

Rainfall data analysis and environmental impacts on groundwater system of Ujjain area, Madhya Pradesh, India

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Abstract

The rainfall data analysis for a period of 31 years has been conducted to visualize the environmental impacts on groundwater system of Ujjain area, situated in Madhya Pradesh, India. The rainfall data have been subjected to the mathematical and statistical treatment. Mathematical analysis indicates a fairly good variation range from 497.8 mm to 2019 mm with an average of 994.98 mm. The annual departures with respect to the average rainfall and cumulative departure both reflect the positive and negative recharge trends of groundwater system. The statistical computations of rainfall data reveal the values of Mean = 1000.08 mm, Median = 1037.58 mm, Mode = 1222.22 mm, Standard Deviation = 328.59 mm, Co-efficient of Dispersion = 0.3254 mm, Co-efficient of Variation = 32.54 and Co-efficient of Skewness = - 0.6468. The statistical treatment of rainfall data provides precise values indicating the nature of recharge trend.

The time series analysis of rainfall data has been conducted to envision the trends of expected future rainfall. The computed high values infer the increasing trend of rainfall amount than the average, indicating favourable period for recharge to groundwater system, whereas, low values than the average, pointing the negative trend of recharge that reflecting shortage of water supply, which causes the crisis. The rainfall is most vital hydrometeorological factor that controls the recharge of groundwater system. This rainfall is an important factor influencing the environment of society, forest and optimum growth of agriculture and vegetation. The environmental impacts on the ground water system are discussed.

Keywords: Rainfall factor, Groundwater System, Ujjain, Environmental impacts, Forecast, Madhya Pradesh, India

Introduction

Rainfall is a common term for the precipitation, which has been defined as “the depositing of water from the atmosphere on to the surface. This deposit may be in the form of solid or liquids” (Wiesner, 1970) ^[21]. The liquid water is characterizing drops having more than 0.5 mm diameter with a intensity of 1.25 mm. According to Navarra (1979) ^[12], the rainfall is usually related with “the amount of precipitation of any type usually taken as that amount which is measured by means of a rain gauge thus a small varying amount of direct condensation is included”. Sharma and Sharma (1996) ^[17] have considered the precipitation as the total supply of water derived from the atmosphere in the form of rain, snow, mist, frost, hail, sleet and others, which is of particular concern to man and agriculture.

Rainfall is usually described as the total product of precipitation or condensation from the atmosphere as received and measured by the rain gauge. The amount of rain that reaches to earth surface is expressed in millimeter (mm), centimeter (cm), or inch depth of water over an area. The daily rainfall pertains to the rainfall from 08.30 hrs of previous day to 08.30 hrs IST of date. Rainfall differs from; place to place and year to year. Variation in rainfall is due to the difference in seasonal temperatures (Raghunath, 2007) ^[15]. Rain is the major component of the hydrological cycle. Every region is characterized by its own natural hydrologic cycle. The examination of the water resources begins with an examination of the hydrologic cycle within the region (Central Ground Water Board, 2008) ^[1]. Rainfall is highly correlated with air, temperature and atmospheric humidity,

and is closely affected by temperature through the process of evaporation. If the evaporation is higher than the annual rainfall is also very high. The rainfall amount and frequency depend upon the time period and space (Singh, 2010) ^[18].

Analysis of Rainfall Data

The rainfall data of Ujjain have been collected from Ujjain Observatory for a period of 31 years from 1983 to 2013 and recorded (Table 1, 2). These data have been treated by both the mathematical and statistical analyses. The analyzed rainfall data are represented by (a) Hyetograph method and (b) Point rainfall method. In the present study of rainfall data both tabular and graphical methods of representation are adopted. Hyetograph is a bar diagram plotted against intensity of rainfall verses time while point rainfall data is represented graphically as plots of magnitude verses chronological time (weekly, monthly, annually or seasonal). Mathematical analysis involves computation of monthly, seasonal and annual rainfall data, which indicate the variation trends in the rainfall pattern. The variables of rainfall data for the statistical analysis are displayed (Table 3). The frequency distribution and cumulative frequencies have been worked out for 9 classes of rainfall data. Wiesner (1970) ^[21] considered that 25 to 50 observations of precipitation data are required to provide a suitable frequency distribution to measure the central tendency and dispersion. This view of Wiesner has been adopted herein.

Mathematical Analysis

The monthly and annual rainfall values of Ujjain area for a

period of 31 years (1983 - 2013) have been recorded (Table 1). The minimum value of rainfall as 497.8 mm has been observed during the year of 2005 and the maximum rainfall value has been recorded as 2019 mm during 2006. The computed average annual rainfall value is 994.98 mm. The seasonal variation lies within the range of 6.02 mm to 229.8 mm (Table 2). The departure and cumulative departure from the average rainfall have been recorded (Table 3), and represented by graphs. The graphical representation (Figure 1) reveals positive trend (1984, 1986, 1990, 1993-1998, 2003, 2006-2007, 2009, 2011-2013) and negative trend (1983, 1985, 1987-1989, 1991-1992, 1999-2002, 2004-2005, 2008, 2010) indicating a notable trend of fluctuations in the rainfall.

The variation of the rainfall from year to year is indicated by the study of rainfall data. Graph exhibits that the annual rainfall suffers wide departure from the normal rainfall, every year, although the unpredictability is high during individual months, but the rainfall is rather stable over the year as a whole, which is a significant aspect. Even during rainy season the rainfall is subjected to uncertainty of occurrence as marked by prolonged dry spells and aberration in time of commencement and withdrawal and also the total amount received (Sharma, 1996) ^[17]. The annual rainfall data exceeding the computed average annual rainfall value indicates favourable period for recharge of groundwater regime.

Table 1: Rainfall data of Ujjain area for a period of 31 years from 1983 to 2013

S. No.	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1	1983	0	0	0	0.7	18	61.1	171.1	297.8	141	41	0	0	730.7
2	1984	21.9	0	0	0	0	84.2	197.2	727.8	51	0	0	0	1082.1
3	1985	2.4	0	0	0.2	19.5	147	107.8	164.8	81.7	81.3	0	0	604.7
4	1986	1.1	20.8	0	0	3.7	185.7	567.7	453.6	10.9	10.1	0	0	1253.6
5	1987	30	9	3.5	0	12.9	49.4	237.2	465.4	1.8	52.6	8.2	8.2	878.2
6	1988	0	0	0	3.8	0	106.8	254.2	269.8	174.6	163	4.2	0	976.4
7	1989	0	0	30.2	0	0	198.8	184.8	228.8	108	0	0	0	750.6
8	1990	4	3.4	0	0	9	270.8	255.2	484	179	0	8.4	6.8	1220.6
9	1991	0	0	0	0	0	102.8	553.2	254.4	6	0	2.4	0	918.8
10	1992	0	0	0	0	0	35.6	193.6	240.3	111.1	50.8	0	0	631.4
11	1993	0	0	14	0	0	161.1	676.3	291.4	115.2	0	0	0	1258
12	1994	59	0	0	0	0	103.7	360.1	368.8	328.7	0	30	0	1250.3
13	1995	11.2	0	23	0	0	7.7	501.6	223.7	300.8	24.2	3	23.2	1118.4
14	1996	9.9	0	27	0	0	24.2	579.8	392	157.8	61.8	13.6	0	1266.1
15	1997	9	0	0	6	0	74.2	341.4	329	65.4	47	33.5	143.5	1049
16	1998	0	0	0	0	0	103.5	349.5	143.5	380.6	29.9	6	0	1013
17	1999	0	96	0	0	13	64	249	105.4	344.6	88.8	0	0	960.8
18	2000	0	0	0	0	125	62	205	143.8	433.2	0	0	1	970
19	2001	4	0	0	0	4	245.2	173.2	61.2	1.4	81.6	0	0	570.6
20	2002	0	32	2.6	0	0	53	391	130	0	0	8	1	617.6
21	2003	2	11	0	0	0	163	380.4	109	347	0	0	0	1012.4
22	2004	16.6	0	0	0	0	59.2	331	425	11	19	0	0	861.8
23	2005	0	0	6.8	19	0	0	172	155	145	0	0	0	497.8
24	2006	0	0	22	0	0	148	260	1132	445	11	1	0	2019
25	2007	0	0	0	0	0	110	558	550.5	175	0	0	0	1393.5
26	2008	0	0	0	2	136.5	113.2	215.8	95.2	6.2	0	1	5	574.9
27	2009	0	0	0	0	0	102.3	508.3	135	134.6	96.5	84.6	36	1097.3
28	2010	2	15.3	0	0	9.5	6	188.6	294.9	96.4	39.5	84.5	14	750.7
29	2011	0	0	0	0	0	174.4	452.5	458.9	147	0	0	0	1232.8
30	2012	0	0	0	0	3	12	455	214	323	0	0	0	1007
31	2013	0	4	33	7	0	174	452.5	458.9	147	0	0	0	1276.4
Tot.		173.1	191.5	162.1	38.7	354.1	3202.9	10523	9803.9	4970	898.1	288	238.7	30844.5
Ave.		5.58	6.18	5.23	1.25	11.42	103.32	339.45	316.25	160.32	28.97	9.30	7.70	994.98

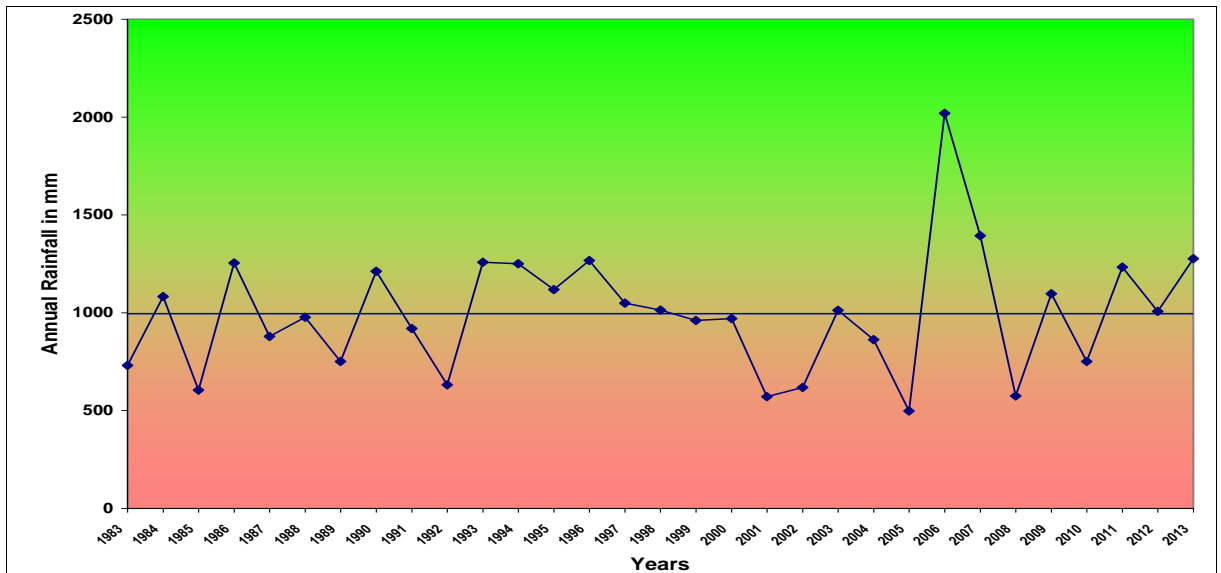


Fig 1: Total Annual Rainfall of the Ujjain study area (1983 -2013)

Table 2: Analysis of Monthly Rainfall of Ujjain area, Madhya Pradesh

S. No.	Seasons	Months	Mean monthly rainfall (mm)	Average rainfall (mm)
1.	Monsoon	June	103.32	229.83
		July	339.45	
		August	316.25	
		September	160.32	
2.	Winter	October	28.97	12.9
		November	9.3	
		December	7.7	
		January	5.58	
3.		February	6.18	6.02
		March	5.23	
		April	1.25	
		May	11.42	

The average monthly rainfall data from 1983 to 2013 for a period of 31 years have been represented by bar diagram (Figure 2), indicating variations in the amount of rainfall for the period (1983-2013).The observation reveals that the minimum value of 1.25 mm rainfall is recorded in April and

maximum value 339.45 mm is recorded in July (Table 2). The calculated values of rainfall during monsoon, winter and summer seasons are 229.83 mm, 12.9 mm and 6.02 mm respectively (Table 2, Figure 2).).

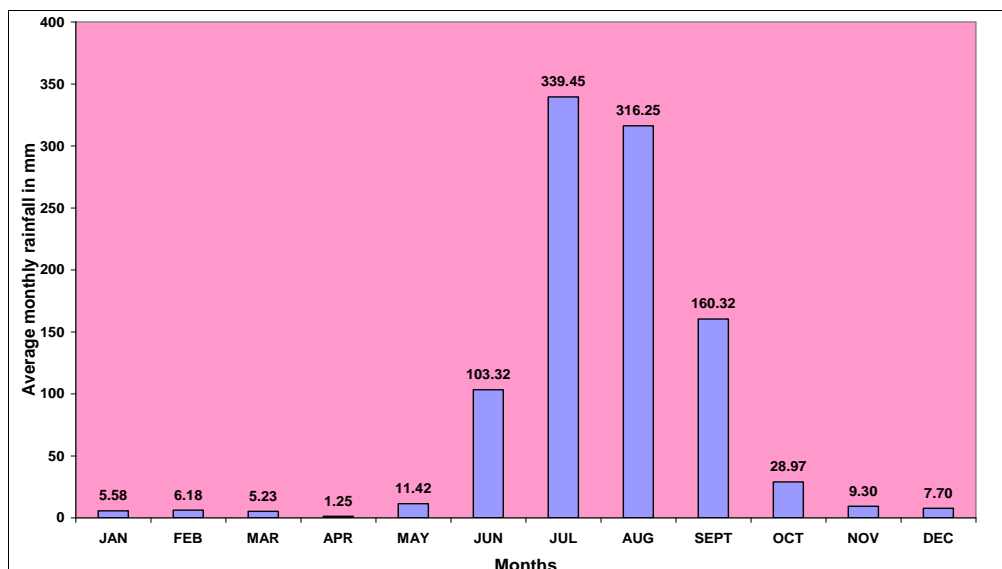


Fig 2: Bar diagram representing average monthly rainfall data (1983-2013) in Ujjain.

The departure and the cumulative departure from the average annual rainfall have been worked out, and the values are displayed (Table 3), the nature of rainfall trends have been graphically represented (Figure 3, 4). The values of rainfall departure exceeding average rainfall values have been recorded during the years 1984, 1986, 1990, 1993, 1994, 1995, 1996, 1997, 1998, 2003, 2006, 2007, 2010, 2012,

2013. The values of cumulative departure from the average rainfall value reveal that the maximum rainfall peak is recorded during the year 1998 subsequently followed by the years of 1997, 1996, 1999, 2000, 2007, and 1984. These peaks indicate fairly good infiltration of rain water to the groundwater reservoir. These years are favourable for recharge of rainwater to the groundwater system.

Table 3: Rainfall Data of Ujjain area for a period of 31 years (1983 - 2013) (Values are expressed in mm)

S. No.	Year	Total rainfall in mm	Departure from average rainfall	Cumulative departure from average rainfall
1	1983	730.7	-263.99	-263.99
2	1984	1082.1	87.41	-176.58
3	1985	604.7	-389.99	-566.57
4	1986	1253.6	258.91	-307.66
5	1987	878.2	-116.49	-424.15
6	1988	976.4	-18.29	-442.44
7	1989	750.6	-244.09	-686.53
8	1990	1211.6	216.91	-469.62
9	1991	918.8	-75.89	-545.51
10	1992	631.4	-363.29	-908.8
11	1993	1258	263.31	-645.49
12	1994	1250.3	255.61	-389.88
13	1995	1118.4	123.71	-266.17
14	1996	1266.1	271.41	5.24
15	1997	1049	54.31	59.55
16	1998	1013	18.31	77.86
17	1999	960.8	-33.89	43.97
18	2000	970	-24.69	19.28
19	2001	570.6	-424.09	-404.81
20	2002	617.6	-377.09	-781.9
21	2003	1012.4	17.71	-764.19
22	2004	861.8	-132.89	-897.08
23	2005	497.8	-496.89	-1393.97
24	2006	2019	1024.31	-369.66
25	2007	1393.5	398.81	29.15
26	2008	574.9	-419.79	-390.64
27	2009	1097.3	102.61	-288.03
28	2010	750.7	-243.99	-532.02
29	2011	1232.8	238.11	-293.91
30	2012	1007	12.31	-281.6
31	2013	1276.4	281.71	0.11
Total		30835.5	0.11	-12256.04
Avg.		994.69	0.00	-395.36

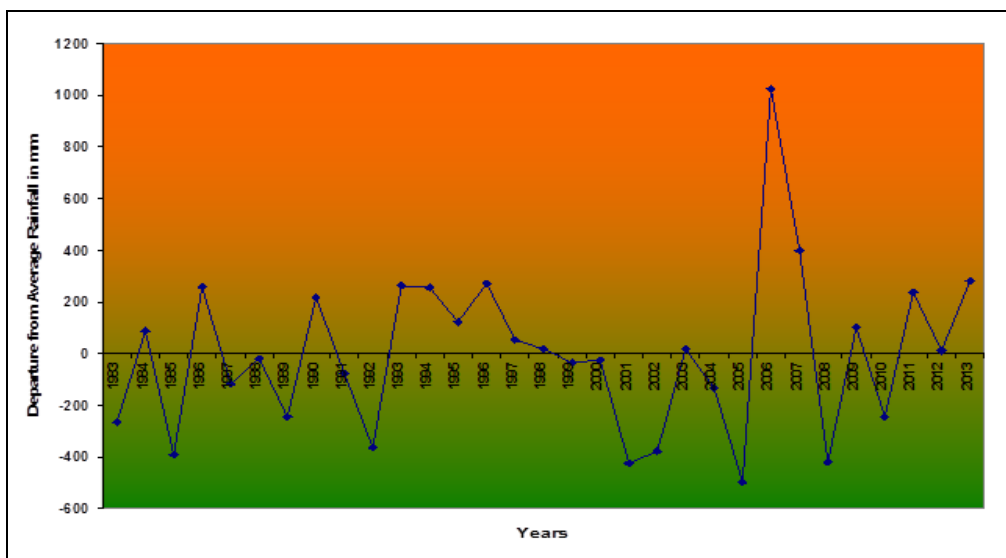


Fig 3: Graph representing the departure from average rainfall of Ujjain area for the period from 1983 - 2013.

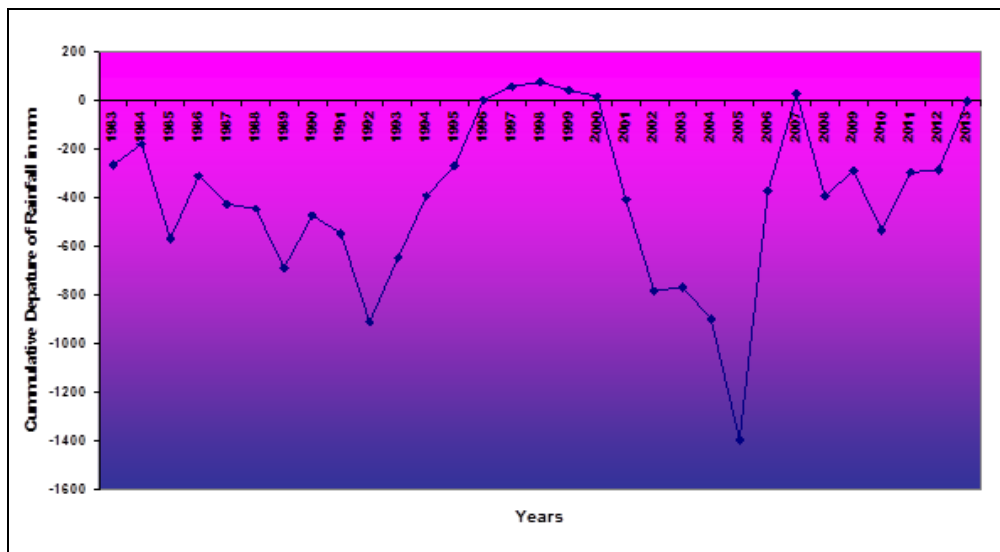


Fig 4: Graph representing the cumulative departure of rainfall from 1983- 2013

2. Statistical Analysis

Statistics has been defined as “the series which deals with the collection, analysis and interpretation of numerical data” (Croxtan *et al*, 1988) [2]. “Statistics refers to a branch of applied mathematics dealing with science or perhaps an art of the collection, presentation, description, inference, significance testing and prediction of numerical information” (Sarkar, 2004) [16]. The variables of rainfall data for the statistical analysis are displayed (Table 4), the frequency distribution and cumulative frequencies have been worked out for 9 classes of rainfall data. According to Weisner (1970) [21], 25 to 50 observations of precipitation data are required to provide a suitable frequency distribution. Monthly and seasonal rainfall data have been calculated to detect the variation trends in the rainfall pattern to measure

the central tendency and dispersion. Central tendency involves determination of mean, median and mode. Dispersion means scatteredness, and it gives an idea about the homogeneity or heterogeneity of the distribution. It includes the following measures: -

- i) range
- ii) quartile deviation
- iii) semi quartile deviation
- iv) mean deviation
- v) standard deviation.

The standard deviation has been determined herein. The procedure of computation of different statistical parameters described by Davis (1986, 2002) has been followed in the present paper:

Table 4: Statistical variables of rainfall data of the Ujjain study area

Class Interval (i)	Mid-Value (x)	Frequency (f)	Cumulative Frequency	Deviation from the assumed value	Total deviation	Deviation squared up	Frequency * square of deviation
			(C)	$u=(x-A)/i$	$f * u$	u^2	$f * u^2$
400 -600	500	3	3	-4	-12	16	48
600 - 800	700	6	9	-3	-18	9	54
800 - 1000	900	6	15	-2	-12	4	24
1000 - 1200	1100	7	22	-1	-7	1	7
1200 - 1400	1300	8	30	0	0	0	0
1400 - 1600	1500	0	30	1	0	1	0
1600 - 1800	1700	0	30	2	0	4	0
1800 - 2000	1900	0	30	3	0	9	0
2000 - 2200	2100	1	31	4	4	16	16
		31		0	-45	60	149

X = Mid-value A = Assumed mean i = Class interval f = Frequency C = Cumulative frequency u = x-A/I N = Sum of frequency
Based on the determined values of statistical variables the following parameters have been calculated-

Mean

Mean, in ungrouped data is the sum of all the observations divided by the number of observations. It is calculated by the following formula-

$$\text{Mean} = A + i * \Sigma fu / N$$

Where;

- A = Assumed mean = 1300
- i = Class interval = 200

$$N = \text{Sum of frequency} = 31$$

$$= 1300 + (-45)*200/31$$

$$\text{Mean} = 1009.68$$

Median

Median of a distribution is that value of variable which divides the group into two equal parts, one part consisting of all values exceeding median and the other part consisting

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 values less than the median. It is represented by the formula as follows-

$$\text{Median} = l_1 + i / f (N/2 - C)$$

Where:

- l_1 = lower limit of median class,
- i = Class interval
- f = frequency of median class
- N = sum of frequency
- C = cumulative frequency preceding the median class
 $= 1200 + 200 / 8 (31/2 - 22)$
- Median = 1037.50

Mode

Mode of the distribution is that value which has the maximum frequency or the value which occurs most frequently in a set of observations and around which other items of set cluster densely. It is calculated by the following formula –

$$\text{Mode} = l_1 + (f - f_1) / 2 (f - f_1 - f_2) * i$$

Where;

- l_1 = lower limit of modal class
- f = frequency of modal
- f_1 = frequency of pre modal class
- f_2 = frequency of post modal class
- i = Class interval
- Mode = $1200 + (8-7) / 2 (8 - 7 - 0) * 200$
- Mode = 1222.22

Standard Deviation (σ)

Standard deviation is the measure of the positive square root of the arithmetic mean of the direction of given value from their arithmetic mean. It is denoted by the Greek word ‘Sigma,’ and is represented by the symbol ‘ σ ’. Represented by the following formula-

$$\begin{aligned} \sigma &= i \sqrt{\Sigma fu^2/N - (\Sigma fu/N)^2} \\ &= 200 \sqrt{149/31 - (-45/31)^2} \\ &= 200 \sqrt{4.8064 - 2.1071} \\ &= 200 * 1.6429 \\ &= 328.59 \end{aligned}$$

Co-efficient of dispersion (CD)

Co-efficient of dispersion is a pure number independent of the units of measurements. The determined values help in comparison of the variability of two series. It is determined by the formula as follows-

$$\begin{aligned} \text{CD} &= \sigma / m \\ &= 328.59/1009.68 \\ &= 0.3254 \end{aligned}$$

Co-efficient of variation (CV)

Co-efficient of variation has been defined as the percentage variation in the mean, standard deviation is considered as the total variation in the mean, and is calculated by the following formula:-

$$\begin{aligned} \text{CV} &= 100 * \sigma / m \\ &= 100 * 328.59/1009.68 \\ \text{CV} &= 32.54 \end{aligned}$$

Coefficient of Skewness

Coefficient of Skewness refers to the ‘lack of symmetry’, and gives an idea about the shape of the curve. It is a relative measure which is a pure number independent of unit of measurement, and is computed by the formula as follows:-

$$\begin{aligned} \text{Coefficient of Skewness} &= (\text{Mean} - \text{Mode}) * \sigma \\ &= 1009.68 - 1222.22 / 328.59 \\ &= -0.6468 \end{aligned}$$

In the present study, the calculated value of co-efficient of skewness is negative indicating that the mean value of rainfall is less than the values of median and mode.

The statistical analysis of the rainfall of Ujjain region reveals that the mean, median, and mode rainfall value is 1009.68 mm, 1037.50 mm, and 1222.22 mm respectively. The standard deviation reveals that deviation of rainfall is 328.59 mm for the duration of 31 years. Co-efficient of variation reflects the amount of rainfall variation from year to year. It indicates that the amount of rainfall varies up to 32.54 mm. The value of co-efficient of dispersion of rainfall is 0.3254 mm. The co-efficient of skewness is less than one indicating lack of symmetry in the rainfall quantity during the analysis of 31 years duration.

Time Series Analysis

A time series is a set of observations generated sequentially in time. The time series analysis provide significant information relating to the characterization of the trend of series of observations (Gupta and Kapoor, 2002). Thus a set of data depending on time is called a Time Series analysis, has been conducted to find the trend in precipitation and to forecast it for the future event. The measurement of trend is generally done for two reasons – (i) to study the manner in which the value of a variable behaves in long time, (ii) to study fluctuations in the value of the variable. The rainfall trend is very crucial for the economic development and hydrological planning (Stella Maragatham, 2012) [19]. In the present work, procedure described by Gupta and Kapoor (2002) have been adopted for time series analysis. The computations of variables for Time series analysis of rainfall data have been displayed (Table 5).

Table 5: Computation of variables for Time series analysis of rainfall data

S. No.	Year	t=x-1998	Total rainfall in mm (y)	x ²	x ³	x ⁴	xy	x ² y
1	1983	-15	730.7	225	-3375	50625	-10960.5	164407.5
2	1984	-14	1082.1	196	-2744	38416	-15149.4	212091.6
3	1985	-13	604.7	169	-2197	28561	-7861.1	102194.3
4	1986	-12	1253.6	144	-1728	20736	-15043.2	180518.4
5	1987	-11	878.2	121	-1331	14641	-9660.2	106262.2

6	1988	-10	976.4	100	-1000	10000	-9764	97640
7	1989	-9	750.6	81	-729	6561	-6755.4	60798.6
8	1990	-8	1211.6	64	-512	4096	-9692.8	77542.4
9	1991	-7	918.8	49	-343	2401	-6431.6	45021.2
10	1992	-6	631.4	36	-216	1296	-3788.4	22730.4
11	1993	-5	1258	25	-125	625	-6290	31450
12	1994	-4	1250.3	16	-64	256	-5001.2	20004.8
13	1995	-3	1118.4	9	-27	81	-3355.2	10065.6
14	1996	-2	1266.1	4	-8	16	-2532.2	5064.4
15	1997	-1	1049	1	-1	1	-1049	1049
16	1998	0	1013	0	0	0	0	0
17	1999	1	960.8	1	1	1	960.8	960.8
18	2000	2	970	4	8	16	1940	3880
19	2001	3	570.6	9	27	81	1711.8	5135.4
20	2002	4	617.6	16	64	256	2470.4	9881.6
21	2003	5	1012.4	25	125	625	5062	25310
22	2004	6	861.8	36	216	1296	5170.8	31024.8
23	2005	7	497.8	49	343	2401	3484.6	24392.2
24	2006	8	2019	64	512	4096	16152	129216
25	2007	9	1393.5	81	729	6561	12541.5	112873.5
26	2008	10	574.9	100	1000	10000	5749	57490
27	2009	11	1097.3	121	1331	14641	12070.3	132773.3
28	2010	12	750.7	144	1728	20736	9008.4	108100.8
29	2011	13	1232.8	169	2197	28561	16026.4	208343.2
30	2012	14	1007	196	2744	38416	14098	197372
31	2013	15	1276.4	225	3375	50625	19146	287190
		0	30835.5	2480	0	356624	12257.8	2470784

The parabolic equation of second degree is, expressed as follows-

$$y_c = a + bx + cx^2$$

Where;

- y_c = trend value of dependent variable (annual rainfall)
- x = independent variable (year)
- a, b and c is unknown

In a parabola of second degree there are three unknown values and, therefore, three simultaneous equations are obtained to secure the required values, given below:-

$$\sum x = N a + b \sum x + c \sum x^2 \dots\dots\dots (1)$$

$$\sum xy = a \sum x + b \sum x^2 + c \sum x^3 \dots\dots\dots (2)$$

$$\sum x^2 y = a \sum x^2 + b \sum x^3 + c \sum x^4 \dots\dots\dots (3)$$

The relevant value (Table 5) is substituted in the above normal equations:-

$$\begin{aligned} \sum x &= 0 & \sum y &= 30835.5 & \sum xy &= 12257.8 \\ \sum x^2 y &= 2470784 & \sum x^2 &= 2480 \\ \sum x^3 &= 0 & \sum x^4 &= 356624 \end{aligned}$$

By substituting these values in the above normal equations we get:

$$30835.5 = a (31) + b (0) + c (2480) \dots\dots\dots (4)$$

$$12257.8 = a (0) + b (2480) + c (0) \dots\dots\dots (5)$$

$$2470784 = a (2480) + b (0) + c (356624) \dots\dots\dots (6)$$

Hence, the normal equations have been obtained, by solving the equations (4), (5) and (6), the values of $a, b,$ and c obtained respectively, is given below:-

$$a = 992.70 \quad b = 4.94 \quad c = 0.025$$

Equation of the parabola of the second degree would be as give as follows:-

$$y_c = 992.70 + 4.94 x + 0.025 x^2 \dots\dots\dots (7)$$

The trend values obtained by using the above parabolic equation for the future expected rainfall for period of ten years, from duration (2014 to 2023) are displayed (Table 6). The future forecast may show a variation of + 50 mm or - 50 mm in the rainfall trend. The time series analysis indicates a positive trend in the amount and intensity of rainfall for the incoming ten years.

Table 6: Future forecast of the rainfall of Ujjain area.

S. No.	Year	Expected rainfall in mm	S. No.	Year	Expected rainfall in mm
1	2014	1078.14	6	2019	1107.47
2	2015	1083.91	7	2020	1113.48
3	2016	1089.72	8	2021	1119.55
4	2017	1095.59	9	2022	1125.66
5	2018	1101.50	10	2023	1131.83

Analysis of Rainfall Parameters

The rainfall parameters include runoff, infiltration, recharge, etc. Runoff is defined as that portion of precipitation which is not absorbed by the deep strata but finds its way into the

streams after meeting the persistent demands of evapotranspiration including interception and other losses (Sharma, and Sharma, 1996) [17]. Runoff occurs only when the rate of precipitation exceeds the rate of infiltration. The

rainstorms generate runoff and its occurrence and quantity are dependent on the characteristics of rainfall events such as intensity, duration and distribution (Manoharan and Murugappan, 2012). The runoff of a catchments area in any specified period is the total quantity of water draining into a stream or into a reservoir in that period. This can be expressed as (i) centimeters of water over a catchments, or (ii) the total water in cubic-meter or hectare-meter for a given catchments (Punmia *et al.*, 2009).

Relationship of Rainfall with Runoff

Inglis and De Souza (1930) [7], Lacey (1942) [9], Khosla (1949) [8], and others have studied the relationship between the rainfall and runoff. Inglis and De Souza (1930) [7] gave the following formulae to derive the relationship between the rainfall and runoff for Ghat and non Ghat regions.

For Ghat regions (western India),

$$\text{Runoff} = (0.85 \text{ Rainfall}) - 12 \text{ inch}$$

Non Ghat regions,

$$\text{Runoff} = (\text{Rainfall} - 7 \text{inch} / 100) * 100$$

The study area being a non Ghat region, the above formula has been applied to calculate the amount of runoff and is displayed (Table 6). The observation reveals that the intensity of rainfall is directly proportional to the rate of runoff.

For Ghat regions of western India

$$= (0.85 P - 30.5)$$

For Deccan Plateau (non Ghat)

$$R = P * (P - 17.8) / 254,$$

Where,
 P = annual rainfall and R = annual runoff in cm.

Table 7: Relationship of Rainfall, Runoff and Recharge during the period 1983 to 2013 in the study area.
 Relationship of Rainfall, Runoff and Recharge

S. No.	Year	Rainfall in mm	Rainfall in inches	Runoff	Recharge
1	1983	730.7	29.82	6.81	5.37
2	1984	1082.1	44.17	16.42	7.41
3	1985	604.7	24.68	4.36	4.41
4	1986	1253.6	51.17	22.60	8.23
5	1987	878.2	35.84	10.34	6.31
6	1988	976.4	39.85	13.09	6.86
7	1989	750.6	30.64	7.24	5.51
8	1990	1211.6	49.45	20.99	8.04
9	1991	918.8	37.50	11.44	6.54
10	1992	631.4	25.77	4.84	4.63
11	1993	1258	51.35	22.77	8.25
12	1994	1250.3	51.03	22.47	8.22
13	1995	1118.4	45.65	17.64	7.59
14	1996	1266.1	51.68	23.09	8.29
15	1997	1049	42.82	15.34	7.25
16	1998	1013	41.35	14.20	7.06
17	1999	960.8	39.22	12.63	6.78
18	2000	970	39.59	12.90	6.83
19	2001	570.6	23.29	3.79	4.11
20	2002	617.6	25.21	4.59	4.52
21	2003	1012.4	41.32	14.18	7.06
22	2004	861.8	35.18	9.91	6.21
23	2005	497.8	20.32	2.71	3.39
24	2006	2019	82.41	62.14	11.17
25	2007	1393.5	56.88	28.37	8.84
26	2008	574.9	23.47	3.86	4.15
27	2009	1097.3	44.79	16.92	7.49
28	2010	750.7	30.64	7.24	5.51
29	2011	1232.8	50.32	21.80	8.14
30	2012	1007	41.10	14.02	7.03
31	2013	1276.4	52.10	23.50	8.33
Total		30835.5	1258.6	472.21	209.53

Relationship of Rainfall with Recharge

Recharge is defined as the downward flow of water reaching the water table, adding to groundwater storage (Meinzer, 1923, Freeze and Cherry, 1979, and Lerner *et al.*, 1990) [5, 10]. The amount of groundwater recharge depends upon the rate and duration of rainfall, as rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water (Oke *et al.*, 2014). Based on the

water level fluctuations and rainfall derived an empirical relationship between the recharge and annual precipitation, given by the following formula:-

$$R = 2.0 (P - 15)^{0.4} \dots\dots\dots (1)$$

Where,
 R = net recharge due to precipitation during the year (inch);
 P = annual precipitation (inch).

This formula was later modified by the Irrigation Research Institute, Roorkee and the modified form of the formula is

$$R = 1.35 (P - 14)^{0.5} \dots\dots\dots (2)$$

For preliminary estimations of groundwater recharge due to rainfall, the above mentioned formula of Chaturvedi has been used to calculate the recharge amount and the values are recorded (Table 7).

Environmental Impact of Rainfall

The rainfall data analysis of Ujjain area, Madhya Pradesh. Indicates a fairly good range of variation reflecting the positive and negative trends. These trends reflect picture of the recharge of the groundwater reservoir. The present trends of over exploitation and scanty rainfall are indicating a reducing pattern of the groundwater levels. Todd, (1980) remarked that the groundwater levels may exhibit seasonal variation due to rainfall. Drought extending over a period of several years, contribute to declining water levels. The depletion of groundwater levels may be assigned to seasonal variation in the static groundwater levels, which are governed by the infiltration of rainwater.

The rainfall excess or shortage both causes adverse and useful effects, Rainfall excess disrupts communication; causes flood and loss to vegetation while shortage leads to loss of crops and causes drought conditions. The environmental impacts of rainfall factor in recharge phenomena of groundwater system have been discussed. The rainfall pattern plays a vital role in the recharge phenomena of groundwater system, besides other environmental impacts. It is realized that the groundwater recharge phenomena can be better by augmentation of rain water. The implementation of a suitable measure for increasing the rainfall factor may likely to provide remedy in managing the rapidly depleting trend of groundwater levels resulting into crisis of sustained water supply, which. may even cause the drought condition in Ujjain study area.

Conclusion

Rainfall is a key hydro meteorological factor that plays imperative role in environmental entity as a major source for the recharge of groundwater system. The rainfall data records of 31 years 1983-2913) in respect of the Ujjain study area have been analyzed by mathematical and statistical techniques. The analyzed data reveal the trend of vaiations, which may be attributed to the difference in seasonal temperatures. The rainfall factor has played a vital role in the recharge phenomena of groundwater system.

The time series analysis of the rainfall data has been conducted for the approximation of future rainfall trend for the next ten years that indicates negative trend of recharge. The environmental impacts of rainfall factor in recharge phenomena of groundwater system have been discussed. It is visualized that augmentation of rain water would enhance the groundwater recharge phenomena. The implementation of a suitable measure may provide remedy in managing the rapidly developing situation of groundwater level depletion resulting in the drought condition in the Ujjain study area.

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