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STATISTICAL ANALYSIS OF RAINFALL DEVELOPMENT IN BADNAGAR, MADHYAPRADESH AND ITS IMPACT ON THE GROUNDWATER SYSTEM

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ABSTRACT

Rainfall is a critical factor for groundwater recharge. This paper analyzes the impact of rainfall data on the groundwater system in Badnagar, Madhya Pradesh, India. The analysis of 25 years of rainfall data was conducted to assess its impact on the groundwater system of Bardnagar, located in Madhya Pradesh, India. The rainfall data underwent mathematical and statistical analysis. Mathematical analysis reveals both positive and negative trends in groundwater recharge. The analysis of rainfall data includes determining the mean, median, mode, standard deviation, dispersion coefficient, variation coefficient, and skewness coefficient. The rainfall data has been analyzed to predict future rainfall trends. High values indicate an increasing trend in rainfall, which is beneficial for groundwater recharge, while low values indicate a decreasing trend, leading to water shortages and crises. Rainfall plays a critical role in recharging groundwater and has a significant impact on the environment, including society, forests, agriculture, and vegetation. The environmental effects on thegroundwater system are also addressed in the analysis.

Keyword: Rainfall, Groundwater, Environment, Statistical analysis, Time series, Badnagar.

1. INTRODUCTION

Precipitation, commonly known as rainfall, is one of the most essential atmospheric factors that significantly influence the recharge phenomenon of hydrogeological systems. It is universally recognized that water evaporates from various surfaces such as ponds, rivers, streams, seas, land, and vegetation in the form of water vapours, which then enter the atmosphere. As the evaporation process continues, the amount of atmospheric vapour increases, and eventually condenses on surfaces in the forms of hail, mist, rain, snow, and more (Ragunath, 2006). The water that returns to the earth's surface in any of these forms is known as precipitation. Most precipitation occurs as rain, with a smaller portion occurring as snow. Due to their smaller scale, other forms of precipitation, such as hail and mist, are generally not extensively considered in hydrogeological studies. Precipitation, as described by Weisner (1970), is the depositing of water from the atmosphereonto the surface. This deposit may be in the form of solids or liquids. Rainfall is the precipitation of liquid water characterized by drops with a diameter of more than 0.5 mm and an intensity of 1.25 mm/hr.

LOCATION OF STUDY AREA: The study area is Barnagar, located in Ujjain district in Madhya Pradesh state. Barnagr is connected with SH 18 about 45 km West of Ujjain. It is located between 23°05/00 and 23°1500 in the north and 20°00/30 in the east. It covers an area of about 154.4 km2. There are 51 small communities and one small city with a total of 24 local governing councils. The place is about 457 meters high from the mean Sea Level (MSL).

Figure 1.1 Location Map of Badnagar Study Area.

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ANALYSIS OF RAINFALL DATA: Rainfall data are computed based on daily rainfall data by simply adding them together. Observing the trend of rainfall distribution and intensity is done by analyzing rainfall data collected by rain gauges. Rainfall amount and frequency mainly depend upon time and space.Rainfall data analysis is complicated due to varying space and time. The most usually engaged procedure of rainfall data analysis includes arithmetical and statistical methods.

2. ARITHMETICAL METHOD

In this method, the average rainfall for specific months or years is expressed by the arithmeticmean of the period of months or years. The variation in rainfall is reflected by a stable mean. A record of 20 to 25 years or more of rainfall data is commonly used for the determination of the average (Rathore, 2024). The departure of rainfall from the average rainfall determines the pattern of rainfall. The determination of cumulative departure of rainfall provides information regarding the total departure rainfall from the mean value over a specific period.

Table 1 Annual Rainfall data from 1999 – 2023, Badnagar, Madhya Pradesh

S. No.	Year	Total Rainfall in mm.
1	1999	1000.0
2	2000	**480.0**
3	2001	601.0
4	2002	685.0
5	2003	844.0
6	2004	720.0
7	2005	588.7
8	2006	**1647.0**
9	2007	992.0
10	2008	624.0
11	2009	819.0
12	2010	900.6
13	2011	977.4
14	2012	958.0
15	2013	1303.0
16	2014	834.0
17	2015	1451.0
18	2016	885.0
19	2017	792.0
20	2018	679.0
21	2019	1414.0
22	2020	1287.0
23	2021	1046.0
24	2022	1045.0
25	2023	1134.0
Total	**23706.7**	
Ave.	**948.268**	

The rainfall data in the Badnagar area for the period 1999-2023, collected from Ground WaterSurvey department, Ujjain, has been analyzed both mathematically and statistically. As shown in Table 1, rainfall data are recorded. Graphical devices are very useful and effective for rapid representation of a limited amountof information. A simple attractive and well-illustrated graph, diagram or map is also easier toexhibit data and may serve as a tool for further analysis.

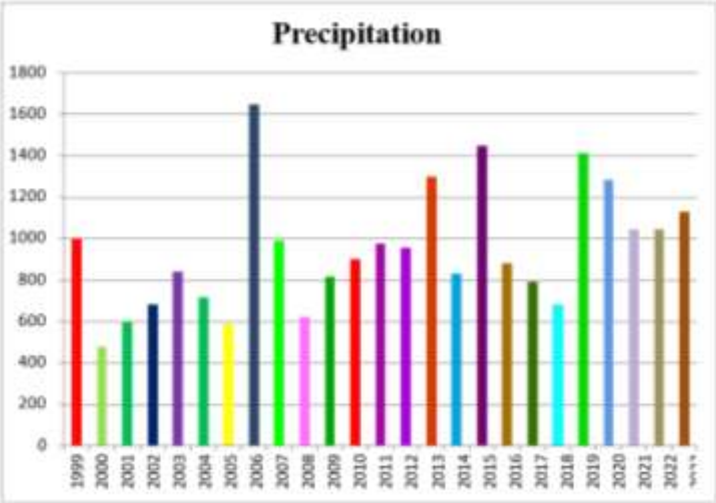

Figure 1 Total Annual rainfall of Badnagar study area, M.P. for the period of 1999-2023.

Figure 2 Total annual rainfalls in mm. for the period of 1999-2023.

The total rainfall has been shown (Table 1) that reflects the minimum rainfall of 480.0 mmduring a period of last 25 years was recorded in the year of 2000 and maximum rainfall was

recorded as 1647.0 mm in the year of 2006 (Fig.1) having an average rainfall value of 948.26 mm.

The departure (Fig. 3) and cumulative departure (Fig.4) from the average rainfall of the studyarea has been given in the Table 4.2

Table 2. Annual Rainfall, its Departure and Cumulative Departure from Average AnnualRainfall in the Study Area (1999 - 2023)

S. No.	Year	Total rainfall in mm.	Departure from Average rainfall	Cumulative Departure
1	1999	1000.0	+51.74	+51.74
2	2000	480.0	**-468.26**	**-416.52**
3	2001	601.0	-347.26	69.26
4	2002	685.0	-263.26	-332.52
5	2003	844.0	-104.26	228.26
6	2004	720.0	-228.26	-456.52
7	2005	588.7	-359.56	96.96
8	2006	1647.0	**+698.74**	**601.78**

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9	2007	992.0	+43.74	-558.04
10	2008	624.0	-324.26	233.78
11	2009	819.0	-129.26	-363.04
12	2010	900.6	-48.26	314.78
13	2011	977.4	+29.14	-285.64
14	2012	958.0	+9.74	314.78
15	2013	1303.0	+354.74	39.96
16	2014	834.0	-114.26	-154.22
17	2015	1451.0	+502.74	656.96
18	2016	885.0	-63.26	-720.22
19	2017	792.0	-156.26	563.96
20	2018	679.0	-269.26	-833.22
21	2019	1414.0	+465.74	-367.48
22	2020	1287.0	+338.74	706.48
23	2021	1046.0	+97.74	-608.74
24	2022	1045.0	+96.74	704.74
25	2023	1134.0	+185.74	-519
Total	**23706.7**			
Ave.	**948.268**			

Departure and cumulative departure from the average rainfall have been calculated. The recorded rainfall value is presented in Table 3, and the nature of the rainfall pattern is also shown graphically.

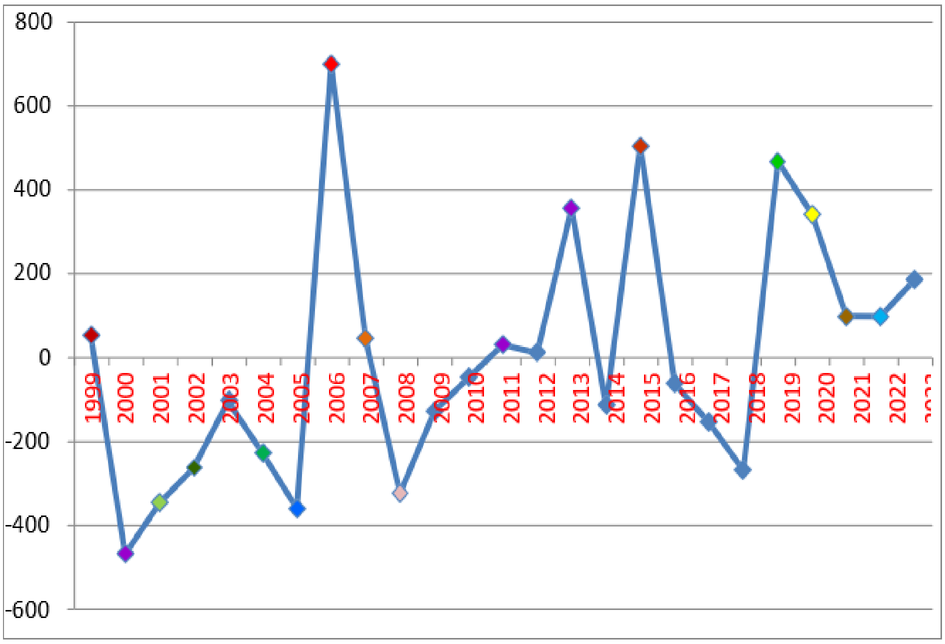

Figure 3 Departure of Average Rainfall of the Badnagar study area 1999 – 2023

In the following years, there were above-average rainfall departures: 1999, 2006, 2007, 2011 – 2012, and 2019 to 2023. This suggests a positive trend, indicating higher rainfall levels favorable for recharging groundwater reservoirs (see Figure 4.3). Conversely, in the years 2000 to 2005, 2008, 20010, 2014, and 2016 to 2018 the rainfall departure was lower than average, indicating a negative trend in recharge to the groundwater system.

The most extreme rainfall peaks were recorded during 2000-2005, 2008-2010, 2014, and 2016-2018, with the highest cumulative departure from the average rainfall value (see Figure 4).

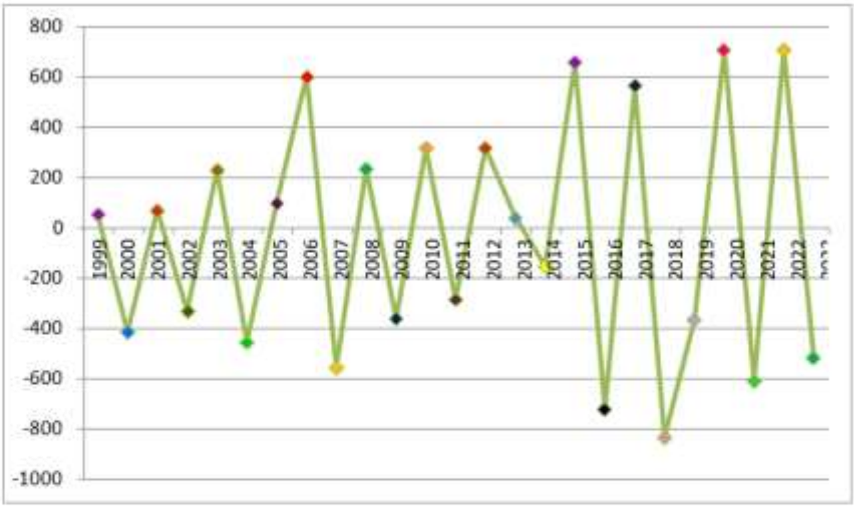

Figure 4 Cumulative departure of the Badnagar Study Area for the Period 1999 – 2023

STATISTICAL METHODS

The field of statistics is a branch of applied mathematics that involves the collection, presentation, description, analysis, interpretation, and prediction of numerical data. Accordingto Croxton and Cowden (1988), statistics is "The science which deals with the collection, analysis and interpretation of numerical data."

The statistical method provides central tendency values such as mean, median, mode, skewness, variation, dispersion, and time series analyses. The rainfall data for the Badnagar area from 1999 to 2023 has been categorized into 7 groups (see Table 3) and various statistical parameters have been calculated. The process for computing the data is outlined in the following text.

Table 3 Statistical Parameter Determination of Rainfall Data of Study Area.

Class Interval	**Mid Value(x)**	**Frequency(f)**	**U = x-A/h**	**fu**	**u^2**	**fu^2**	**Cumulative frequency**
400 – 600	500	2	-2	-4	4	8	2
600 – 800	700	7	-1	-7	1	7	9
800 – 1000	900	9	0	0	0	0	18
1000 – 1200	1100	2	1	2	1	2	20
1200 – 1400	1300	2	2	4	4	8	22
1400 – 1600	1500	2	3	6	9	18	24
1600 – 1800	1700	1	4	4	16	16	25
Total	**X =7700**	**∑f = 25**	**∑u =7**	**∑fu =5**	**$\sum u^2$ = 35**	**$\sum fu^2$ = 59**	

Mean:

The arithmetic mean is calculated by adding up all the values of various items and dividing by the number of items. It is also known as the arithmetic average and is defined as the sumof all observations divided by the number of observations. To find the mean of a set of observations, you divide the sum by the total count of observations.

$\sum fu$

Where,

A = Assumed mean =900,I = Class interval = 200 F = frequency = fu = 5

N = Total frequency = 25

Mean = 940 mm

Mean = A +

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Mean = 900 +
× I
N
5
× 200
25

Based on this, we calculate the mean rainfall as: 940 mm.

Median

The median is the middle value in a distribution, dividing it into two equal parts with thesame number of items in each part. When the values are arranged in order, the median is the central value of the variable. It is the value that separates the distribution into two halves, with one half containing all values greater than the median and the other half containing all values less than the median. The median can

be calculated using a specific formula.

Median

i □ **N**
□ **L** □
□
□ **C**

Where,

f □ 2 □

L is the lower limit of median class = 800

i is the Magnitude of the median class interval = 200

f is the frequency of median class = 9

C is the Cumulative frequency of class preceding the median class = 9N is total frequency = 25

800 +
200 25
(□9)
9 2

= 877.77 mm

Mode:

The mode of distribution was defined by Croxton and Cowden (1988) as "the value at the point armed with the item tends to be to the greatest extent consolidated." It may be regarded as the most typical of a series of values." The formula below can be used to figure out the exact value of the mode.

□ fm □f1 □
Mode = l □ h□ □
2 fm □f1 □f 2
□ □

l	= lower limit of the modal class	= 1000
f_m	= frequency of the modal class	= 2
f_1	= frequency of preceding to modal class	=9
f_2	= frequency of the post modal class	= 2
h	= Interval class	=200

= 1000 □200 □
2 □9 □
□ □
2 □2 □9 □2
□ □

= **1200.0 mm.**

The computed value of mode 1200.0 mm indicates ideal rainfall for the area.

Standard Deviation:

The standard deviation is a measure of the positive square root of the arithmetic mean of the squared deviations of given values from their arithmetic mean. This arithmetic mean is provided by Gupta and Kapoor in 1977 and 2003. We can calculate the standard deviation using the following formula:

Standard Deviation (δ) = I

$$\sqrt{\frac{(\sum fu_2)}{\sum f} - \frac{(\sum fu)_2}{\sum f}}$$

Where,

200 $\sqrt{\frac{59}{25} - \frac{25}{25}}$

δ. = Standard deviation

I = Class interval =200

$\sum f$ = N = Number of samples = 25

$\sum fu^2$ = 59

$\sum fu$ = 5

δ= 200 $\sqrt{\frac{(59)}{25} - \frac{(5)2}{25}}$

Standard Deviation = 233.23 mm

Co-efficient of Dispersion (C.D.):

The co-efficient of dispersion is pure number, independent of the units of measurement. Thedetermined value helps in comparison of the variability of two series.

Co-efficient of dispersion is measured by following formula:-

C. D. = Standard DeviationMean

$$= \frac{233.23}{940}$$

The determined value of Coefficient of dispersion is **0.248 mm.**

Co-efficient of Variation:

Karl Pearson (vide, Gupta,2006) considered the coefficient of variation as the percentage variation in the mean, with standard deviation as total variations in the mean. To compare the variability of two series, we calculate the coefficient of variation for each series. The series

having a greater variance coefficient is more variable than the other. The series having a lesser coefficient of variation is said to be more consistent than the other.

A hundred times the coefficient of dispersion based on standard deviation is called the coefficient of variation. It is given by:-

$$C.V. = 100 \times \frac{\text{Standard Deviation}}{\text{Mean}}$$

$$C.V. = 100 \times \frac{233.23}{940}$$

= 24.811 mm

The coefficient of variation shows the extent to which rainfall amounts vary.

Co-efficient of skewness:

Skewness refers to the "lack of symmetry" in a distribution. It provides insight into the shape of the curve that can be drawn using the given data. The coefficient of skewness is a relative measure expressed as a pure number, independent of the units of measurement. The coefficient of skewness is calculated using the following expression:

Co-efficient of Skewness =

Mean - Mode
Standard Deviation
= 940 - 1200

233.23

= **-1.114 mm.**

The skewness coefficient is **-1.114**, indicating a negative trend.

3. TIME SERIES ANALYSIS

The time series analysis generates valuable information regarding the trend of a series of observations. It helps in measurements of the deviation from the trend and enables information on the nature of the trend. This analysis is regarded as a tool to forecast the futurebehavior of trends. It helps us to compare the changes in values of different phenomena at different times or places. Also, it enables us to study the post behavior of the phenomena under consideration i.e., to determine the type and nature of the variation in data.

Time series is defined as an arrangement of statistical data in chronological order i.e.,following the occurrence of time. According to Hirsch, W.Z. (1959), the main objective in analyzing time series is to understand, interpret, and evaluate changes in economic phenomena in the hope of more correctly anticipating the course of future events.

Time series analysis is one of the most powerful methods in use, especially for short-term forecasting. This analysis looks for the dependence between values in a time series and a set of values recorded at equal time intervals to accurately identify the underlying pattern of the data. The earlier trends can be projected into future trends, to predict the changes, which are likely to occur in the economic and hydrometeorological cycle.

The method of fitting of second-degree parabola has been adopted for the trend analysis ofthe behavior of the annual rainfall. The parabola equation can be expressed as:

Yc = a + bx

Where, Yc = Trends value of dependent variablesX = Independent variables

Observed data must be used to determine the value of **a** and **b** in order to establish a best fitstraight line. To do so, two normal equations must be solved simultaneously.

$\sum y = Na + b\ \Sigma x$ .... (1)

$\sum x\ y = a\sum x + b\sum x2$ ....(2)

The value of different elements in the above equation has been determined by Considering ‘y’as variables (annual rainfall) and ‘x’ as constant (year), (Table 4).

The calculations are completed as per the following procedure

$\sum y$ = **23706.7**, $\sum x$ = **0**

$\sum xy$ =**22865.2**, $\sum x2$ =**1300**

N = **25**

According to equation (1) and (2) two equations in term of A and B are determined-

23706.7 =25a + b 0..(3)

2286.2 = a (0) + b (1300)...(4)

In order to get the values of (1) and (2), we solve equations (3) and (4). Attempts have been made to forecast rainfall amounts for the ten years 2021 to 2030. Depending on the expected amount, there may be a variation of 50 mm.

Σy = Na +b Σx

23706.7 = 25 (a) + (b) 0

23706.7 = 25 aa= 23706.7/25a = 948.24

$\Sigma xy = a\Sigma x + b\Sigma x^2$

22865.2= 0 + b (1300)

22865.2 = 0 + b (1300)b = 22865.2/1300

b = 17.58

According to the equation: **Yc = a + bx**

Yc= 948.24+ 17.58×24Yc=**1370.16**

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Table 4 Time Series analysis of Rainfall data of the Badnagar Study Area.

S. No.	Years	Total Rainfall (mm.) Year	X	XY	X^2
1	1999	1000.0	-12	-12000	144
2	2000	480.0	-11	-5280	121
3	2001	601.0	-10	-6010	100
4	2002	685.0	-9	-6165	81
5	2003	844.0	-8	-6752	64
6	2004	720.0	-7	-5040	49
7	2005	588.7	-6	-3532.2	36
8	2006	1647.0	-5	-8235	25
9	2007	992.0	-4	-3968	16
10	2008	624.0	-3	-1872	9
11	2009	819.0	-2	-1638	4
12	2010	900.6	-1	-900.6	1
13	2011	977.4	0	0	0
14	2012	958.0	1	958.0	1
15	2013	1303.0	2	2606.0	4
16	2014	834.0	3	2502.0	9
17	2015	1451.0	4	5804.0	16
18	2016	885.0	5	4425.0	25
19	2017	792.0	6	4752.0	36
20	2018	679.0	7	4753.0	49
21	2019	1414.0	8	11312.0	64
22	2020	1287.0	9	11583.0	81
23	2021	1046.0	10	10460.0	100
24	2022	1045.0	11	11495.0	121
25	2023	1134.0	12	13608.0	144
Total		**ΣY=23706.7**	**ΣX=0**	**ΣXY=22865.2**	**ΣX^2=1300**

Table 5 Calculation of the rainfall expected in Badnagar area.

S. No.	Years	Expected Rainfall (mm.)
1	2024	1370.16
2	2025	1387.74
3	2026	1405.32
4	2027	1422.9
5	2028	1440.48
6	2029	1458.06
7	2030	1475.64

This figure (5) shows the expected future rainfall trend for the study area up to the year 2030.Rainfall is expected to increase.

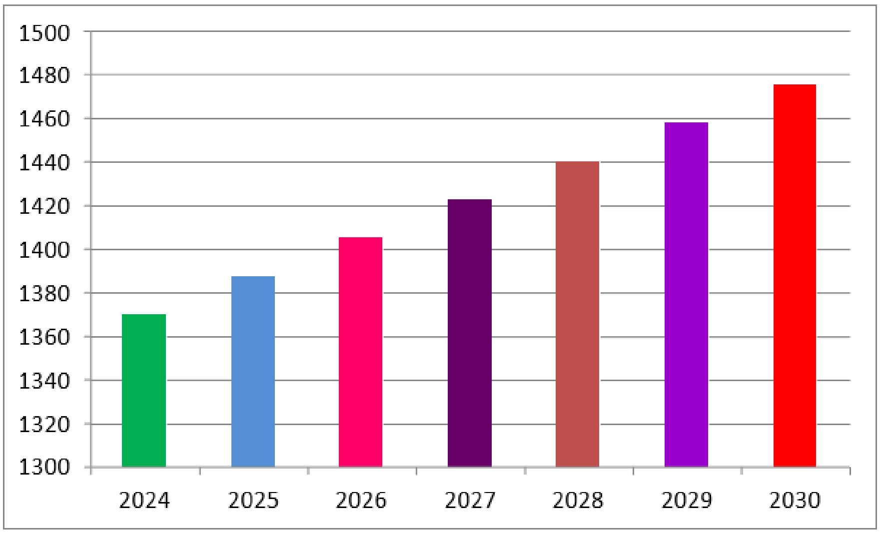

Figure 5 Forecasted rainfalls for the period of 2021-2030 in the Badnagar Study Area.

4. ENVIRONMENTAL IMPACTS

The most significant climatological feature of South Asia is the monsoons. The southwest or summer monsoon brings the majority of the region's water, while the northeast or winter monsoon supplies water to the southern parts of India and Sri Lanka. India's monsoon rains have a profound impact on millions of lives, and various factors such as its size, topography, and upper tropospheric conditions significantly influence its rainfall. Dealing with this

phenomenon from a regional perspective is considered the most effective approach (Guhathakurta and Rajeevan, 2008). In India, there is a significant degree of variation in rainfall, resulting in extreme monsoon rainfall deficits and excesses across extensive areas of the country (Dash et al., 2007).

According to Todd (1980), in groundwater systems, the pattern of rainfall is crucial in determining recharge rates. In the Badnagar area, data on rainfall shows a fairly broad range of variation, indicating both positive and negative trends that impact groundwater recharge. The current trend of overexploitation and scanty rainfall is leading to a decrease in groundwater levels.

The fluctuation of groundwater levels can be attributed to seasonal rainfall. Extended periods of drought lead to a decrease in water levels. On the other hand, increased rainwater facilitates the replenishment of groundwater. Based on this study, taking appropriate actions can aid in mitigating the rapidly worsening issue of groundwater depletion, which has led to drought conditions in Badnagar. The negative trends in rainfall over recent years serve as a warning sign, necessitating the implementation of measures to enhance precipitation. One of the suggested methods is to develop a plan for afforestation, which would promote evapotranspiration and increase the amount and intensity of precipitation. To address the water crisis, it may also be beneficial to utilize water resources judiciously, as rainfall patterns play a significant role in exacerbating the water crisis.

5. CONCLUSION

The paper presents the findings of an analysis of rainfall data. The mathematical analysis reveals a range of 480.0 mm to 1647.0 mm, with an annual average of 948.26 mm. The statistical analysis of the rainfall data includes the following measures: mean: 940.0 mm, median: 877.77 mm, mode: 1200.0 mm, standard deviation: 233.33 mm, coefficient of variation: 24.81 mm, and coefficient of skewness: -1.11. These statistical analyses provide precise values for the variables within the rainfall data. The time series analysis suggests the future trend of expected rainfall. It is recommended that the optimal development of rainwater harvesting be pursued to address the existing issue of acute water supply shortagein the Badnagar region. Increasing groundwater reservoirs by capturing more rainwater and implementing afforestation schemes would help meet the demand for water supply.

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