भारत के कर्नाटक प्रांत के जिले मैसूर के हुनसूर तालुक में झीलों/तालाबों के अवक्षयण पर किए गए अध्ययन के शोध कार्य का एक भाग है। इस अध्ययन में 1975-2014 तक की अवधि के लिए प्रतिदिन की वर्षा की मात्रा के आंकड़ों का रिग्रेशन विश्लेषण किया गया है। वर्षा वाले दिनों माध्य दैनिक तीव्रता बनाम ऋतुनिष्ठ/वार्षिक वर्षा की मात्रा के बीच संबंध स्थापित कर वर्षा की मात्रा में परिवर्तनशीलता का अध्ययन करना इस शोध पत्र का मुख्य उदेश्य है। यह देखा गया है कि इस क्षेत्र में अत्यधिक उतार चढ़ाव की वजह से तीसरी श्रेणी के पॉलिनॉमिअल कर्व फिटिंग अच्छे फिट हैं। इस रिग्रेशेन की तुलना लीनियर, लॉगरिथ्मिक एक्सपोनेन्शियल और पॉवर रिग्रेशन कर्व फिटिंग के साथ की गई है। मीन एनसॉल्यूट त्रुटि (MAE) और रूट मीन त्रुटि (RMSE) के न्यूनम मान का विश्लेषण भी सर्वश्रेष्ठ फिट के रूप में तीसरे क्रम के पॉलिनॉमिअल कर्व फिटिंग की ओर संकेत करता है। वर्षा की मात्रा का विश्लेषण भारत मौसम विज्ञान विभाग के अनुसार किया जाता है। यह देखा गया है कि हाल ही के वर्षों में बहुत हल्की वर्षा और हल्की वर्षा की तीव्रता विशेष रूप से बढ़ी है जबकि भारी और बहुत भारी वर्षा की तीव्रता धीरे-धीरे कम हुई है। हालांकि क्षेत्र में औसत वार्षिक वर्षा सामान्य है। माध्य दैनिक तीव्रता में कमी की प्रवृति पाई गई है और वर्षा वाले दिनों की संख्या में बढ़ोतरी की प्रवृति देखी गई है। इसलिए जलग्रहण क्षेत्रों में सतह रन ऑफ में कमी आई है जो कि इस क्षेत्रों में झीलों और तालाबों के सूखने का कारण है।

ABSTRACT. This paper is a part of research work on the study of degradation of lakes/tanks in Hunsur taluk of Mysore district, Karnataka, India. The study deals with the regression analysis of daily rainfall data for the period 1975-2014. The main objective of the study is on the variation of rainfall intensity, to establish a relationship between Rainy Days (RND), Mean Daily Intensity (MDI) versus Seasonal/Annual Rainfall. It is seen that, 3rd order polynomial curve fitting is a better fit due to the erratic fluctuation of rainfall in the region. The regression is compared with linear, logarithmic, exponential and power regression curve fitting. Least values of Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) analysis of the residue also suggest 3rd order polynomial curve fitting as best fit. Analysis of intensity of rainfall is carried as per Indian Meteorological Department (IMD). It is observed that, very light rain and light rain intensities have significantly increased in the recent years while rather heavy and heavy rain intensities have decreased gradually. Although the average annual rainfall is normal in the region, mean daily intensity is in the decreasing trend and the number of rainy days is in the increasing trend. Hence, surface runoff may have reduced in the catchment, which is one of the factors affecting the drying of lakes/tanks in the region.

Key words – Rainfall intensity, Mean daily intensity, Rainy days, Bilikere & Halebidu, MAE, RMSE.

1. Introduction

Inconsistency of precipitation is a major factor affecting the water resources and watersheds in tropics. The development and maintenance of watersheds in the rain fed areas requires spatial quantitative understanding of temporal variation of precipitation. The number of Rainy Days (RND) and Mean Daily Intensity (MDI) are the two comparative criterions which assist in contributing a better picture of rainfall conditions than the sum of monthly or annual rainfall. The annual, seasonal, monthly and daily precipitation received and its variability directly influences the success or failure of minor irrigation, using lakes/tanks. Therefore, the study of trends of annual, seasonal, monthly and daily precipitation is necessary in the selection of suitable rain water harvesting structures like tanks/lakes, maintenance of channels and watersheds. Aforesaid analysis is applicable in forecasting the probability of precipitation and hence useful in the management of watershed and water resources.

A number of studies on the relationship between rainfall intensity and rainy days have been carried by several investigators and researchers. A study of 41 years data collected from 50 stations at various places in India, suggested that a linear relationship fits better than the logarithmic relationship between the rainy days, mean daily intensity and seasonal rainfall. As well, suggested

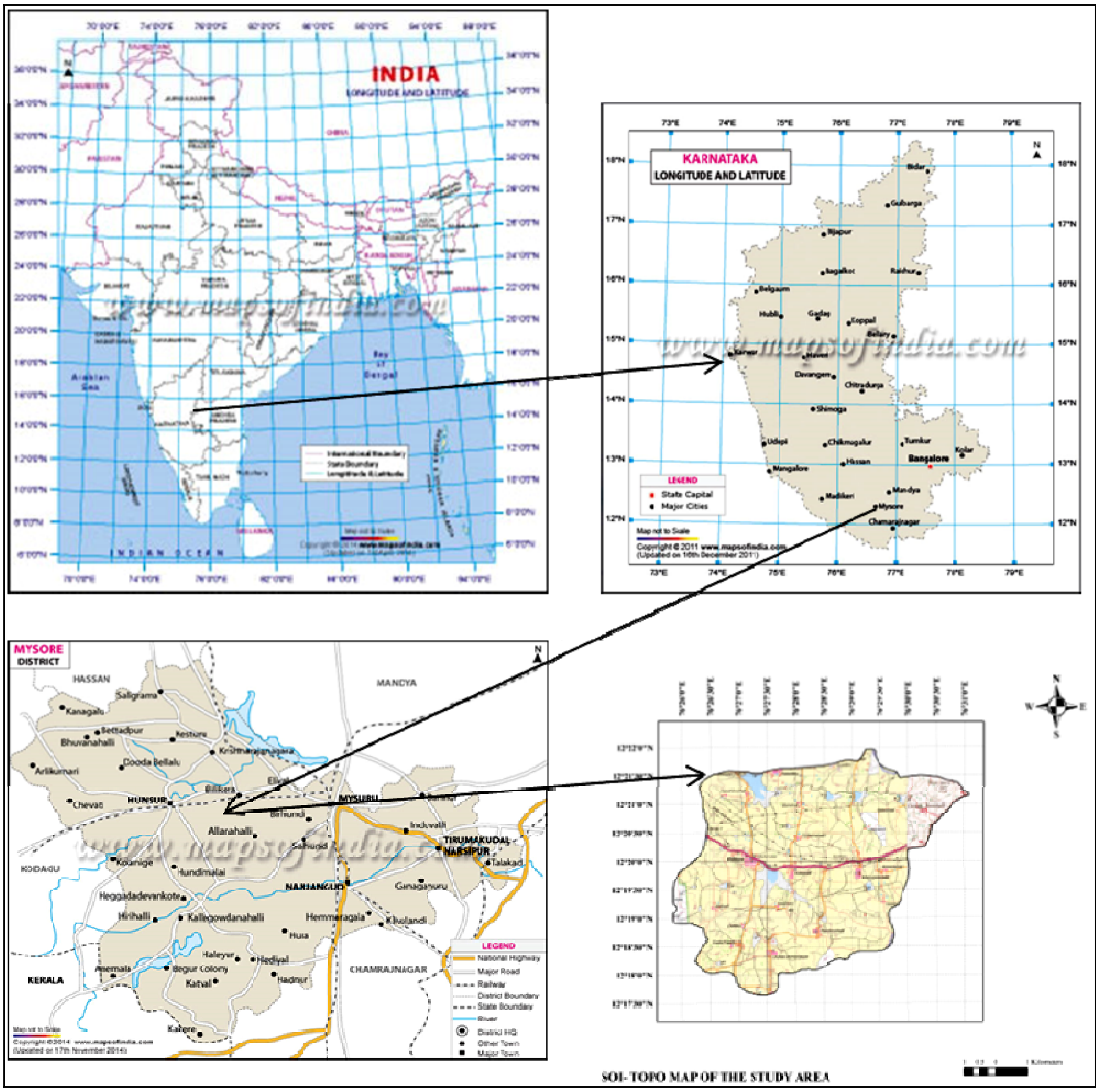

Fig.1. Location of study area

that the Mean Absolute Error (MAE) is less in linear relationship than logarithmic relationship (Singh, 1998). Statistical analysis of daily rainfall data for the period 1901-1980, collected from 15 Indian stations illustrated a normalized rainfall curve (NRC) between cumulated percentage rain amount and cumulated percentage of number of rainy days and shows that the NRC is uniquely determined by the coefficient of variation (CV) of the rainfall series. The intensity of rainfall equivalent to any point on the NRC is inversely proportional to the slope of the tangent at that point (Ananthakrishnan & Soman, 1989; Soman & Kumar, 1990. Investigation of daily rainfall for the period 1961-2005, collected in Koyna catchment (India) was carried and established a relationship between seasonal rainfall *versus* MDI & RND. The study showed that linear relationship is better than logarithmic between MDI and seasonal rainfall and logarithmic fit is better than linear relationship between RND and seasonal rainfall (Nandargi & Mulye, 2012). Other studies include an investigation by Endo *et al.*, 2005 in China using a linear trend line for the analysis. Olascoaga, 1982 made an investigation of percent cumulative rainfall against percent cumulative number of rainy days for the annual precipitation of all zones of Argentina with a single Normalized rainfall curve. Linear trend analysis was carried by Rani *et al.*, 2014.

TABLE 1

Regression equation with coefficient '*r*' values – Mean daily intensity *vs.*rainfall

Pre-monsoon – Normal years – (26 years)			Pre-monsoon – Excess years – (8 years)		
Equation	r^2	r	**Equation**	r^2	r
$8.3975x+28.53$	0.366	0.605	$6.1425x+137.91$	0.399	0.632
$127.57\ln(x)-182.95$	0.414	0.644	$116.08\ln(x)-77.823$	0.412	0.642
$35.251e^{0.0846x}$	0.429	0.655	$158.14e^{0.023x}$	0.405	0.637
$0.0278x^3-1.8005x^2+43.23x-168.94$	***0.422***	***0.649***	$0.0176x^3-1.2383x^2+33.16x-38.56$	***0.413***	***0.643***
$2.6891x^{1.444}$	***0.615***	***0.784***	$69.693x^{0.4385}$	***0.424***	***0.651***
Pre-monsoon – Deficient years – (6 years)			**SW-monsoon – Normal years – (26 years)**		
$6.3335x-5.829$	0.874	0.935	$13.894x+206.65$	0.216	0.464
NIL	-	-	$192.9\ln(x)-101.96439.09$	0.229	0.479
NIL	-	-	$240.23e^{0.0345x}$	0.182	0.427
$-0.0895x^3+3.2309x^2-21.997x-0.3105$	***0.941***	***0.970***	$0.3914x^3-18.153x^2+281.63x-1049.2$	***0.266***	***0.516***
NIL	-	-	$111x^{0.4812}$	0.196	0.443
SW-monsoon – Excess years – (8 years)			**SW-monsoon – Deficient years – (6 years)**		
$39.155x+30.33$	0.531	0.729	$15.062x+36.846$	0.463	0.680
$434.48\ln(x)-568.75$	0.468	0.684	$215.72\ln(x)-301.88$	0.395	0.629
$203.35e^{0.0718x}$	0.456	0.675	$68.534e^{0.06277x}$	0.114	0.337
$-1.6376x^3+63.585x^2-753.44x+3192.1$	***0.634***	***0.796***	$-0.0584x^3+3.365x^2-43.921x+344.2$	***0.487***	***0.698***
$68.062x^{0.7953}$	0.400	0.632	$22.561x^{0.7807}$	0.073	0.271
NE-monsoon – Normal years – (26 years)			**NE-monsoon – Excess years – (8 years)**		
$7.8911x+72.209$	0.421	0.648	$17.32x+8.6367$	0.209	0.457
$156.38\ln(x)-228.98$	0.470	0.685	$301.95\ln(x)-535.37$	0.170	0.412
$98.64e^{0.0392x}$	0.364	0.603	$162.02e^{0.0336x}$	0.138	0.371
$-0.224x^3+0.9945x^2-1.6675x+66.588$	***0.503***	***0.709***	$1.165x^3-68.155x^2+1286.2x-7475.2$	***0.720***	***0.849***
$20.586x^{0.8017}$	0.433	0.658	$57.194x^{0.5813}$	0.110	0.332
NE-monsoon – Deficient years – (6 years)			**Annual – Normal years – (26 years)**		
$2.3323x+91.104$	0.148	0.384	$7.6906x+659.15$	0.065	0.255
$69.406\ln(x)-59.244$	0.337	0.581	$124.76\ln(x)+439.09$	0.075	0.273
$72.263e^{0.0222x}$	0.238	0.488	$666.04e^{0.0097x}$	0.064	0.254
$-0.029x^3+1.571x^2-12.512x+68.423$	***0.972***	***0.986***	$-0.814x^3+36.063x^2-507.08x+3032.4$	***0.159***	***0.399***
$19.183x^{0.6489}$	0.481	0.693	$505.76x^{0.1563}$	0.074	0.271
Annual – Excess years – (8 years)			**Annual – Deficient years – (6 years)**		
$30.828x+669.05$	0.542	0.736	$26.56x+73.587$	0.295	0.543
$441.84\ln(x)-53.525$	0.516	0.718	$431.22\ln(x)-683.3$	0.341	0.584
$756.47e^{0.0264x}$	0.557	0.746	$100.19e^{0.0937x}$	0.282	0.531
$4.0732x^3-180.77x^2+2650.1x-11719$	***0.759***	***0.871***	$2.5062x^3-126.75x^2+2102.9x-10865$	***0.629***	***0.793***
$406.18x^{0.3796}$	0.533	0.730	$7.2361x^{1.5058}$	0.319	0.564

Bold-Italic values indicate highest r-squared value

Discussion on using MAE versus RMSE to find the residual errors and best fit regression line was carried out by Chai and Draxler, 2014. They discussed about the merits and demerits of the model performance in meteorology. The study also shows that a combination of both metrics is often required to assess model performance (Chai and Draxler, 2014). Pratiwi carried an investigation (Dian Pratiwi, 2013) on the variability of rainfall and found 4^{th} degree polynomial regression analysis as a good fit. The present study focuses on the degrading/drying lakes. Study is carried out to establish a relationship between rainy days, mean daily intensity with seasonal and annual rainfall and as well to find the variation in intensity of rainfall for the period 1975-2014.

TABLE 2

Regression equation with coefficient '*r*' values – Rainy Day v/s Rainfall

Pre-monsoon – Normal years – (26 years)			Pre-monsoon – Excess years – (8 years)		
Equation	r^2	r	**Equation**	r^2	r
$14.616x+24.814$	0.579	0.761	$-0.0183x+252.68$	0.000	0.000
$124.37\ln(x)-105.09$	0.593	0.770	$8.6811\ln(x)+229.42$	0.000	0.000
$41.954e^{0.1261x}$	0.490	0.700	NIL	0.000	0.000
$-0.056x^3+1.245x^2+10.176x+7.9848$	***0.621***	***0.788***	$0.1047x^3-6.3416x^2+112.96x-339.84$	***0.110***	***0.331***
$8.3495x^{1.2952}$	***0.744***	***0.863***	$226.93x^{0.0258}$	0.001	0.028
Pre-monsoon – Deficient years – (6 years)			**SW-monsoon–Normal years–(26 years)**		
$17.803x-1.8833$	0.862	0.929	$6.9835x+163.29$	0.291	0.539
NIL	-	-	$197.15\ln(x)-291.62$	0.292	0.540
NIL	-	-	$197.71e^{0.0201x}$	0.331	0.575
$-2.2429x^3+23.15x^2-36.938x-3E-11$	***0.985***	***0.992***	$0.0132x^3-1.2483x^2+44.554x-193.53$	***0.295***	***0.544***
NIL	-	-	$52.16x^{0.5745}$	***0.341***	***0.584***
SW-monsoon – Excess years – (8 years)			**SW-monsoon–Deficient years–(6 years)**		
$8.811x+134.03$	0.282	0.531	$9.2333x+77.288$	0.337	0.580
$361\ln(x)-836.98$	0.320	0.566	$86.159\ln(x)-27.773$	0.489	0.699
$215.72e^{0.0193x}$	0.344	0.587	$21.83e^{0.1094x}$	0.669	0.818
$-0.1221x^3+13.583x^2-474.44x+5607.1$	***0.595***	***0.771***	$0.2897x^3-14.817x^2+201.54x-173.35$	***0.872***	***0.934***
$25.425x^{0.7937}$	0.395	0.628	$13.76x^{0.9717}$	***0.881***	***0.938***
NE-monsoon – Normal years – (26 years)			**NE-monsoon – Excess years – (8 years)**		
$11.041x+77.274$	0.231	0.481	$21.253x-7.6935$	0.646	0.804
$123.16\ln(x)-90.803$	0.256	0.506	$323.57\ln(x)-526.06$	0.567	0.753
$86.996e^{0.0671x}$	0.300	0.548	$125.15e^{0.0539x}$	0.725	0.852
$-0.1026x^3+2.3767x^2+0.0137x+57.71$	***0.273***	***0.523***	$0.3039x^3-15.555x^2+254.97x-1017.4$	***0.891***	***0.944***
$29.369x^{0.7747}$	***0.356***	***0.597***	$30.406x^{0.8563}$	0.695	0.833
NE-monsoon – Deficient years – (6 years)			**Annual – Normal years – (26 years)**		
$15.022x+16.098$	0.360	0.600	$2.612x+630.97$	0.090	0.299
$67.674\ln(x)-0.0669$	0.185	0.431	$135.23\ln(x)+234.92$	0.089	0.299
$54.414e^{0.0973x}$	0.246	0.496	$641.08e^{0.0036x}$	0.092	0.302
$0.1474x^3+3.3719x^2-59.688x+273.74$	***0.897***	***0.947***	$0.0025x^3-0.4051x^2+24.037x+264.01$	***0.091***	***0.301***
$53.64x^{0.3925}$	0.102	0.319	$387.35x^{0.1722}$	0.091	0.302
Annual – Excess years – (8 years)			**Annual – Deficient years – (6 years)**		
$-3.3562x+1403.5$	0.091	0.302	$12.056x+92.459$	0.686	0.828
$-239.3\ln(x)+2181.8$	0.077	0.278	$295.87\ln(x)-514.33$	0.820	0.905
$1428.5e^{-0.003x}$	0.099	0.315	$102.82e^{0.0438x}$	0.695	0.834
$0.057x^3-13.574x^2+1057.8x-25826$	***0.581***	***0.762***	$0.0519x^3-4.925x^2+148.3x-874.43$	***0.951***	***0.975***
$2866.7x^{-0.213}$	0.086	0.293	$10.479x^{1.0991}$	0.867	0.931

Bold-Italic values indicate highest *r*-squared value

2. Study area

The study area is a combined catchment of Bilikere and Halebidu Minor Irrigation (MI) tanks of Hunsur taluk, Mysore district, Karnataka, India (Fig. 1). It is located between 76°31'4" E &76°25'46" E longitude and 12°22'00" N and 12°17'38" N latitude with an elevation ranging from 601 m (MSL) to 774 m (MSL). The catchment is a part of Lakshman Theertha River which is a tributary to river Cauvery. The area experiences tropical/semiarid climate with seasons (*i*) Winter (*ii*) Pre-Monsoon (*iii*) Southwest-Monsoon (*iv*) Northeast-Monsoon. The relative humidity is generally high during the southwest monsoon season. Relative humidity is about

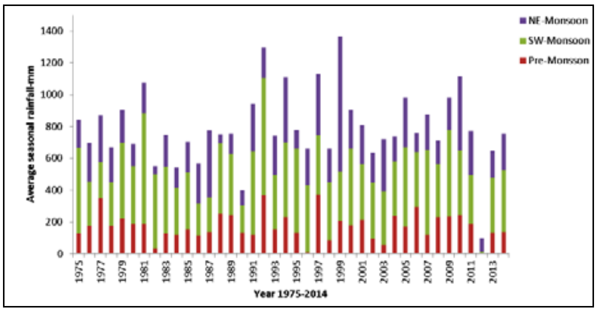

Fig. 2. Seasonal distribution of rainfall (1975-2014)

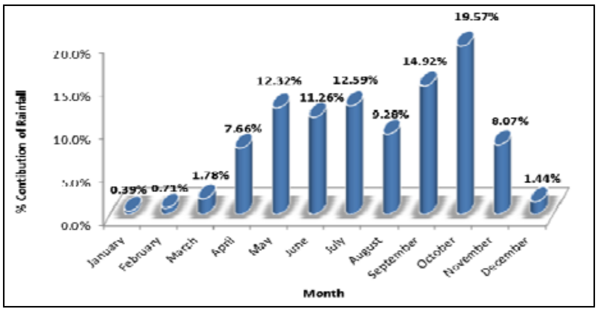

Fig. 3. Percentage contribution of monthly rainfall (1975-2014)

70% and above in the mornings throughout the year, while in the afternoons, humidity is comparatively lower except during the southwest monsoon. The period January to March is the driest part of the year with relative humidity of about 30% and still lower in the afternoons. Both the lakes/tanks were the lifelines for the people living around them. The lakes have dried up completely since 2004. The combined catchment is primarily covered with agricultural and farm land.

3. Data and methodology

The daily rainfall data is collected from Karnataka State Natural Disaster Monitoring Center, Bengaluru (KSNDMC), for Hunsur taluk, Mysore district from 1975 to 2014 (40 Years). The variability of precipitation with the number of rainy days on daily, monthly and annually is carried outby applying standard statistical techniques and parameters. Seasonal, monthly and annual contribution of precipitationis computed. The normal value of average annual rainfall (a.a.r.) is calculated as per the Indian meteorological department (IMD) (India Meteorological Department 2016) classification; E: Excess rainfall (Percentage departure of realized rainfall from normal rainfall is +20% or more), N: Normal rainfall (Percentage departure of realized rainfall from normal rainfall is between –19% to +19%), D: Deficient rainfall (Percentage departure of realized rainfall from normal rainfall is between –20% to –59%), S: Scanty rainfall (Percentage departure of realized rainfall from normal rainfall is between –60% to -99%), NR: No rainfall (Percentage departure of realized rainfall from normal rainfall is –100%) and their distribution is investigated.

3.1. *Regression analysis*

In statistical modelling, regression analysis is a set of statistical method for estimating the relationship among variables. It is widely used for prediction and forecasting. In the present study Rainy Days (RND) and Mean Daily Intensity (MDI) is used as descriptive variable (*x*) and annual/seasonal rainfall as response variable (*y*). The daily rainfall data for the period 1975-2014 is studied and classified as Normal, Excess and Deficient years as per IMD. It is observed that 26 years of the data fall in the class of Normal, 8 years in Excess and 6 years in Deficient (including one year of scanty rainfall) years. Winter season (January and February) is not considered as the quantity of rainfall is negligible. Pre-Monsoon is from March to May, South-west (SW) Monsoon is from June to September, North-East (NE) Monsoon is from October to December. In this paper a Rainy Day has been defined as per IMD; a day with 2.5 mm rain or more. Mean daily intensity is the ratio of average rainfall to number of rainy days. Annual/seasonal rainfall against RND and MDI is fitted to a number of mathematical functions. These are arranged into five groups linear, logarithmic, exponential, 3rd order polynomial and power, based on their characteristics performance. Tables 1&2 show the equations used in the regression analysis with '*r*-squared' value and '*r*' value for 40 year period.

3.2. *MAE & RMSE*

MAE: Mean Absolute Error is a measure of difference between observed rainfall and predicted rainfall which is the residual error. It is the mean of the absolute values of the individual prediction errors. It is given by:

$$\text{MAE} = \frac{1}{\text{n}} \Sigma_{j=1}^{n} \left| y_j - y'_j \right| \quad (1)$$

RMSE: Root Mean Squared Error is a quadratic scoring rule that also measures the average magnitude of the error. It's the square root of the average of squared differences between predicted and actual rainfall. It is given by:

$$\text{RMSE} = \sqrt{\frac{1}{\text{n}} \Sigma_{j}^{n} \left(\left| y_j - y'_j \right| \right)^2} \quad (2)$$

where, '*n*' is the number of years of rainfall data, y_j is the actual rainfall and y'_j is the predicted rainfall.

TABLE 3

Statistical data for monthly/seasonal rainfall (1975-2014)

S. No.	Month/Season	Max	Min	Mean	SD	% CV	% of a.a.r.	Rainy days
1.	January	29.2	0	3.14	7.27	**231.74**	0.4	0
2.	February	48	0	5.73	11.8	206.11	0.7	0
3.	March	97.2	0	14.29	26.27	183.81	1.8	1
4.	April	192.2	0	61.44	42.51	69.18	7.7	4
5.	May	**267.6**	0	98.87	57.20	57.86	12.3	6
6.	June	260.6	0	90.35	50.3	55.67	11.3	7
7.	July	248.4	0	101.06	61.22	60.58	12.6	9
8.	August	177.6	0	74.46	48.71	65.42	9.3	8
9.	September	275	4.8	119.72	69.34	57.92	14.9	7
10.	October	810	19	**157.01**	**129.93**	82.75	**19.6**	8
11.	November	264.9	0	64.73	62.41	96.41	8.1	4
12.	December	75.7	0	11.58	19.42	167.68	1.4	1
14.	Winter	48.0	0.0	8.86	13.31	**150.17**	1.1	0
15.	Pre-Monsoon	373.9	0.0	174.61	85.77	49.12	21.8	11
16.	SW-Monsoon	736.8	12.5	**385.80**	135.48	35.14	48.1	31
17.	NE-Monsoon	850.0	49.0	233.32	**137.93**	**59.12**	29.1	13
18.	Annual	2746.4	23.8	802.37	235.41	29.34	100.0	55

TABLE 4

Statistical data for Decadal and Lustra period

S. No.	Period	Max	Min	Mean RND	Mean Rainfall	SD	%CV
				Decade			
1.	1975-1984	1073	550	46	767.27	168.00	21.90
2.	1985-1994	1297.2	428.6	49	812.76	257.25	31.65
3.	1995-2004	1416	637.4	60	853.87	249.64	29.24
4.	2005-2014	1126.4	100	66	775.577	279.62	36.05
				Lustra			
5.	1975-1979	940.9	689.1	48	811.96	111.96	13.79
6.	1980-1984	1073	550	43	722.58	214.41	29.67
7.	1985-1989	776.5	566.9	42	713.64	86.64	12.14
8.	1990-1994	1297.2	428.6	57	911.88	341.81	37.48
9.	1995-1999	1416	661	62	934.22	332.74	35.62
10.	2000-2004	942.8	637.4	58	773.52	115.61	14.95
11.	2005-2009	1003.2	721.2	76	868.2	127.12	14.64
12.	2010-2014	1126.4	100	56	682.95	371.91	54.46

In this study least values of MAE and RMSE are used to find the minimum residual error in the regression analysis. The relationship for best fit has been established for the said variables considering the higher value of regression coefficient '*r*' as evidenced in Tables 1&2.

4. Results and discussion

4.1. *Monthly &seasonal Precipitation*

Monthly precipitation analysis shows that maximum rainfall occurs in October with a mean value of

TABLE 5

Intensity of rainfall, rainy days and mean daily intensity (MDI)

S. No.	Year	a.a.r.	NR	VLR	LR	MR	RH	HR	VHR	RND	MDI
1.	1975	862.30	320	1	14	25	4	1	0	44	19.60
2.	1976	699.20	330	2	7	20	6	1	0	34	20.56
3.	1977	868.30	309	1	22	28	3	2	0	55	15.79
4.	1978	689.10	316	0	14	32	2	1	0	49	14.06
5.	1979	940.90	309	0	16	34	6	0	0	56	16.80
6.	1980	691.00	320	0	12	31	2	1	0	46	15.02
7.	1981	1073.00	306	0	9	43	4	3	0	59	18.19
8.	1982	550.40	333	5	10	14	2	0	1	27	20.39
9.	1983	748.50	277	32	32	18	5	1	0	56	13.37
10.	1984	550.00	337	0	5	19	4	1	0	29	18.97
11.	1985	703.90	325	1	11	25	3	0	0	39	18.05
12.	1986	566.90	328	0	8	26	3	0	0	37	15.32
13.	1987	776.50	327	1	14	16	5	1	1	37	20.99
14.	1988	766.00	292	27	17	26	3	1	0	47	16.30
15.	1989	754.90	281	34	22	24	3	1	0	50	15.10
16.	1990	428.60	283	43	24	14	1	0	0	39	10.99
17.	1991	942.40	291	21	24	20	8	1	0	53	17.78
18.	1992	1297.20	275	21	27	30	12	1	0	70	18.53
19.	1993	743.00	290	19	28	24	3	1	0	56	13.27
20.	1994	1148.20	275	25	25	33	5	2	0	65	17.66
21.	1995	792.90	297	13	18	33	3	1	0	55	14.42
22.	1996	661.00	311	6	22	25	2	0	0	49	13.49
23.	1997	1139.20	259	35	28	36	5	2	0	71	16.05
24.	1998	662.00	287	16	33	27	2	0	0	62	10.68
25.	1999	1416.00	275	17	20	44	6	3	0	73	19.40
26.	2000	942.80	278	20	37	26	2	3	0	68	13.86
27.	2001	823.90	281	30	33	14	4	3	0	54	15.26
28.	2002	637.40	290	27	28	18	1	1	0	48	13.28
29.	2003	720.60	291	22	23	23	6	0	0	52	13.86
30.	2004	742.90	282	16	33	34	1	0	0	68	10.93
31.	2005	1003.20	238	37	43	45	2	0	0	90	11.15
32.	2006	758.20	259	36	40	28	1	1	0	70	10.83
33.	2007	877.90	262	32	33	35	3	0	0	71	12.36
34.	2008	721.20	265	37	37	25	2	0	0	64	11.27
35.	2009	980.50	180	102	47	33	3	0	0	83	11.81
36.	2010	1126.40	182	85	52	42	3	1	0	98	11.49
37.	2011	780.87	250	54	34	23	4	0	0	61	12.80
38.	2012	100.00	354	3	4	5	0	0	0	9	11.11
39.	2013	647.50	277	41	21	24	2	0	0	47	13.78
40.	2014	760.00	261	41	39	18	6	0	0	63	12.06
	Average	**802.37**	**288**	**23**	**24**	**27**	**4**	**1**	**0**	**55**	**14.92**

157.01 mm, maximum of 810 mm in the year 1999 and minimum of 19 mm in the year 2006. The standard deviation (SD) is 129.93 mm and coefficient of variation (CV) of 82.75% indicating most unreliable rainfall month,

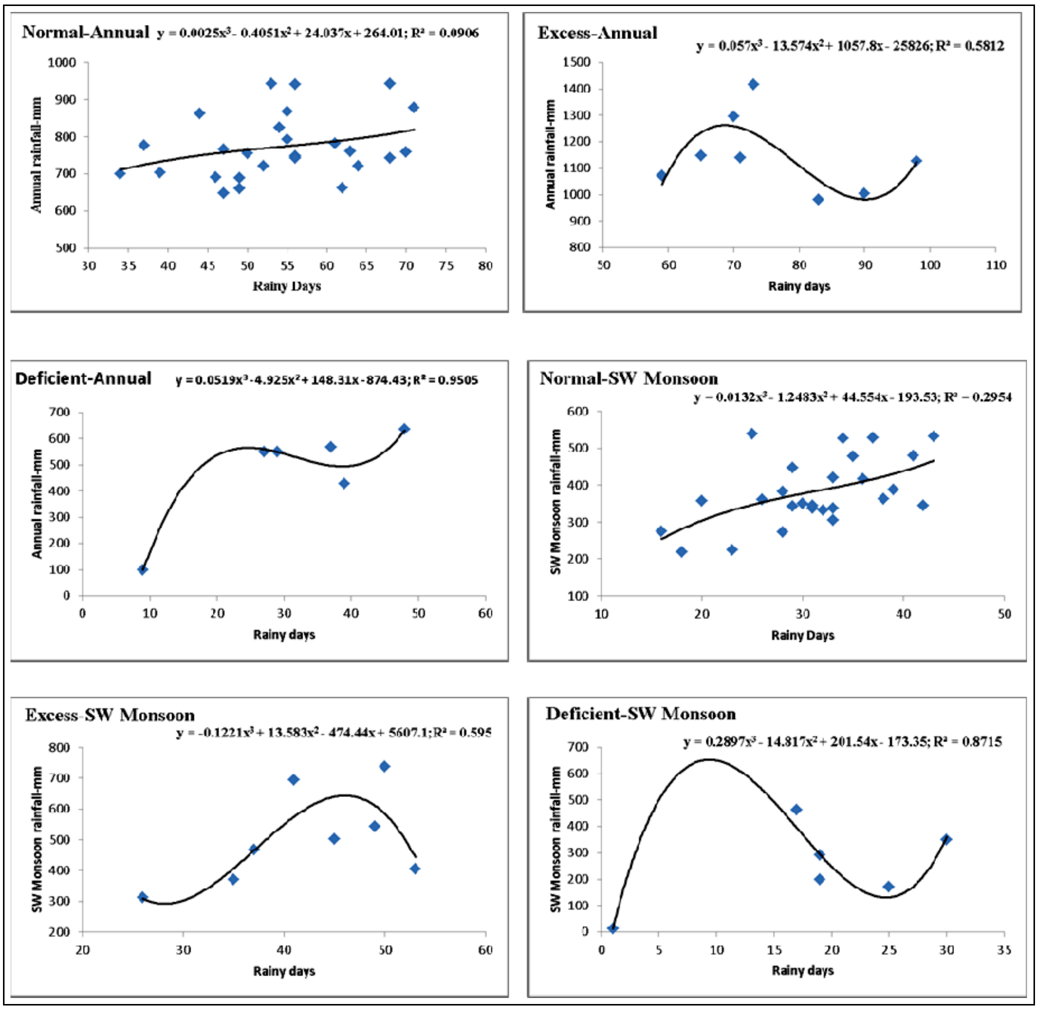

Fig. 4. 3rd order polynomial relation between annual & SWM rainfall against RND

the next higher rainfall-month is September which has a mean of 119.72 mm, maximum of 275 mm in 1981 and a minimum of 4.8 mm in 2003 with a SD of 69.34 mm, CV of 56.07%. Next in the order are July, May, June, August, November, April, March, February and January. January is the month of least rainfall which has 3.14 mm as the mean, 29 mm as maximum in the year 1990 and minimum of zero in most of the year.

The seasonal variation shows that southwest monsoon is the main contributor (48.1% of a.a.r.) of rainfall. The mean value of SW monsoon is 385.58 mm, SD of 135.48 mm and CV of 35.14%. North-east monsoon has a mean value of 233.32 mm, SD of 137.93 mm, CV of 59.12%. Fig. 2 shows seasonal rainfall distribution and noticed that NE-Monsoon is in increasing trend and SW Monsoon is in decreasing trend.

The percent contribution of monthly rainfall is shown in Fig. 3 and Table 3. 19.6% of rain occurs in October, 14.9% in September. CV for the Monsoon months varies from 55.67% to 65.42% and SD ranges from 50.3 mm to 69.34 mm. But NE monsoon months have more CV and SD than SW-Monsoon.

4.2. *Annual precipitation*

Average annual rainfall of Hunsur taluk is 802.37 mm distributed with a CV of 29.34%, SD of 235.4 mm. The minimum a.a.r. of 100 mm was in 2012 and a maximum a.a.r. of 1416 mm in 1999. Excess precipitation (>962.8 mm) occurred in 8 years out of 40 years in 1981(34%), 1992(62%), 1994(43%), 1997(42%), 1999(76%), 2005(25%), 2009(22%) and 2010(40%). Deficient rainfall occurred in 5 years out of 40 years in 1982(-31%), 1984(-31%), 1986(-29%), 1990(-47%)

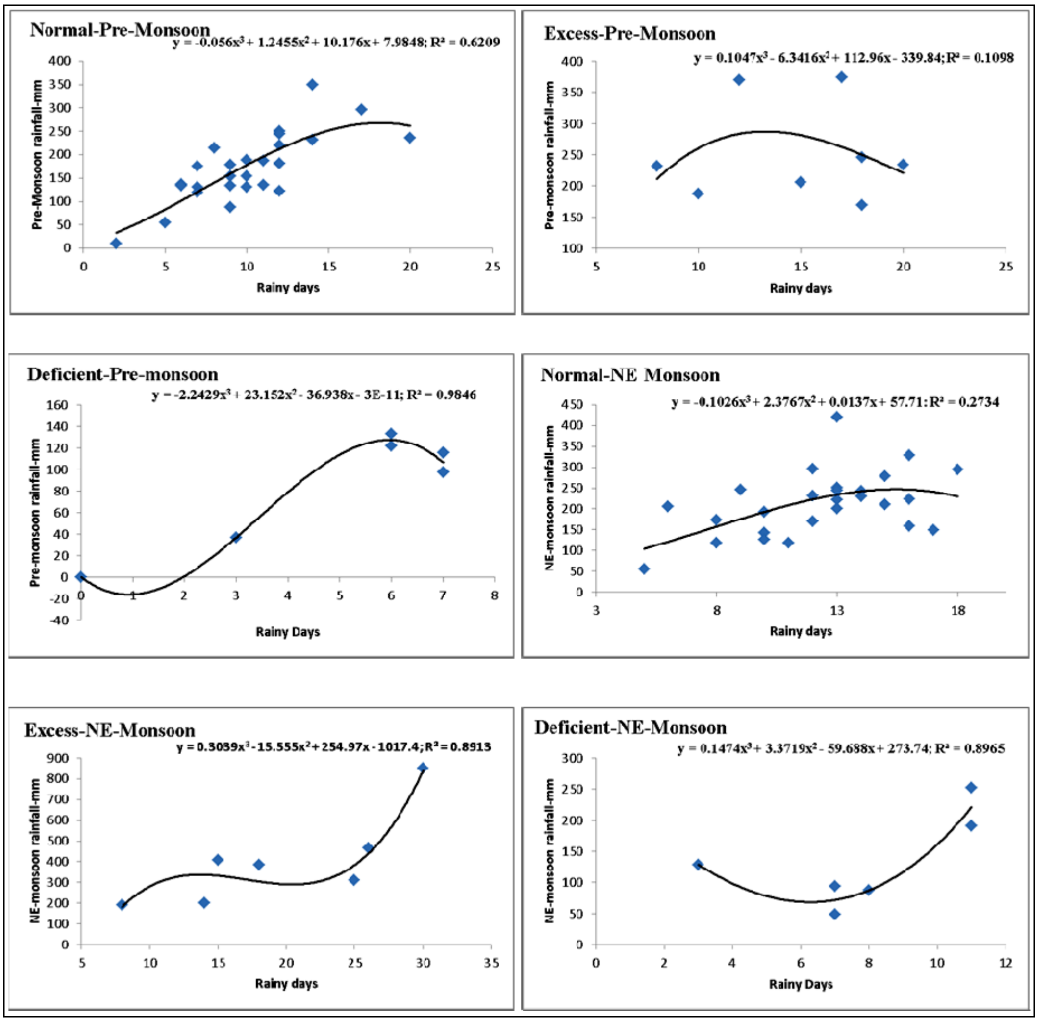

Fig. 5. 3rd order polynomial relation between PMN& NEM rainfall against RND

& 2002(-21%), Scanty rainfall occurred in only one year, *i.e.*, in 2012(-88%). Normal rainfall (range 649.9 mm to 954.82 mm) occurred in 26 years among 40 years indicating that the a.a.r. is normal in the taluk. Depending on the CV and SD, it can be said that uncertainty is high and certainty is less.

Further investigation is carried at 10 year (Decadal) and 5 Year (Lustrum) interval as shown in Table 4; It is observed that the third decade (1995-2004) is having better rainfall with a mean value of 853.87 mm, CV of 29.24% and SD of 249.64 mm, whereas the first decade is having a mean value of 767.27 mm, CV of 21.89%, SD of 168 mm. The lustra variation shows that fifth lustrum (1995-99) is having a highest mean of 934.22 mm, SD 332.73 mm & CV of 35.62%, whereas last lustrum (2010-14) has a mean 682.95 mm, CV of 54.46% and SD of 371.9 mm expressing that as the mean value decreases, SD value increases. The lustrum analysis reveals that,if the mean value lies between 700-900 mm, SD varies from 86 mm to 150 mm and CV varies from 12% to 30%, indicating normal rainfall and if the mean value is less than 700 mm and greater than 900 mm; SD is greater than 200 mm and CV is greater than 30%; showing excess or deficient rainfall.

4.3. *Rain day and rainy days*

A rain day (RD) indicates a day of rainfall greater than 0.1 mm which differs from a rainy day (RND) described as a day with a rain amount of 2.5 mm or more. Annual mean of number of rainy days is 55, maximum of 98 days with 1126.4 mm rainfall in 2010, minimum of 9 days in 2012 with 100 mm rainfall. Excess rain fall years recorded a maximum of 98 days (2010), minimum of 65 days (1994) and mean of 76 days. Rainy days in normal

TABLE 6

Regression results for Pre-monsoon and NE-monsoon rainfall and rainy days

Value	Rainy day	Observed value	Predicted value				
			Linear	Logarithm	Exponential	Polynomial	Power
Pre-monsoon rainfall & rainy days							
Normal years (26)							
Mean	10.04	171.54	171.54	171.54	167.55	171.59	169.97
SD	3.72	71.41	54.31	54.98	94.54	56.31	80.30
MAE			36.35	36.01	50.50	**34.79**	41.68
RMSE			46.36	45.56	73.52	**43.97**	55.13
Excess years (8)							
Mean	14.75	252.41	252.41	252.41	243.09	252.19	242.98
SD	4.02	72.73	0.07	2.65	0.09	24.12	1.91
MAE			59.57	59.52	55.63	**57.82**	55.17
RMSE			72.73	72.68	73.33	**68.63**	73.30
Deficient years (6)							
Mean	4.83	84.17	84.16	Nil	Nil	84.09	Nil
SD	2.54	48.77	45.29	Nil	Nil	48.35	Nil
MAE			15.60	Nil	Nil	**4.80**	Nil
RMSE			18.09	Nil	Nil	**6.06**	Nil
Northeastmonsoon rainfall & rainy days							
Normal years (26)							
Mean	12.27	212.74	212.74	212.73	202.84	212.64	203.44
SD	3.26	74.95	36.05	37.95	42.73	39.14	43.20
MAE			49.67	49.17	51.51	**49.6**	50.44
RMSE			64.72	64.64	68.18	**63.89**	66.41
Excess years (8)							
Mean	18	374.86	374.86	374.86	360.35	374.82	356.96
SD	7.76	205.26	164.97	154.57	150.79	193.73	134.09
MAE			95.52	104.99	85.43	**52.37**	90.07
RMSE			122.14	135.05	113.28	**67.69**	128.57
Deficient years (6)							
Mean	7.83	133.77	133.77	133.77	120.63	133.77	118.18
SD	2.73	68.46	41.06	29.48	30.35	64.82	18.45
MAE			49.3	57.67	47.36	**17.79**	55.81
RMSE			54.77	61.79	53.92	**22.02**	63.31

years varied from 34 days (1976) to 71 days (2007) with a mean of 54 days. The deficient years has a minimum of 27days (1982), a maximum of 48 (2002) days, mean of 36 days. Scanty rain has occurred in one year with 9 days in 2012. During these periods the excess rainfall ranged from 980.5 mm (2009) to 1416.0 mm (1999) with a mean of 1147.96 mm, Normal rainfall varied from 647.5 mm (2013) to 942.80 mm (2000) and 772.22 mm as mean, deficient rainfall fluctuated from 428.60 mm (1990) to 637.40 mm (2002) with a mean of 544.66 mm as shown in Table 5.

In the present investigation, the catchment receives light rain to moderate rain in the year. The catchment has a flat terrain having a moderate slope and high permeability. It is observed that July has recorded highest number of rainy days (9 days) followed by August and October (8 days). In order to know the rainfall condition for forecasting and predicting, scatter plot is drawn with 3rd order polynomial regression curve for normal, excess and deficient years and seasons as shown in Figs. 4&5.

TABLE 7

Regression results for annual and SW-monsoon rainfall and rainy days

Value	Rainy day	Observed value	Predicted value				
			Linear	Logarithm	Exponential	Polynomial	Power
Annual rainfall & rainy days							
Normal years (26)							
Mean	54.08	772.22	747.88	772.2	766.73	774.4	768.18
SD	9.79	85.49	21.17	25.56	24.73	26.79	24.8
MAE			64.17	67.09	65.94	**67.28**	66.19
RMSE			85.24	81.58	81.77	**81.56**	81.68
Excess years (8)							
Mean	76.13	1147.96	1148	1148.1	1137.61	1146.19	1142.99
SD	12.29	136.6	41.26	37.98	41.6	104.56	38.49
MAE			109.53	108.83	107.02	**69.46**	107.72
RMSE			130.22	131.21	130.82	**88.42**	131.54
Deficient years (6)							
Mean	31.5	472.22	472.22	472.2	463.86	474.14	469.01
SD	12.19	177.42	146.96	160.64	215.86	173.99	193.85
MAE			89.58	58.94	140.23	**24.74**	95.55
RMSE			99.41	75.31	155.96	**39.53**	113.07
Southwest monsoon rainfall & rainy days							
Normal years (26)							
Mean	31.15	380.85	380.85	380.85	373.34	379.83	373.69
SD	6.91	89.64	48.29	48.43	50.75	48.16	49.62
MAE			61.92	63.10	61.23	**62.54**	62.45
RMSE			75.51	75.42	76.24	**75.25**	75.75
Excess years (8)							
Mean	42.00	504.09	504.09	504.09	491.55	501.52	492.15
SD	8.47	140.59	74.63	79.58	77.16	107.72	80.22
MAE			92.43	88.53	91.68	**69.31**	88.37
RMSE			119.15	115.90	122.83	**89.52**	119.11
Deficient years (6)							
Mean	18.5	248.08	248.10	192.54	238.54	247.71	233.28
SD	8.98	142.87	82.89	99.89	178.33	133.26	111.94
MAE			89.50	90.21	145.63	**36.79**	84.86
RMSE			116.38	116.27	182.72	**51.21**	120.27

It is seen from the Figs. 4&5 and Tables 6&7, 3rd order polynomial curve fits better compared to any of the other regression (Linear, Logarithmic, Exponential and Power) relationship between rainfall and rainy days. Although there is a small difference exists in the '*r*' values. Least MAE and RMSE values also suggest that 3rd order polynomial fit is a best fit for predicting rainfall with rainy days.

4.4. *Intensity of rainfall*

The intensity of rainfall is a measure of the amount of rain that falls over time. Forty (40) year daily rainfall data is analyzed and classified as per IMD; NR: No rain (Intensity of rainfall equal to zero), VLR: Very light rain (rainfall between 0.1 mm-2.4 mm per day), LR: Light rain (between 2.5 mm-7.5 mm per day), MR: Moderate rain

TABLE 8

Monthly and seasonal intensity of rain as per IMD

Month/season	Annual rainfall	Rain day	Rainy day	No rain	Very light rain	Light rain	Moderate rain	Rather heavy	Heavy rain	Mean daily intensity
January	3.14	0	0	31	0	0	0	0	0	12.55
February	5.73	1	0	28	0	0	0	0	0	12.05
March	14.29	1	1	30	0	0	0	0	0	17.87
April	61.44	5	4	25	1	1	2	0	0	16.61
May	98.87	7	6	24	2	2	4	0	0	17.35
June	90.35	11	7	19	4	3	4	0	0	12.25
July	101.06	**13**	**9**	18	4	5	4	0	0	10.93
August	74.46	12	8	19	4	5	3	0	0	9.83
September	119.72	10	7	20	3	3	4	1	0	16.57
October	157.01	10	8	21	2	3	4	1	0	**19.09**
November	64.73	5	4	25	1	1	2	0	0	17.26
December	11.58	1	1	30	0	0	0	0	0	14.95
Winter	8.86	1	1	58	0	0	0	0	0	12.22
Pre-Monsoon	174.61	13	10	79	3	3	6	1	0	17.12
SW-Monsoon	385.58	46	31	75	15	16	13	1	0	12.27
NE-Monsoon	233.32	17	13	75	4	4	6	2	0	18.30
Annual	802.37	77	55	288	23	24	27	4	0	14.56

TABLE 9

Decadal intensity of rain as per IMD

Decade	1975-1984	1985-1994	1995-2004	2005-2014
Very light rain: (0.1 mm-2.4 mm)	4	19	20	47
Light rain: (2.5 mm-7.5 mm)	14	20	28	35
Moderate rain: (7.6 mm-35.5 mm)	26	24	28	28
Rather heavy rain: (35.6 mm-64.4 mm)	4	5	3	3
Heavy rain: (64.5 mm-124.4 mm)	1	1	1	0
Rainy days	46	49	60	66
Average annual rainfall	767.27	812.76	853.87	775.577

TABLE 10

Lustra Intensity of rainfall as per IMD

Lustra	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Very light rain: (0.1 mm-2.4 mm)	1	7	13	26	17	23	49	45
Light rain:(2.5 mm-7.5 mm)	15	14	14	26	24	31	40	30
Moderate rain: (7.6 mm-35.5 mm)	28	25	23	24	33	23	33	22
Rather heavy rain: (35.6 mm-64.4 mm)	4	3	3	6	4	3	2	3
Heavy rain:(64.5 mm-124.4 mm)	1	1	1	1	1	1	0	0
Rainy days	48	43	42	57	62	58	76	56
Average annual rainfall	811.96	722.58	713.64	911.88	934.22	773.52	868.2	682.95

(7.6 mm-35.5 mm), RH: Rather heavy (35.6 mm-64.4 mm), HR: Heavy rain (64.5 mm-124.4 mm), VHR: Very heavy rain (124.5 mm-244.4 mm), HER: Extremely heavy rain (greater than 244.5 mm). Monthly

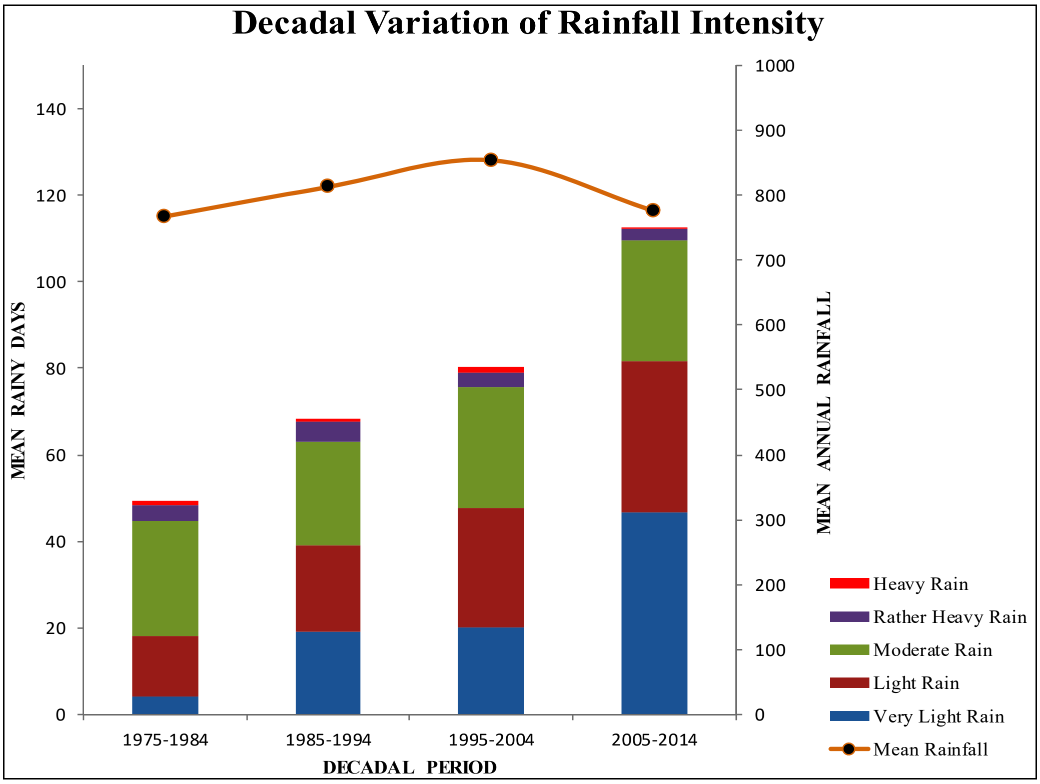

Fig. 6. Decadal variation of rain intensities with average annual rainfall

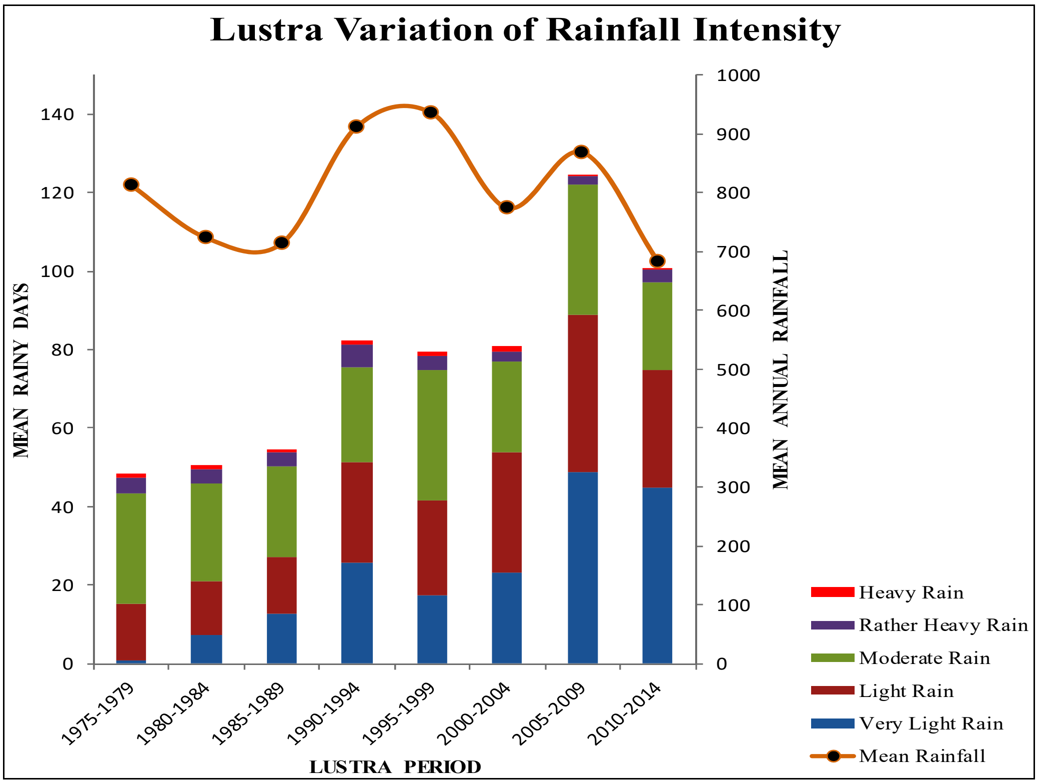

Fig. 7. Lustra variation of rainfall intensities with average annual rainfall

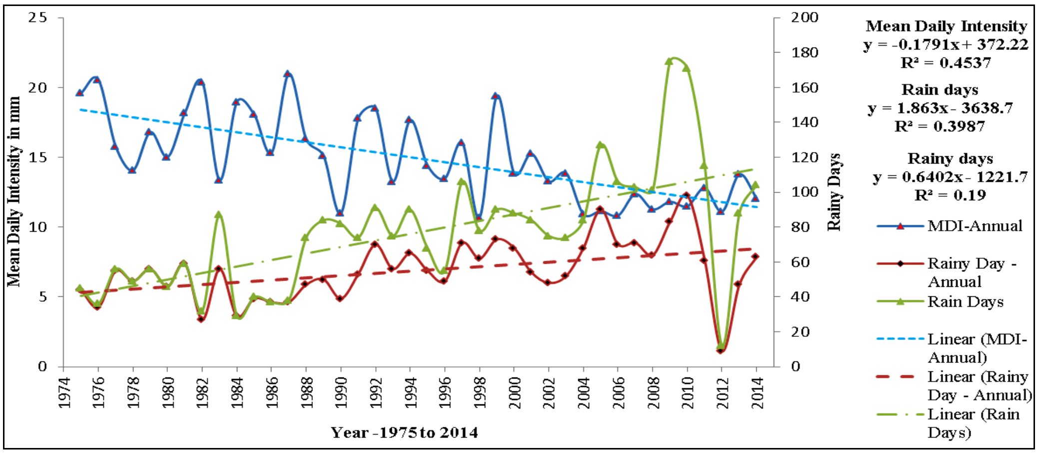

Fig. 8. Variation of mean daily intensity, rain day and rainy day 1975-2014

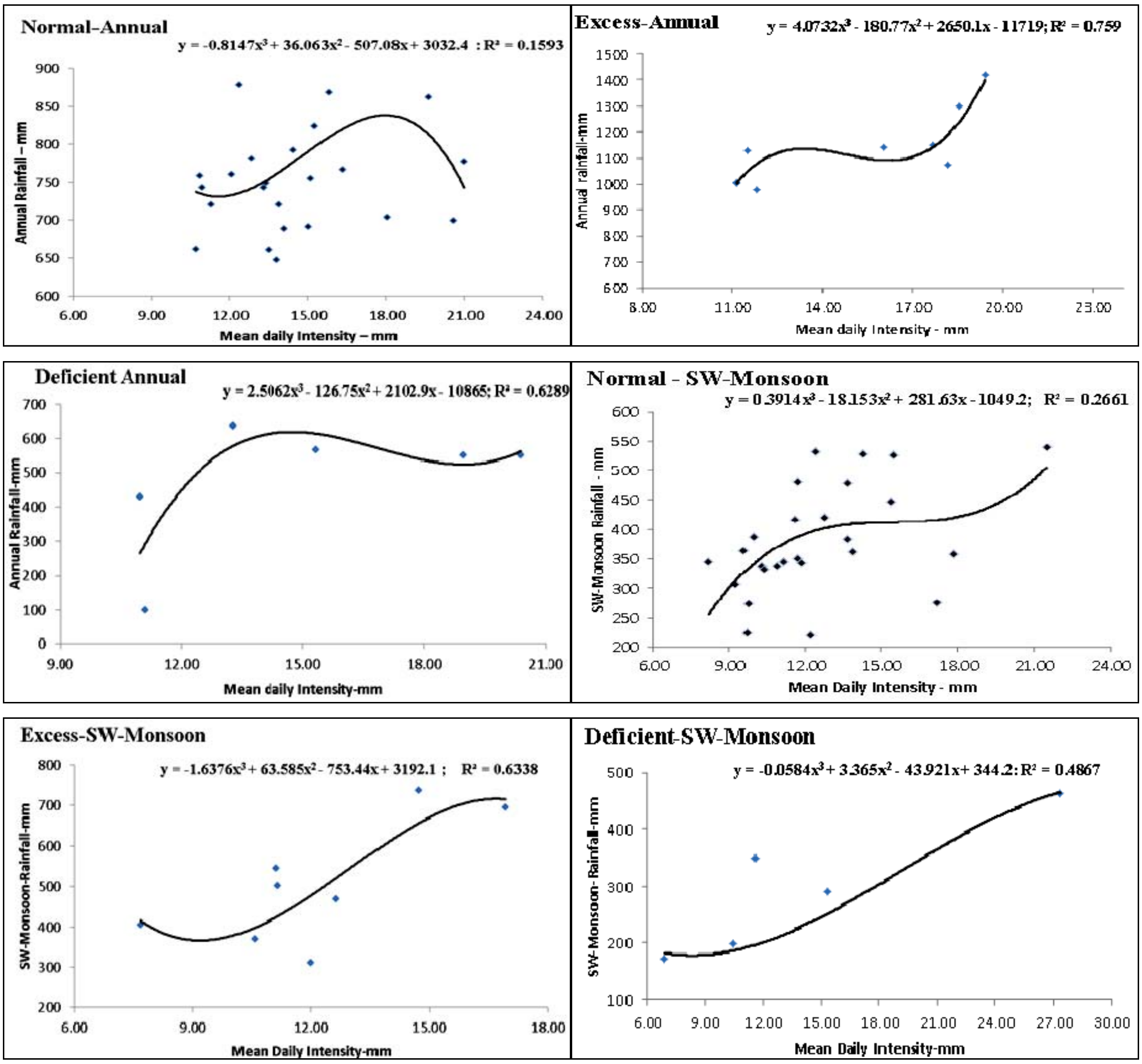

Fig. 9. 3rd order polynomial relationship between annual and SWM against MDI

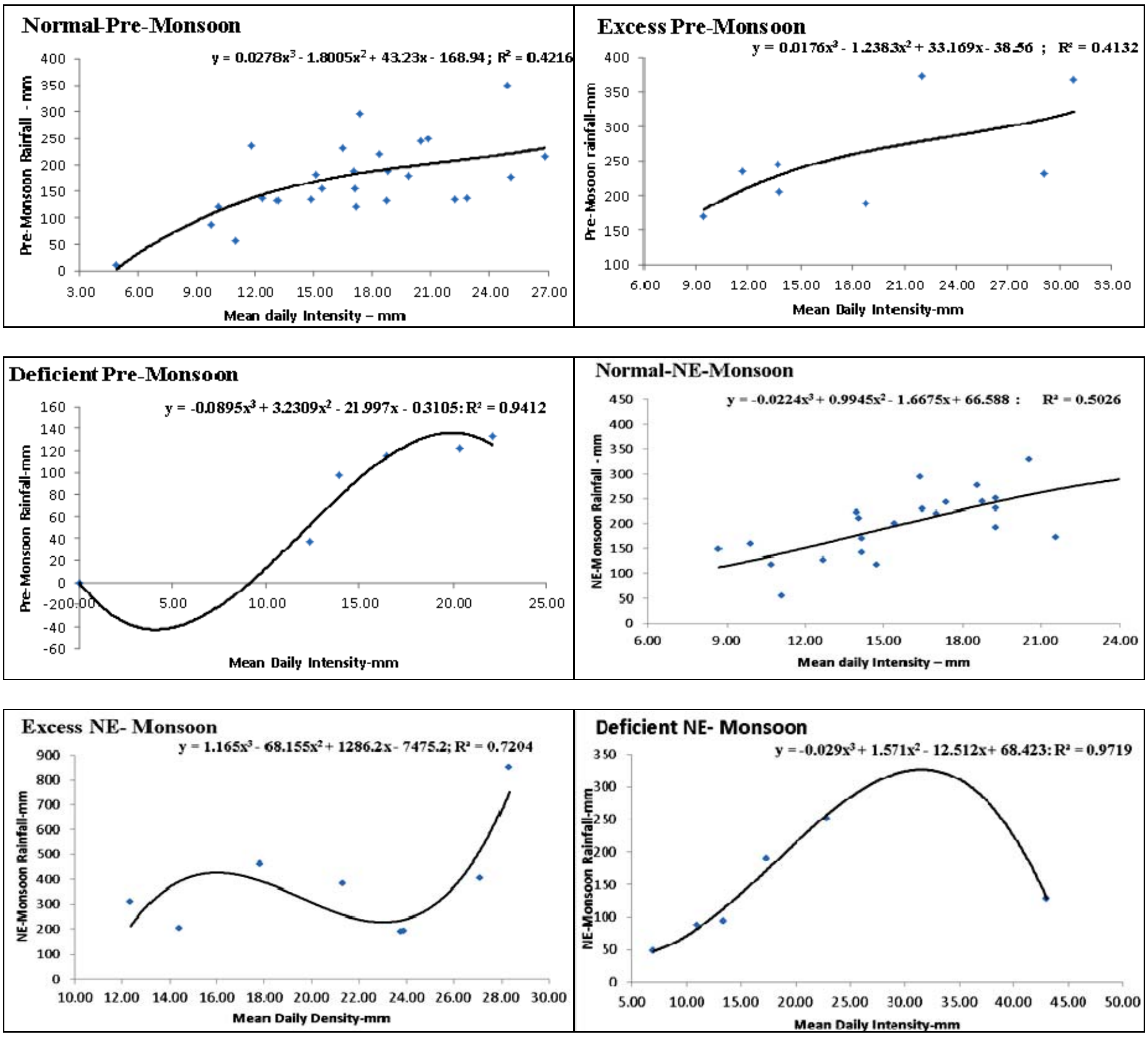

Fig. 10. 3rd order polynomial relationship between PMN and NEM against MDI

mean values of rain intensities are shown in Table 8; Analysis is carried out over 5 year (lustrum) and 10 year (decadal) period. it is noticed that the intensity of VLR and LR has gradually increased in the recent lustrum and decade whereas higher intensity of rainfall has decreased significantly in the same period resulting in less runoff and hence in the deterioration of water retaining and storage structures like tanks/lakes. Figs. 6&7; Tables 9&10; shows the frequency of various intensities of rainfall. It varies from light rain to moderate rain. It is very important to note that the a.a.r. has not changed over forty year period, it remains normal but the intensity of rainfall has decreased drastically since 10 years. It is also observed that RH and HR have decreased whereas VLRand LR have increased substantially.

4.5. *MEAN daily intensity (MDI)*

It is the ratio of average rainfall to the number of rainy days. Annual MDI is 14.56 mm per rainy day. October has the maximum MDI of 19.08 mm/day and August has the minimum MDI of 9.83 mm/day. Seasonally NE-Monsoon has the highest MDI and SW-Monsoon has the lowest MDI. Fig. 8 shows the variation of MDI, RD and RND for the period 1975-2014. It is observed that MDI is in the negative trend whereas RD and RND are in the positive trend. Though the a.a.r. is almost normal in the region, due to the increase of low intensity rain and decrease of high intensity rain, the surface runoff might have reduced in the recent years. Hence the lakes are not getting sufficient inflow even after the rain in normal in the region.

TABLE 11

Regression results for Pre-Monsoon and NE-Monsoon Seasonal Rainfall and MDI

Value	MDI	Observed value	Predicted value				
			Linear	Logarithm	Exponential	Polynomial	Power
Premonsoon rainfall & mean daily intensity (MDI)							
Normal years (26)							
Mean	17.03	171.54	171.54	171.54	163.22	171.83	166.10
SD	7.48	71.41	43.19	45.96	70.20	46.52	68.99
MAE			45.34	42.59	55.26	**42.42**	50.95
RMSE			56.87	54.65	69.08	**54.31**	64.56
Excess years (8)							
Mean	18.64	252.41	252.41	252.40	242.79	252.55	246.45
SD	7.48	72.73	45.96	46.67	43.94	46.98	43.68
MAE			47.93	47.22	48.24	**46.58**	47.92
RMSE			56.37	55.78	57.15	**55.71**	56.33
Deficient years (6)							
Mean	14.21	84.17	84.17	-Nil-	-Nil-	84.26	-Nil-
SD	7.20	48.77	45.61	-Nil-	-Nil-	47.39	-Nil-
MAE			12.60	-Nil-	-Nil-	**9.49**	-Nil-
RMSE			17.29	-Nil-	-Nil-	**11.82**	-Nil-
Northeast monsoon & mean daily intensity (MDI)							
Normal years (26)							
Mean	17.81	212.74	212.74	212.74	204.65	212.56	205.28
SD	6.16	74.95	48.61	51.36	56.71	52.98	56.19
MAE			45.81	44.13	49.77	**41.86**	47.27
RMSE			57.06	54.59	61.79	**52.87**	57.31
Excess years (8)							
Mean	21.14	374.86	374.86	374.86	335.08	374.89	334.15
SD	5.41	205.26	93.79	84.51	59.06	174.07	51.72
MAE			147.37	147.58	140.14	**98.98**	143.02
RMSE			182.58	187.06	187.84	**108.53**	192.80
Deficient years (6)							
Mean	19.11	133.77	135.68	133.77	114.68	133.89	125.15
SD	11.79	68.46	27.49	39.76	34.54	67.51	49.05
MAE			57.45	52.97	56.55	**8.53**	49.45
RMSE			63.24	59.85	74.83	**11.49**	64.07

A scatter plot between MDI (x) and seasonal/annual rainfall (y) is drawn as shown in Figs. 9&10. The results are shown in Tables 11&12; it is noticed that 3rd order polynomial regression curve is a better fit than any other regression relationship. Also the values of MAE and RMSE indicate that polynomial regression fit is the best fit.

TABLE 12

Regression results for Annual and SW-Monsoon Seasonal Rainfall and MDI

Value	MDI	Observed value	Predicted value				
			Linear	Logarithm	Exponential	Polynomial	Power
Annual rainfall & mean daily intensity (MDI)							
Normal years (26)							
Mean	14.70	772.22	772.22	772.22	768.14	774.84	769.86
SD	2.83	85.49	21.78	23.36	21.30	34.99	22.57
MAE			65.95	66.07	65.59	**63.03**	65.66
RMSE			82.67	82.24	82.83	**78.44**	82.41
Excess years (8)							
Mean	15.53	1147.96	1147.96	1147.96	1144.19	1146.12	1144.30
SD	3.26	136.6	100.58	98.08	41.6	118.49	94.69
MAE			77.21	80.32	75.91	**54.42**	79.13
RMSE			92.43	95.08	91.45	**67.09**	94.27
Deficient years (6)							
Mean	15.00	472.22	472.22	472.2	433.68	471.82	436.85
SD	3.63	177.42	96.37	103.62	151.49	140.57	158.08
MAE			120.21	119.01	156.00	**83.40**	154.39
RMSE			142.27	138.09	163.44	**103.22**	160.07
Southwest monsoon & mean daily intensity (MDI)							
Normal years (26)							
Mean	12.54	380.85	380.85	380.85	372.30	380.85	372.33
SD	3.00	89.64	41.63	42.92	40.94	46.28	41.19
MAE			62.18	62.52	61.47	**62.88**	61.83
RMSE			79.38	78.69	80.25	**76.79**	79.44
Excess years (8)							
Mean	12.10	504.09	504.09	504.08	493.54	504.09	492.46
SD	2.62	140.59	102.46	96.15	95.53	111.89	84.98
MAE			79.97	87.61	78.02	**68.99**	85.93
RMSE			96.27	102.57	94.08	**85.08**	99.45
Deficient years (6)							
Mean	14.02	248.08	248.10	248.08	181.74	248.04	174.46
SD	6.45	142.87	97.19	89.82	91.64	99.61	61.35
MAE			70.87	78.77	112.25	**68.38**	123.48
RMSE			104.72	111.11	122.57	**102.36**	133.43

5. Conclusions

(*i*) The change in the average annual rainfall over forty (40) years is significantly less.

(*ii*) The a.a.r. remains normal (±19%) throughout forty years except 6 years where it is deficient.

(*iii*) There is a remarkable change in the intensity of rainfall in the recent decade (2005-2014), particularly rather heavy rain (35.6-64.4 mm) and heavy rain (64.5-124.4 mm).

(*iv*) In the same period (2005-2014) the intensity of very light rain (0.1-2.4 mm) and light rain (2.5-7.5 mm) has increased gradually.

(*v*) Rainfall is more uniform in the monsoon months (Juneto September).

(*vi*) The maximum rainfall occurs in the month of October which is more unpredictable.

(*vii*) Decadal variation shows that the recent decade, 2005-2014 has 36% of coefficient of variation.

(*viii*) There is an increase in the number of rain days and rainy days.

(*ix*) Decreasing trend of mean daily intensity is seen in the recent years (2005-2014).

(*x*) 3rd order polynomial regression curve is the best fit for forecasting the rainfall with RND and MDI.

(*xi*) MAE and RMSE values suggest that 3rd order polynomial is the best fit although there is a marginal difference in '*r*-squared' value.

From these observations, it can be concluded that due to the increase in number of rainy days there is a decrease in mean daily intensity which may not be sufficient to create surface runoff in the catchment and hence no filling of Bilikere and Halebidu tanks. It can also be concluded that, 3rd order polynomial regression curve fitting is a good fit compared to any other regression for the prediction of rainfall in the region.

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