Int. j.econ. & environ. geol. vol:1(2) 10-14

Environmental Implications of Monsoon Seasonal Rainfall on Groundwater Regime of Rajpipla Region, Gujarat, India.

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Abstract. The monsoon seasonal rainfall record of Rajpipla area confined to Gujarat state of India, for a period of 1987-2006, has been treated to mathematical and statistical analyses to observe variation pattern, future trends and their environmental impacts on groundwater regime. The mathematical analysis of monsoon seasonal rainfall data indicates a fairly good range of variation from 321.30 mm to 1319.30 mm with an average rainfall value of 925.61mm. The years indicating positive trend of departure from the computed value of average seasonal rainfall point out favourable intervals for recharge of ground water reservoir. The cumulative departure from the average rainfall except for 1998 and 2006 reveals existence of negative trend. The statistical analysis of rainfall data determines statistical parameters, which indicate rather alternative variation pattern. The forecast of future rainfall trend for a period of next three years indicates an increasing trend in the expected rainfall amount. The environmental impacts of rainfall phenomena have been discussed. The strategy for augmentation of rainfall amount to enhance the groundwater recharge system for Rajpipla area has been suggested.

Introduction

Rainfall is a liquid form of the precipitation that acts as one of the most important hydrometeorological parameter governing the augmentation phenomena of groundwater system. It is well established fact that only 3% of fresh water occurs in streams, lakes and reservoirs, whereas 97% of available fresh water is confined to subsurface of the earth. In the areas of limited rainfall, the groundwater is the only reliable and vital source of fresh water supply. In most parts of the Indian subcontinent, the maximum rainfall is recorded during the monsoon season that is the main source of groundwater recharge. The environmental consequences of monsoon seasonal variations of rainfall have been visualized by selecting an example from Rajpipla region located in Gujarat, Western India.

Materials and Methods

The rainfall amount and intensity are commonly measured by using rain gauges, which are mainly of two types: Storage rain gauge records daily or monthly measurements, Recording rain gauge measures the intensity of rainfall. In India, Symon's rain gauge is in common usage. The rainwater in the gauge is measured daily at a fixed time and is recorded in millimeters. The rain gauge measurements are having accuracy up to 0.1Êmm or 0.01Êin. The natural siphon-recording rain gauge provides continuous record of rainfall, its intensity and duration (Raghunath, 1982). The rainfall data from a number of adjacent stations can be used to depict isohyetal lines or isohyets, which join all points that receive the same amount of precipitation. An isohyetal map shows a real distribution of precipitation and forms the basis for computing the total water potential of a region (Karanth, 2003).

The record of monsoon seasonal rainfall data for a time span of 20 years (1987 to 2006) pertaining to Rajpipla area, located in the state of Gujarat of the Indian subcontinent, has been collected from P.W.C. Rajpipla (Table 1). The rainfall data have been subjected to analysis and interpretation.

Results of Rainfall Data Analysis

The rainfall data of Rajpipla area for a period from 1987 to 2006 have been analyzed by following both the mathematical and statistical methods of data analysis. The mathematical method involves the determination of average rainfall for a specific period. The average value is calculated by dividing the amount of total rainfall by the total period of rainfall record. The departure of rainfall from the average rainfall determines the pattern of rainfall. The determination of the cumulative departure of rainfall provides the information regarding the total departure of rainfall about the mean value, over a particular period. The statistical method employs the determination of parameters such as mean, median, mode, dispersion, standard deviation, variance and the time series analysis. A time series has been defined as a sequence of values arrayed in order of their occurrence which can be characterized by statistical properties by Dawdy and Mathalas (1964). The significant movements of time series are secular, periodic, cyclic and irregular trends. The commonly used procedures of statistical analysis as followed by Gupta and Kapoor (1985), Croxton *et al* (1988), and Davis (2002) have been employed in the present study.

ISSN 2223-957X

Table 1.Yearwise rainfall data of Rajpipla region.

Years	Monsoon Seasonal Rainfall (mm)					Total
	June	July	Aug	Sept	Oct	
1987	65.3	164.5	137.5	4	nil	371.3
1988	55.5	411.3	308	281.5	18.3	1074.6
1989	147.3	357.8	418.5	104.4	0.3	1028.3
1990	167	179	474.5	292.8	13.8	1127.1
1991	33.3	485.5	160	32.5	nil	711.3
1992	145.5	130.4	304.8	166.3	47.8	794.8
1993	117	585.8	70.4	166	5	944.2
1994	308.8	265	138.3	209.8	nil	921.3
1995	nil	368.8	283.6	94.2	nil	746.6
1996	202.2	446.4	324.8	150.2	74.8	1198.4
1997	279	175.2	509.2	95	nil	1058.4
1998	202.7	269.1	129	516.6	78	1195.4
1999	170.7	224.8	35.8	55	52.8	539.1
2000	100.2	269.4	53.6	14.4	nil	437.6
2001	266.8	280	253.6	6.8	51.4	858.6
2002	319.2	21.7	212.3	260.6	nil	813.8
2003	311	461	296.6	190.6	nil	1259.2
2004	271.4	334.2	495	44.4	11.8	1156.8
2005	491.2	24	108.6	112.4	0	956.2
2006	54	589.2	545.4	115.2	15.5	1319.3
Total	3708.1	6043.1	5259.5	2912.7	369.5	18512.3
Average	195.1632	302.155	262.975	145.635	30.79167	925.615

Mathematical Analysis

The common method of arithmetical analysis has been used for monsoon seasonal rainfall data for a period of 1987 to 2006 of Rajpipla area (Table 1). The rainfall records reveal that minimum rainfall value of 30.79 mm (October) and the maximum rainfall value of 302.15 mm (July) with an average of 925.61 mm have been observed (Table 1). The graphic presentation of average monthly monsoon rainfall data for 1987-2006 has been displayed by bar diagram (Fig. 1) that exhibits increase in amount from July to August and a decreasing trend from August onwards up to October. The total monsoon rainfall data for the years (1987 to 2006) have been incorporated (Table 1 & Fig. 2). The graphic presentation exhibits fluctuating trend of increase and decrease in the amount of rainfall for analysis period (Fig. 2). The rainfall pattern indicates that the rainfall was more than the computed average value of the annual rainfall during the years of 1988-1990, 1993, 1996-1998 and 2004-2006. These years revealing higher values of rainfall point out favourable period for the rainwater recharge to the ground water reservoir. The calculated values of departure and cumulative departure from the average rainfall are recorded (Table 2) and the nature of rainfall pattern has also been exhibited by graphic method (Fig. 3 & 4). The departure of rainfall more than the average value have been noted during the years of 1988-1990, 1993, 1996-1998 and 2003-2006 indicating favourable period for groundwater recharge (Table 2, Fig. 3).

The cumulative departure pattern from the average rainfall value (Table 2 & Fig. 4) shows that the maximum peak of rainfall was recorded during the year of 1998. The other subsequent peak was witnessed during the 2006.

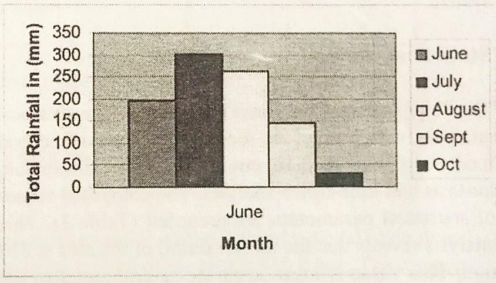

Fig. 1. Total average seasonal monthly rainfall of Rajpipla area (1987-2007).

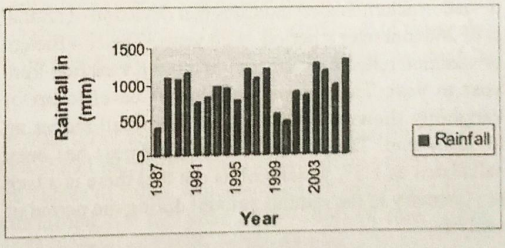

Fig. 2. Total rainfall of the Rajpipla area (1987-2006).

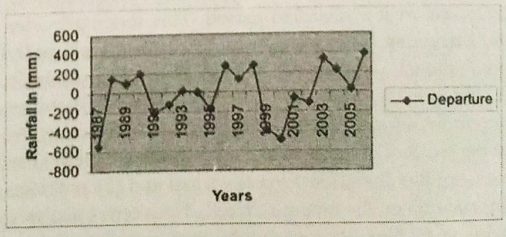

Fig. 3. Departure trend of rainfall data of Rajpipla area, Gujarat, India.

Table. 2. Computation of departure and cumulative departure from the average seasonal rainfall of Rajpipla, Gujarat, India.

Year	Total Monsoon Seasonal Rainfall (mm)	Departure from Average Seasonal rainfall (mm)	Cumulative Departure From Average rainfall (mm)
1987	371.3	-554.3	-554.3
1988	1074.6	148.96	-405.34
1989	1028.3	102.66	-302.68
1990	1127.1	201.46	-101.22
1991	711.3	-214.34	-315.56
1992	794.8	-130.84	-446.4
1993	944.2	18.56	-427.96
1994	921.9	-3.74	-431.58
1995	746.6	-179.04	-610.62
1996	1198.4	272.76	-337.86
1997	1058.4	132.76	-205.1
1998	1195.4	269.76	64.66
1999	539.1	-386.54	-321.88
2000	437.6	-488.04	-809.92
2001	858.6	-67.04	-876.96
2002	813.8	-111.84	-988.8
2003	1259.2	333.56	-655.24
2004	1156.8	231.16	-424.08
2005	956.2	30.56	-393.52
2006	1319.3	393.66	0.14

These peaks indicate the prevalence of favourable periods for sufficient infiltration of rainwater to the ground water system.

Statistical Method

The Rajpipla rainfall data have been subjected to statistical analysis, which involves the computations of central tendency (mean, median, mode), skewness, dispersion, kurtosis and time series analysis. The computed values of statistical parameters are recorded (Table 3). This analysis reveals that the mean rainfall of the area is 810 mm. This value is more accurate as compared to the average value computed by the arithmetic method. The median and mode of the rainfall data have been calculated to be 866.66 mm and 400 mm respectively. The standard deviation determination indicates that deviation of rainfall is of 260 mm over a period of 20 years. The co-efficient of variation reflects the amount in rainfall variation from year to year. The computed value of co-efficient of variability shows that the amount of rainfall ranges up to 32.09 mm. The co-efficient of skewness has been calculated as 1.57, which points out that there is a lack of symmetry in the rainfall amount during the period of analysis.

A time series determines a tendency to increase or decrease, over a specified period. This series provides an interesting illustration because the trend is usually predominant, virtually no other movement is discernable (Croxton *et.al*, 1988). The time series analysis provides important information pertaining to the characterization of the trend of a series of observations. It enables (1) to measure the deviation from the trend and (2) provides information on the nature of trend. Time series analysis helps in making attempt for the forecast of the future behavior of rainfall trend.

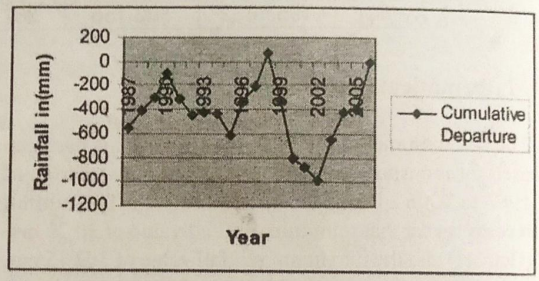

Fig. 4. Cumulative departure trend of rainfall data of Rajpipla area, Gujarat, India.

The value of 'a' and 'b' must be determined from the observed data. This is achieved by simultaneous solving of two normal equations:

$\Sigma y = Na + d\,\Sigma x$ ----------(1)

$\Sigma xy = a\,\Sigma x + b\,\Sigma x^2$ ---------- (2)

The values of the different elements in the above equation have been determined by considering 'y' as variable (annual rainfall) and 't' as constant (year). The determined values are shown in Table 3. The determinations are made as per the following procedure:

$\Sigma x = +10,\ \Sigma y = 18512.9,\ \Sigma x^2 = 670,\ \Sigma xy = 17822.4$

Substituting these values in normal equation (1) and (2), two equations 3 and 4 are developed.

$18512.9 = 20a + b10$ ---------- (3)

$1782.4 = 10a + b670$ ---------- (4)

Solving equations (3) and (4) the values of 'a' and 'b' are obtained as 919.205 and 12.88 respectively. The future forecast of rainfall amount for a period of twenty years from 2007 to 2009 has been made and it can reveal

± 50 mm variation in the expected amount. Future forecast is calculated by given equation:

$$Y = a + b\,(x - 1992)$$

The time series analysis of rainfall data of Rajpipla area reveals a negative trend in the amount and intensity of rainfall. The possible reasons for this rainfall trend can be assigned to the nature of topographical features and deforestation. This trend of rainfall provides an evidence indicator that the recharge phenomenon of ground water system might have been affected by the amount of rainfall, resulting in a state of depletion of the ground water levels in the Rajpipla area.

The graph showing the departure from average rainfall (Fig. 3) shows that during the years of 1988-1990, 1993, 1996-1998 and 2003-2006, the rainfall values were more than the average. Hence, these years are indicative of favourable periods for groundwater recharge.

The graph showing cumulative departure from average rainfall (Fig. 4) exhibits that the maximum peaks occurred during the years of 1998 and 2006 that point out maximum rainfall during the corresponding periods indicating sufficient infiltration of rainwater. The trend of cumulative departure for rest of the years indicates lower values as compared to the average rainfall revealing rather inadequate recharge phenomena.

Table 3. Computation of statistical parameters of rainfall data Rainpipla area, Gujarat, India

Statistical Parameter	Formula	Computed Value
Mean	$\bar{x} = \frac{\sum x}{N}$	810 mm
Median	i+ i/f (N/2-C)	866.66 mm
Mode	i + [i (f_1-f_0)] / [2f_1-f_0-f_2]	400 mm
Standard Deviation	$\sigma = 200\sqrt{1/N \sum fd^2 - (1/N \sum fd)^2}$	260
Coefficient of Dispersion	Standard Deviation/ Mean	0.320
Coefficient of Variation	100× (Standard Deviation / mean)	32.09
Coefficient of Skewness	(mean-mode) / Standard deviation	1.57

Abbreviations

A = Assumed mean
i = Class interval
N = Sum of frequency
L = Lower limit of median class
i = Magnitude of median class
f = Frequency of median class
C = Cumulative frequency of the class preceding the median class
L = Lower limit of modal class
f_1 = Frequency of modal class
f_0 = Frequency of class preceding the modal class
f_2 = Frequency of class succeeding the modal class
σ = Standard deviation
N = Total frequency

Interpretation of Rainfall Data

The average rainfall of the Rajpipla area has been calculated as 925.61 mm. The trends of departure and cumulative departure from the average rainfall of the study area are incorporated herein (Table 2, Fig. 3, 4).

Statistical analysis of the Rajpipla rainfall data reveals that mean rainfall of the area is 810.0 mm. The computed value of mode 400.0 mm indicates inadequate rainfall for the area. The standard deviation value reveals that deviation of rainfall is of 260 mm over a period of twenty years. Coefficient of variation indicates that the amount of rainfall varies up to 32.09. The coefficient of skewness has been noted as 1.57, which indicates negative rainfall trend.

The time series analysis points out a positive trend in the amount and intensity of rainfall for coming three years. The values of future expected rainfall trend have been determined for the year 2007=1060.88 mm, 2008 =1073.76 mm, and 2009 =1086.64 mm.

Environmental Impacts

The rain involves negative as well as positive aspects and its cultural environmental impacts are varied through out the world. The rain can be harvested, whereas excessive rain causes river flooding and scanty rain develops the drought conditions. The rainfall plays a most effective role in the optimum development of agriculture. It is a well-known fact that rainfall considerably affects the growth of plants and crops, for

example, tropical plants require about 250 cm rain for their existence, while cactus survives even in a lesser amount of rainfall. In India, rainfall plays a governing role on growth of agriculture. It has been observed that even a delay of few days in the advent of monsoon rainfall affects the economy of the country.

The rainfall plays a vital role in environmental entity as a main source for the recharge of ground water system. The rainfall data analysis of Rajpipla area indicates a fairly good range of variations indicating the alternating positive and negative values as compared to the average seasonal rainfall. In the recent years, the rainfall trend indicates positive trend. Todd (1980) stated that Groundwater levels may show seasonal variation due to rainfall. Drought extending over a period of several years, contribute to declining water level. In Rajpipla area, the depletion of ground water levels is mainly due to rainfall factor. It is suggested herein that adoption of a proper scheme for rainwater harvesting will enhance the groundwater recharge phenomena. The planning of ground water augmentation will provide a sustained water supply in Rajpipla area.

Conclusion

The variation analysis of monsoon seasonal rainfall data of Rajpipla area for a period from 1987 to 2006 indicates a fairly good range of variation in the amount and frequency. During recent years a positive trend exhibiting more than the seasonal average rainfall value has been observed. The determination of future expected rainfall also reveals an increasing amount of rainfall during the next three years. The augmentation of ground water reservoir by increasing rainwater harvesting and launching of plantation scheme will help in the augmentation of groundwater resource that would solve the existing problem of water supply.

Acknowledgement. The sincere obligation is expressed to Department of Science and Technology, New Delhi for granting the Project No. SR/S4/ES-21/Narmada Window/P3. Many thanks are due to Prof. L. S. Chamyal, Coordinator, Gujarat Window, Science of Shallow Subsurface, D.S.T. Programme. M. S. University, Vadodara, Gujarat, for valuable suggestions and encouragement.

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