CHAPTER 5: HYDRO- METEOROLOGY

5.1 METEOROLOGICAL ANALYSIS

Rainfall is the major component of the hydrologic cycle and is the primary source of runoff (Beven, 2001). Rainfall is essentially required to fulfil various demands including agriculture, hydropower, industries, environment and ecology. It is implicit that the rainfall is a natural phenomenon occurring due to atmospheric and oceanic circulation (local convection, frontal or orographic pattern) and has large variability at different spatial and temporal scales. However, this input is subjected to uncertainty and stochastic errors (Jakeman and Hornberger, 1993; Beven, 2001). using various empirical, statistical, numerical and deterministic techniques there has been many attempts to model and predict rainfall behaviors. They are still in research stage and needs more focused empirical approaches to estimate and predict rainfall accurately.

These data are usually collected using rain gauges, and therefore they are point precipitation data. However, the application of a single rain gauge as precipitation input carries lots of uncertainties regarding estimation of runoff (Faur`es et al., 1995 and Chaubey et al., 1999).This creates a lot of problem for the discharge prediction, especially if the rain gauge is located outside the basin (Schuurmans and Bierkens, 2007).As a result, some utilities such as hydrological modeling need rainfall data that are spatially continuous. The quality of such result is therefore estimated by the quality of the continuous spatial rainfall. Various spatial interpolation techniques to obtain representative rainfall over the entire basin or sub-basins have also been used in the past.

The justification underlying spatial interpolation is the assumption that points closer together in space are more likely to have similar values than points that are more distant. This observation is known as Tobler's First Law of Geography (Tobler, 1970). Spatial interpolation is a very important component of many geographical information systems (GIS), frequently used as a tool to aid spatial decision making both in (1) physical and human geography and (2) related disciplines, such as hydrology and water resources planning and management. Many of the techniques of spatial interpolation are two-dimensional developments of the one-dimensional methods originally developed for time series analysis (Ripley, 1981).

The rainfall data may be used to predict rainfall by time series analysis. The main development of time series models is done by Box and Jenkins in 1970 (Vandaele W, 1983) and further discussed in some other resources (Montgomery and Johnson, 1967). In time series analysis it is assumed that the data consists of a systematic pattern (usually a set of identifiable components) and random noise (error) which usually makes the pattern difficult to identify. Time series analysis techniques usually involve some method of filtering out noise in order to make the pattern more salient. Trend and Seasonality are the two basic classes of components which can help describe the time series patterns. The trend represents a general systematic linear or (most often) nonlinear component that changes over time and does not repeat within the time range. The seasonality may have a formally similar nature; however, it repeats itself in systematic intervals over time. These two classes of time series components may coexist in real-life data.

5.1.1 Rainfall Data

The annual rainfall data was obtained for all talukas from the State Water Data Centre, Gandhinagar for a period of 138 years from 1878 to 2015 for Anjar and Bhuj while for Gandhidham it was obtained for the period of 1998 to 2013. Daily rainfall data was obtained for the period of 1989 to 2015.

5.1.2 Rainfall Pattern Analysis for Kutch

The normal rainfall for Kutch district ranges between 300 to 400 mm. The district receives an average annual rainfall of 356 mm (for study period of 1878 to 2015 - data studied from the thesis of Dr. S.S. Majmundar and from data centre, Gandhinagar), which is erratic and depends on the strength of the summer monsoon. It ranges from 335 mm at Bhuj to 331 mm at Naliya. The variation in the annual rainfall from the year to year is very large. The monsoon rains usually set in by the third week of June in the coastal belt and withdraws by the end of September. The maximum rainfall takes place during the month of July and very less rain occurs during the month of August and September. Most of annual rainfall in the district is received during the southwest monsoon season, July being the rainiest month. Rainfall of about 178 to 468 mm in a single day has also been recorded at many stations.

Rainfall is dominated by the summer monsoon (June through September) with an average annual rainfall in the basin is 400 mm. During the remainder of the year, rainfall is extremely low, rarely exceeding 50 mm per month. The spatial variation in rainfall is moderate in the basin. Average annual rainfall in the most upstream part of the basin is about 400 mm, increasing toward the central basin part (800 mm) and further in the most downstream coastal belt of the basin (1000 mm) (S.S.Majmundar 2007).

According to august 2010 online DNA article it was reported that “Gujarat's desert district, Kutch, has managed quite a feat - its rainfall this year is the highest in the past seven years. In 2003, the district had received 711 mm rainfall. And now, in 2010, while the monsoon is not over yet, the annual rainfall has already exceeded the 600 mm-mark. As per data available from the Gujarat State Disaster Management Authority (GSDMA), two districts of Saurashtra - Surendranagar and Jamnagar, have also received their highest rainfall in three years. A few districts have received more than 100% of their last 10 years' average rainfall.

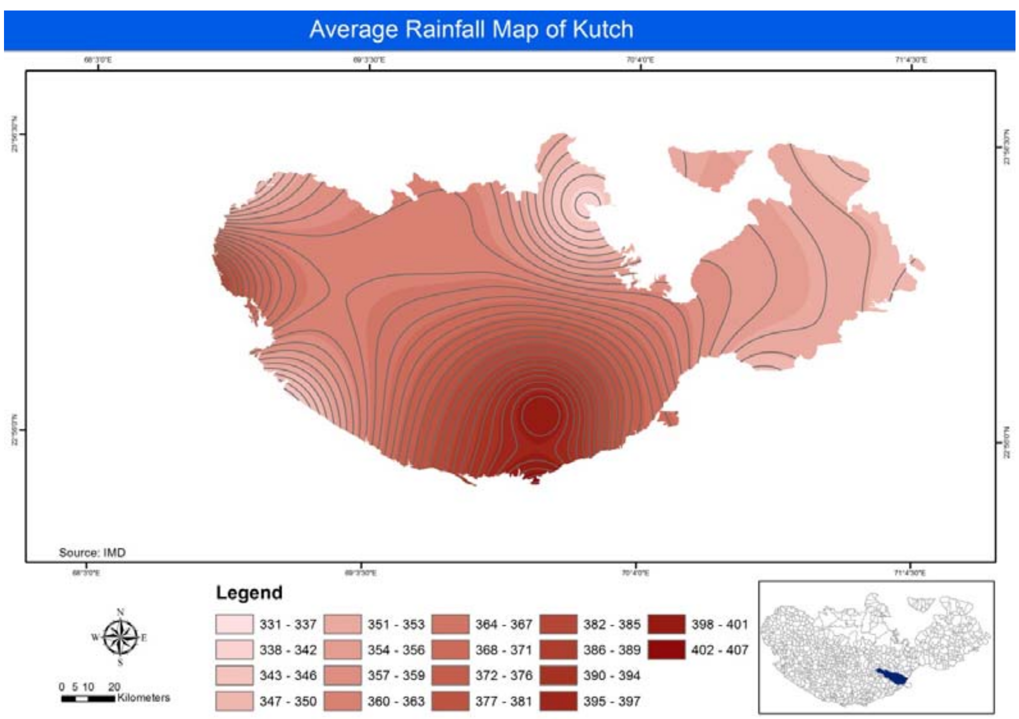

Fig. 5.1 Average annual rainfall of the kutch district

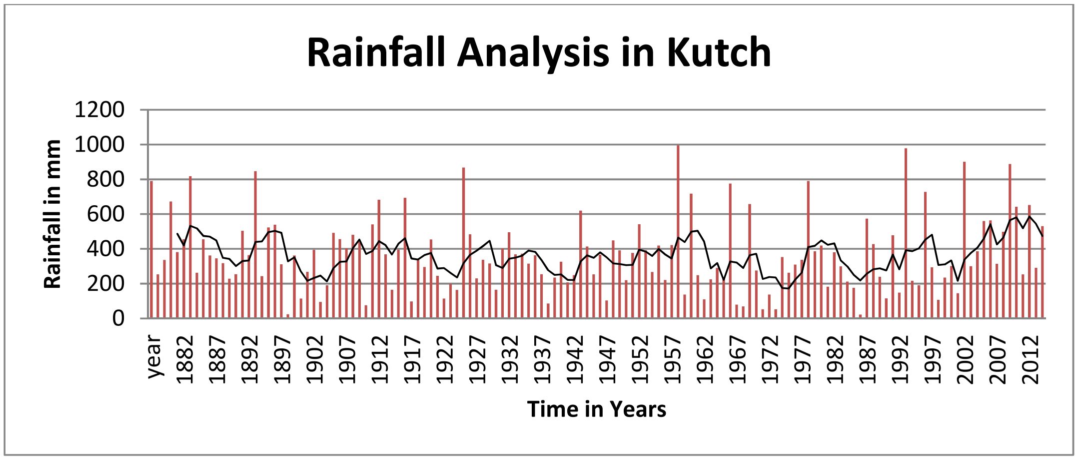

Fig. 5.2 Graph of Rainfall Analysis for Kutch District with 5 years moving average

5.1.2.1 Probability Analysis for Kutch

The probability analysis for the rainfall is done for the period of 138 years and the results for the same are tabulated. The probability of rainfall occurring between 350 to 400 mm for Kutch district is maximum. Fig. 5.3 shows the probability analysis for the district and Table 5.1 shows the probabilities of occurrence of rainfall for the district.

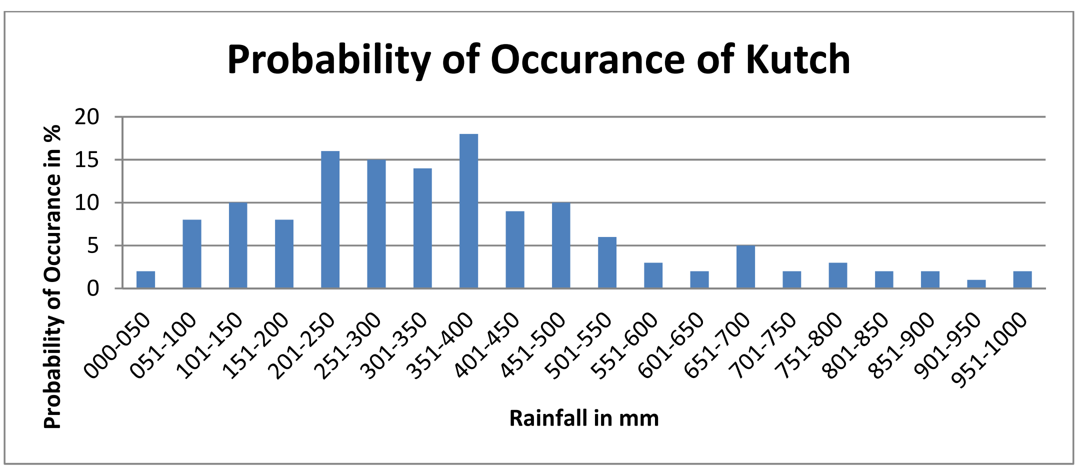

Fig. 5.3 Graph of Probability Analysis for Kutch District

Table 5.1 Probability of Occurrence of Rainfall for Kutch District

Rainfall in mm	**Number of Events**	**Probability of Occurance (%)**
0-50	2	1.45%
51-100	8	5.80%
101-150	10	7.25%
151-200	8	5.80%
201-250	16	11.59%
251-300	15	10.87%
301-350	14	10.14%
351-400	18	13.04%
401-450	9	6.52%
451-500	10	7.25%
501-550	6	4.35%
551-600	3	2.17%
601-650	2	1.45%
651-700	5	3.62%
701-750	2	1.45%
751-800	3	2.17%
801-850	2	1.45%
851-900	2	1.45%
901-950	1	0.72%
951-1000	2	1.45%
Grand Total	**138**	**100.00%**

5.1.2.2 Rainfall Distribution Analysis for District

The annual rainfall during the study period has been classified as drought, deficit, normal, above average and surplus based on Central Arid Zone Research Institute (CAZRI) report prepared by Singh R S et. al (1990,1991) . The criteria for analysis in CAZRI report were as follows:

Table 5.2 Criteria for analysis in CAZRI report

Surplus Years	A year receiving a rainfall of 150 % or more of the normal annual rainfall
Above Normal Years	A year receiving rainfall between 125% to 150% of the normal annual rainfall
Normal Years	A year receiving the rainfall between 75 to 125% of the normal annual rainfall
Below Normal Years	A year receiving the rainfall between 50 to 75% of the normal annual rainfall
Deficit Years	A year receiving the rainfall less than 50% of the normal annual rainfall

Source: CAZRI

5.1.3 Rainfall Pattern Analysis for Anjar

The average annual rainfall for Anjar taluka is 345 mm. During period 1878 to 2015 the highest annual rainfall amounting to 1060 mm for Anjar taluka occurred in the year 1967. Fig.5.4 shows the bar graphs and 5 year moving mean graphs for Anjar taluka as well as Kutch district. Compared to the average annual rainfall of Kutch district, the average annual rainfall for Anjar taluka is less by approximately 3 percent. Also, the Anjar taluka has experienced more number of years with less than average annual rainfall as compared to the Kutch district

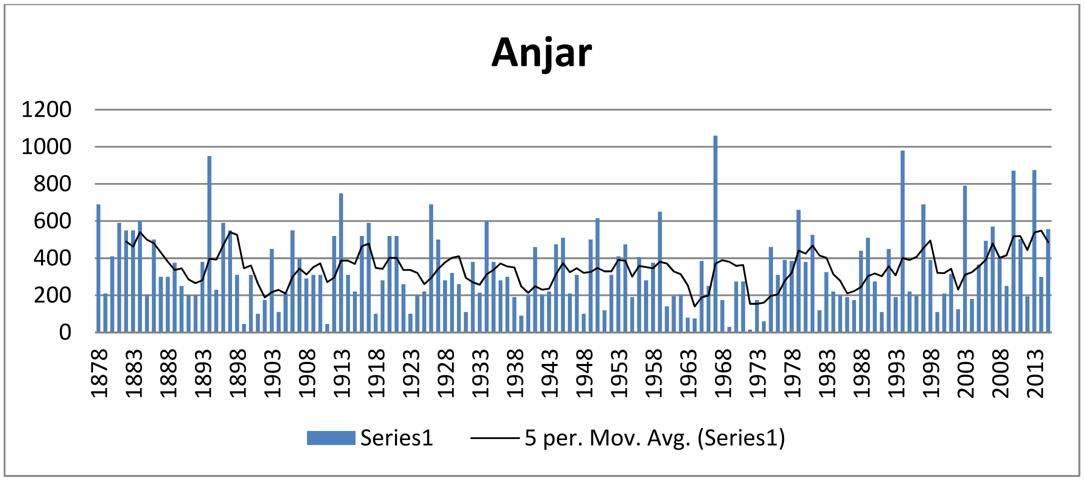

Fig. 5.4 annual rainfall pattern for Anjar taluka and its 5 years moving average

5.1.3.1 Probability Analysis for Anjar

Based on the above data, the probabilities of occurrence of different magnitudes of rainfall have been found out for Anjar taluka. The probability for rainfall occurring between 251 to 300 mm for Anjar taluka is maximum while probability of the rainfall deviating from the average annual value by very high range i.e. below 50 mm or above 800 mm is very less. Fig. 5.6 shows the comparison for probability of occurrence of rainfall for Anjar taluka with that of Kutch district.

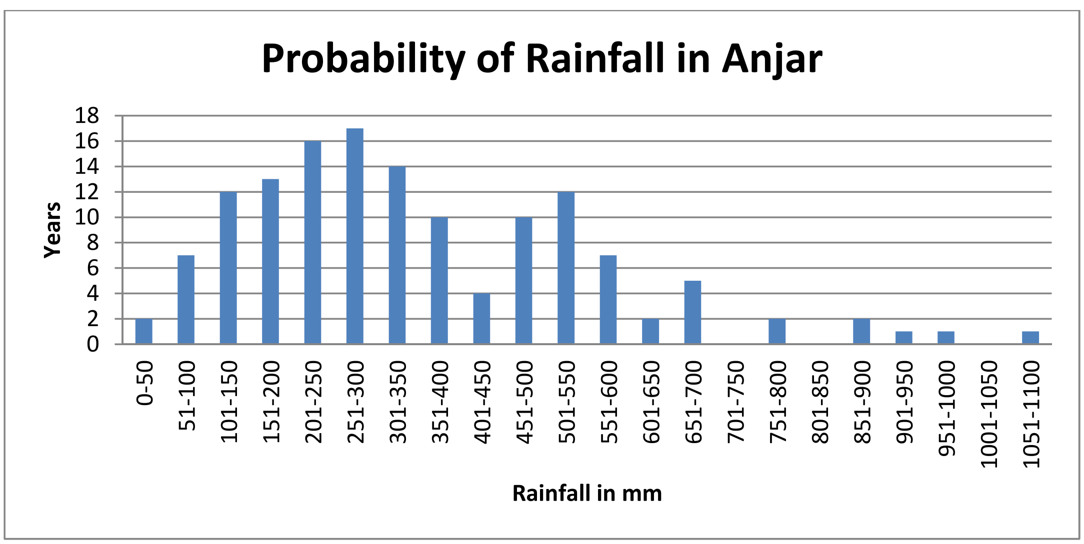

Fig. 5.5 Graph of Probability of Occurrence (Anjar)

Table 5.3 Probability of Occurrence (Anjar)

Rainfall (mm)	Probability of Occurrence	Percentages
0-50	2	1.45%
51-100	7	5.07%
101-150	12	8.70%
151-200	13	9.42%
201-250	16	11.59%
251-300	17	12.32%
301-350	14	10.14%
351-400	10	7.25%
401-450	4	2.90%
451-500	10	7.25%
501-550	12	8.70%
551-600	7	5.07%
601-650	2	1.45%
651-700	5	3.62%
701-750	0	0.00%
751-800	2	1.45%
801-850	0	0.00%
851-900	2	1.45%
901-950	1	0.72%
951-1000	1	0.72%
1001-1050	0	0.00%
1051-1100	1	0.72%
Grand Total	**138**	**100.00%**

5.1.3.2 Distribution of Rainfall for Anjar

During the study period of 138 years, the Anjar taluka has experienced 21 drought years, 45 rainfall deficit years, 22 years having normal rainfall, 13 years having above average rainfall and 29 years having surplus rainfall. The results for the analysis have been tabulated in Table 5.5. Fig. 5.6 shows the distribution of rainfall pattern over a period of 138 years for Anjar Taluka.

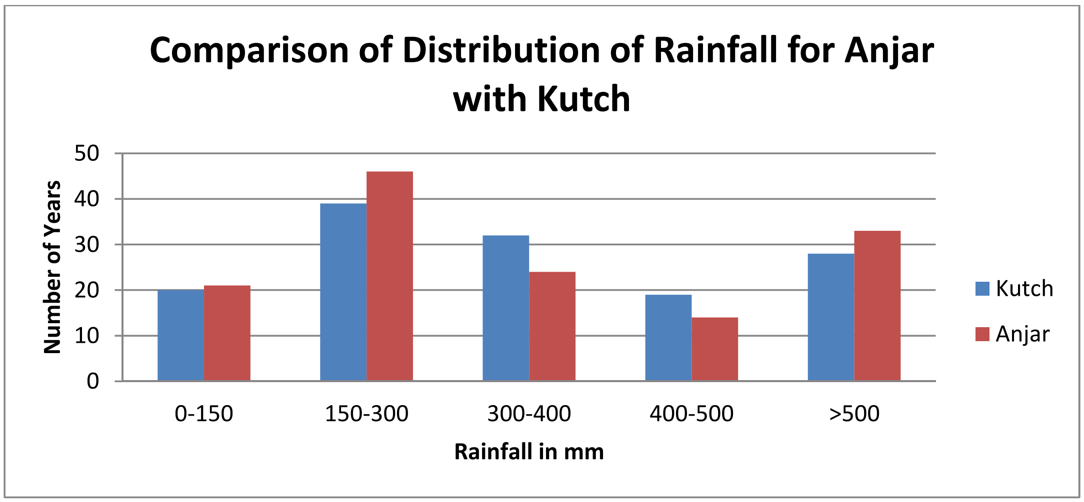

Fig. 5.6 Comparison of Distribution of Rainfall for Anjar Taluka with Kutch District

Table 5.4 Rainfall in Anjar

	Draught Years	Rainfall Deficit Years	Normal Rainfall	Above Average Rainfall	Surplus Rainfall
Rainfall in mm	0-150	150-300	300-400	400-500	>500
Occurrences of Events	21	46	24	14	33
Percentage	15.22%	33.33%	17.39%	10.14%	23.91%

The analysis shows that of the total study period of 138 years, there have been 21 (15.22 %) drought years, 48 (34.78 %) rainfall deficit years, 22 (15.94 %) years having normal rainfall, 14 (10.14 %) years having above average rainfall and 33 (23.91 %) years having surplus rainfall.

Table 5.5 Distribution of Rainfall for Anjar Taluka

Drought years		Rainfall Deficit years		Normal Rainfall Years		Above Average rainfall years	Surplus Rainfall Years
<150		151-300		300-400		400-500	>500
1899	1960	1879	1943	1907	1983	1880	1878
1901	1963	1885	1946	1977	1929	1903	1881
1904	1964	1887	1955	1998	2001	1941	1882
1911	1968	1890	1957	1965	1898	1944	1883
1918	1969	1891	1961	2005	1900	1945	1884
1923	1972	1892	1962	1978	1888	1953	1886
1931	1974	1895	1966	1893	1909	1954	1894
1939	1982	1902	1970	1932	1910	1956	1896
1948	1991	1905	1971	1935	1914	1975	1897
1951	1999	1908	1973	1980	1947	1988	1906
	2002	1915	1984	1889	1952	1989	1912
		1919	1985	1958	1976	1992	1913
		1922	1986			2006	1916
		1924	1987			2008	1917

	1925 1990			1920
	1928 1993			1921
	1930 1995			1926
	1933 1996			1927
	1936 2000			1934
	1937 2004			1949
	1938 2009			1950
	1940 2012			1959
	1942 2014			1967
				1979
				1981
				1994
				1997
				2003
				2007
				2010
				2011
				2013
				2015
Total 21 Years	Total 46 Years	Total 24 Years	Total 14 Years	Total 33 Years

5.1.3.3 Talukawise comparison of rainfall with water level (Anjar)

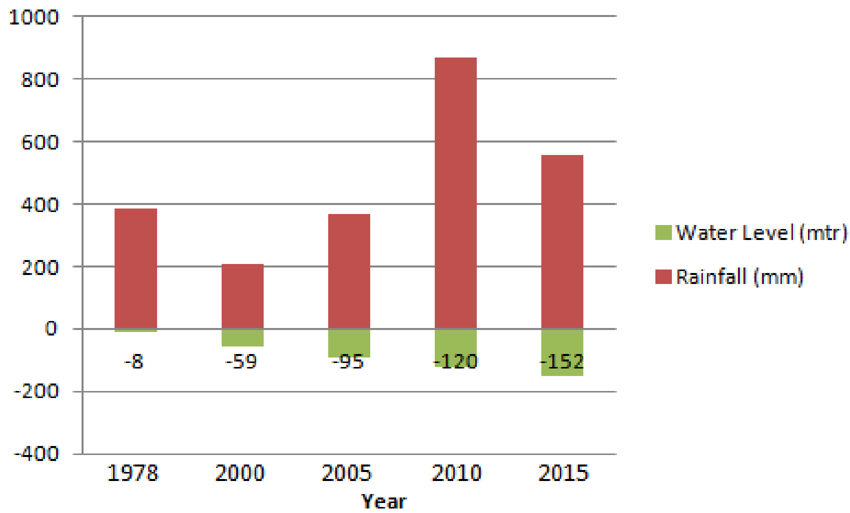

Fig. 5.7 Rainfall Vs SWL Graph for Nagalpar Nani Village

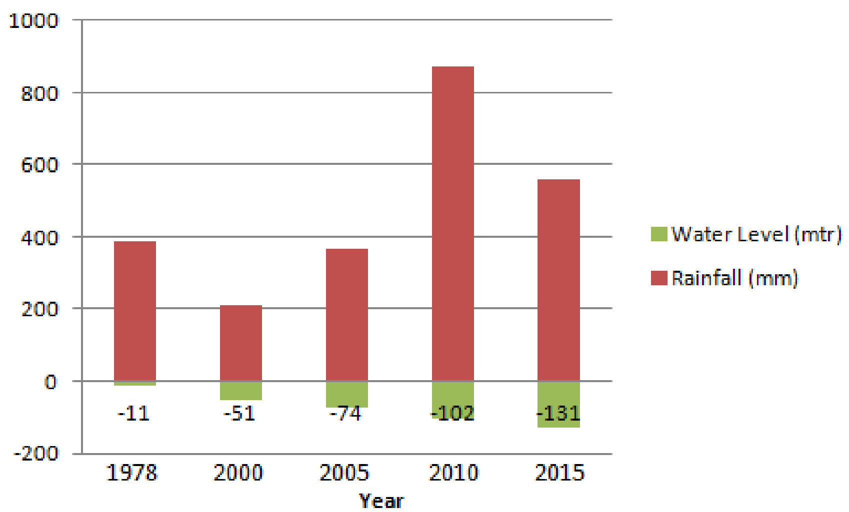

Fig. 5.8 Rainfall Vs SWL Graph for Ningal Village

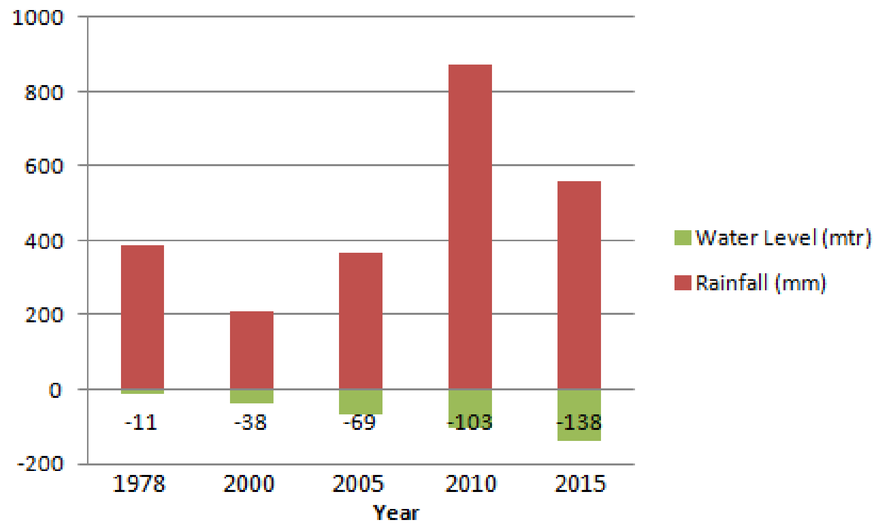

Fig. 5.9 Rainfall Vs SWL Graph for Khambra Village

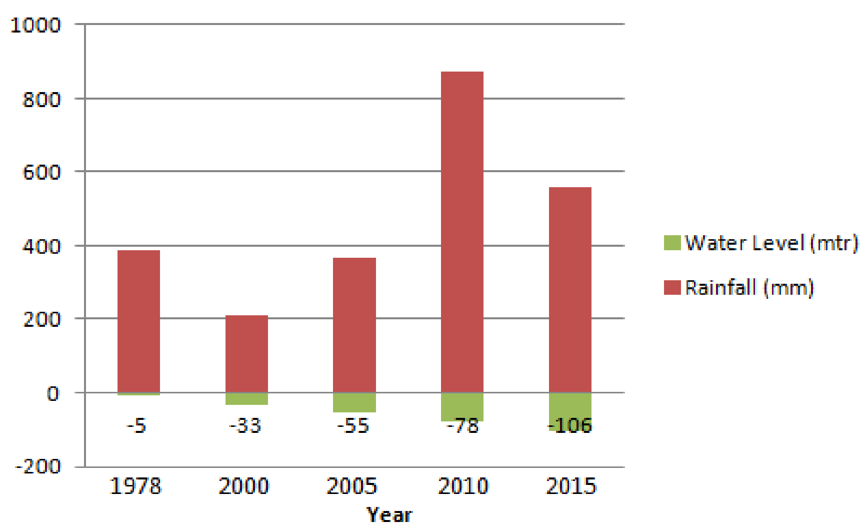

Fig. 5.10 Rainfall Vs SWL Graph for Vidi Village

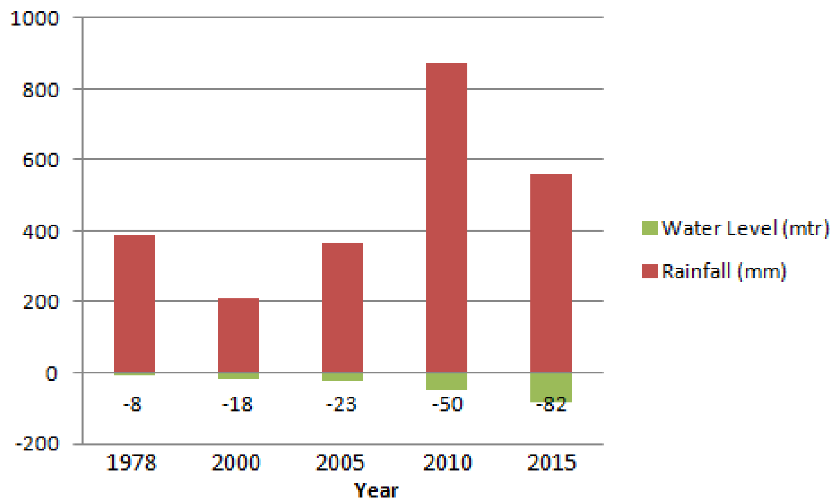

Fig. 5.11 Rainfall Vs SWL Graph for Varsamedi Village

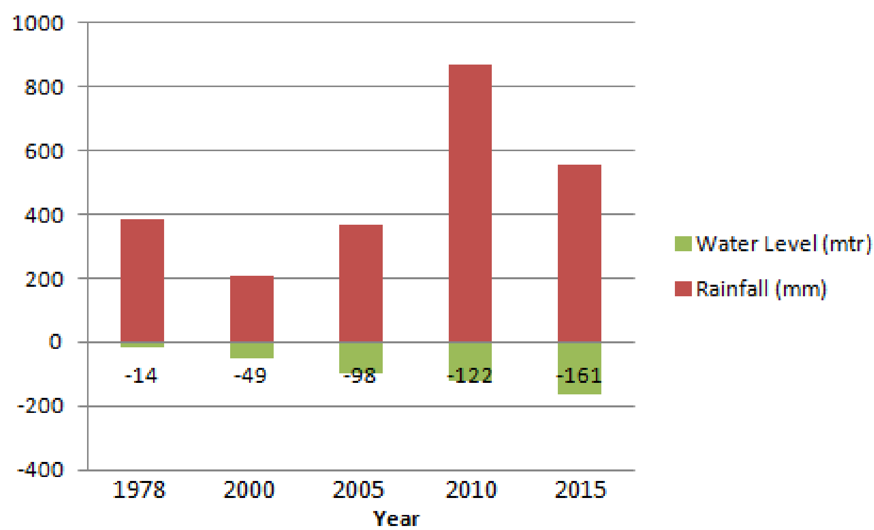

Fig. 5.12 Rainfall Vs SWL Graph for Sapeda Village

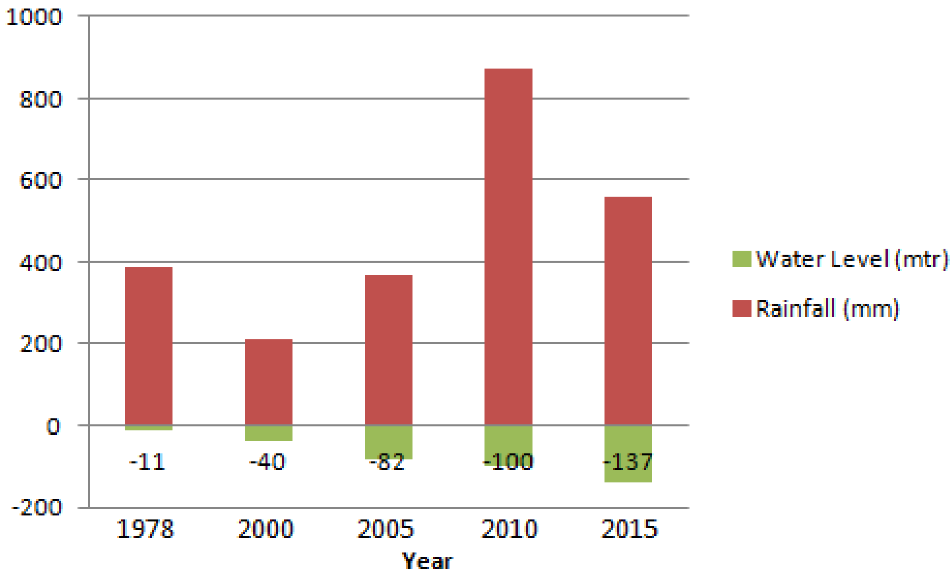

Fig. 5.13 Rainfall Vs SWL Graph for Sinugra Village

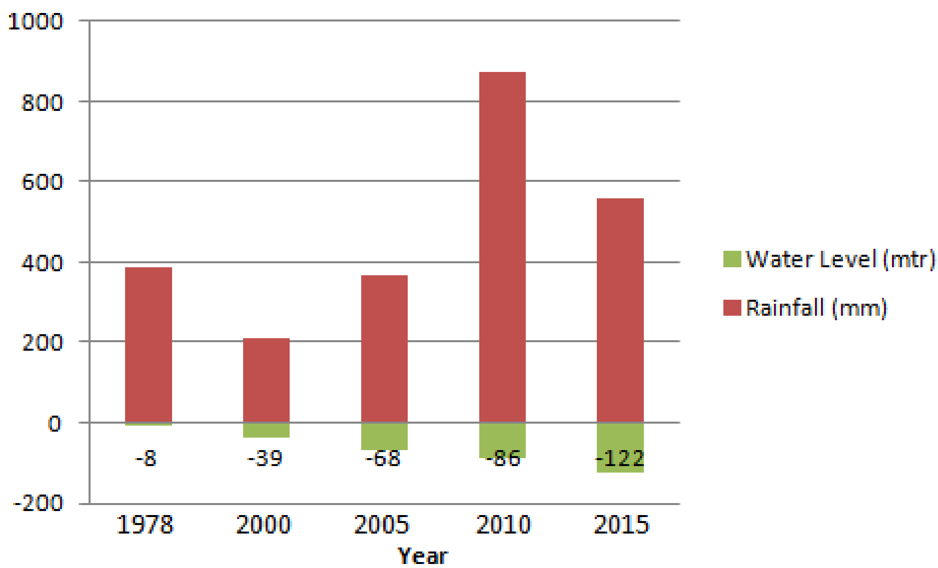

Fig. 5.14 Rainfall Vs SWL Graph for Anjar town

5.1.4 Rainfall Pattern Analysis for Bhuj

The average annual rainfall for Bhuj taluka is 348 mm. During period 1878 to 2015 the highest annual rainfall amounting to 1288 mm for Bhuj taluka occurred in the year 2010. Fig. 5.15 shows the bar graphs and 5 year moving mean graphs for Bhuj taluka. Bhuj taluka has experienced more number of years with less than average annual rainfall as compared to the Kutch district

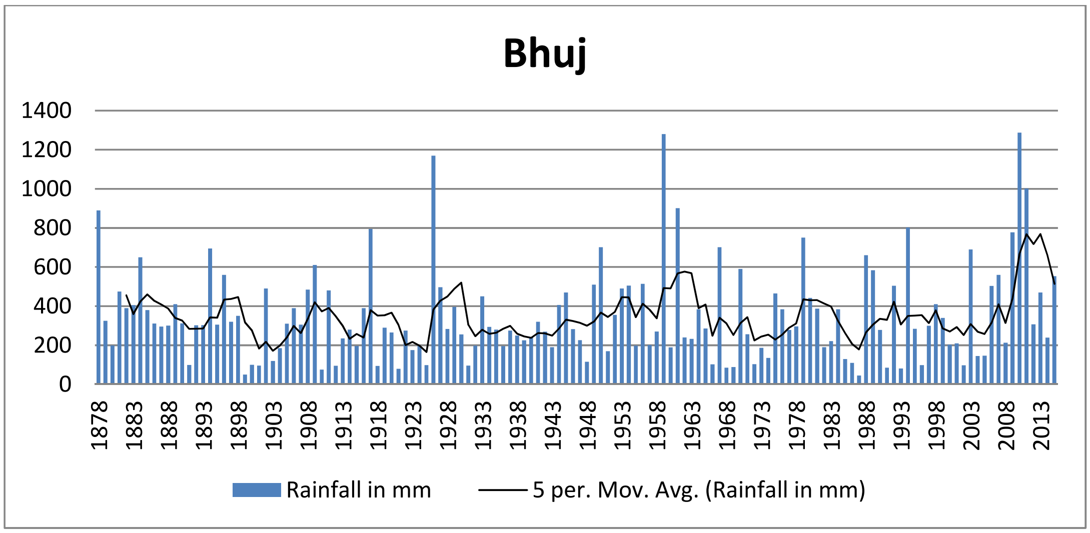

Fig. 5.15 Annual Rainfall Pattern for Bhuj Taluka and 5 Years Moving Average

5.1.4.1 Probability Analysis for Bhuj

Based on the above data, the probabilities of occurrence of different magnitudes of rainfall have been found out for Bhuj taluka. The probability for rainfall occurring between 251 to 300 mm for Bhuj taluka is maximum while probability of the rainfall deviating from the average annual value by very high range i.e. below 50 mm or above 800 mm is very less. Fig. 5.16 shows graph of the probability of occurrence of rainfall for Bhuj taluka.

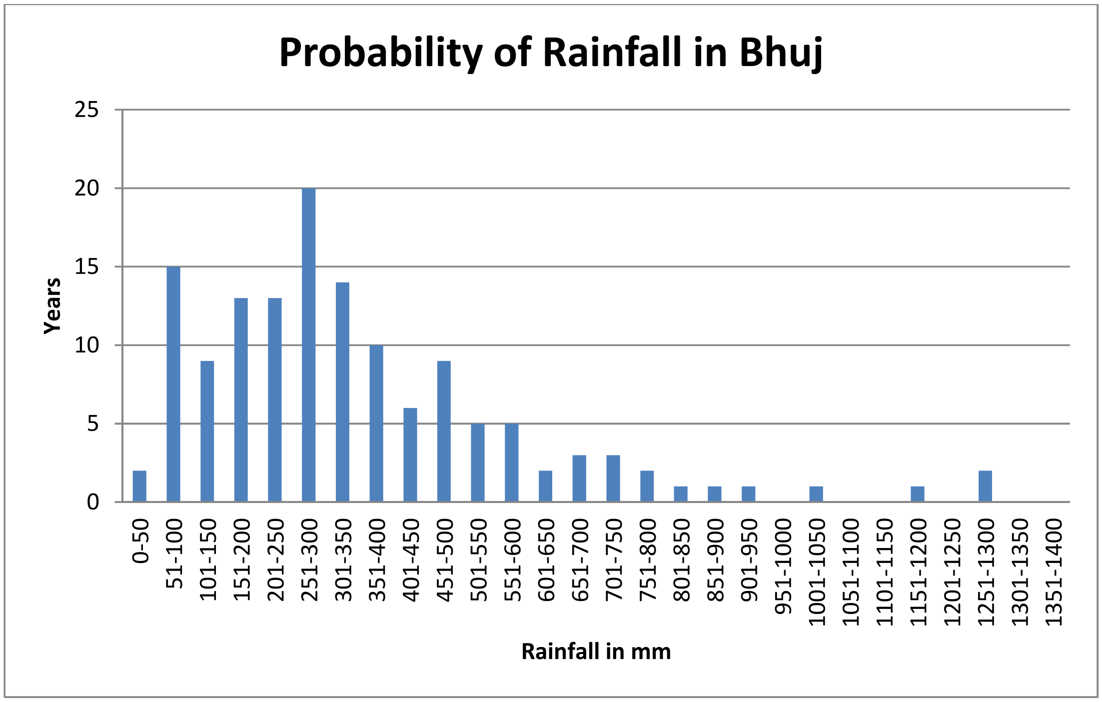

Fig. 5.16 Graph of Probability of Occurrence (Bhuj)

Table 5.6 Probability of Occurrence (Bhuj)

Rainfall (mm)	Probability of Occurrence	Percentages
0-50	2	1.45%
51-100	15	10.87%
101-150	9	6.52%
151-200	13	9.42%
201-250	13	9.42%
251-300	20	14.49%
301-350	14	10.14%
351-400	10	7.25%
401-450	6	4.35%
451-500	9	6.52%

501-550	5	3.62%
551-600	5	3.62%
601-650	2	1.45%
651-700	3	2.17%
701-750	3	2.17%
751-800	2	1.45%
801-850	1	0.72%
851-900	1	0.72%
901-950	1	0.72%
951-1000	0	0.00%
1001-1050	1	0.72%
1051-1100	0	0.00%
1100-1150	0	0.00%
1150-1200	1	0.72%
1200-1250	0	0.00%
1250-1300	2	1.45%
Grand Total	**138**	**100.00%**

5.1.4.2 Distribution of Rainfall for Bhuj

During the study period of 138 years, the Bhuj taluka has experienced 26 drought years, 46 rainfall deficit years, 24 years having normal rainfall, 15 years having above average rainfall and 27 years having surplus rainfall. The results for the analysis have been tabulated in Table 5.8. Fig. 5.17 shows the distribution of rainfall pattern over a period of 138 years for Bhuj Taluka.

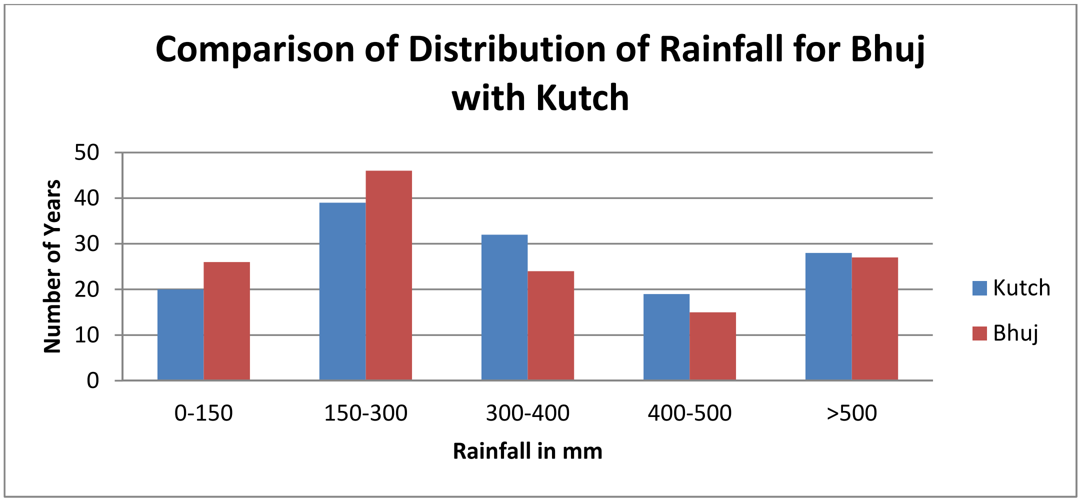

Fig. 5.17 Comparison of Distribution of Rainfall for Bhuj Taluka with Kutch District

Table 5.7 Rainfall in Bhuj

	Draught Years	Rainfall Deficit Years	Normal Rainfall	Above Average Rainfall	Surplus Rainfall
Rainfall in mm	0-150	150-300	300-400	400-500	>500
Occurrences of Events	26	46	24	15	27
Percentage	18.84%	33.33%	17.39%	10.87%	19.56%

The analysis shows that of the total study period of 138 years, there have been 26 (18.84 %) drought years, 46 (33.33 %) rainfall deficit years, 24 (17.39 %) years having normal rainfall, 15 (10.87 %) years having above average rainfall and 27 (19.56 %) years having surplus rainfall.

Table 5.8 Distribution of Rainfall for Bhuj Taluka

Drought years	Rainfall Deficit years		Normal Rainfall Years	Above Average rainfall years	Surplus Rainfall Years
<150	151-300		301-400	401-500	>500
1891	1880	1946	1879	1881	1878
1899	1887	1947	1882	1883	1884
1900	1904	1951	1885	1889	1894
1901	1913	1955	1886	1902	1896
1903	1914	1957	1888	1908	1909
1910	1915	1958	1890	1911	1917
1912	1919	1960	1892	1927	1926
1918	1920	1962	1893	1933	1949
1921	1922	1963	1895	1944	1950
1925	1923	1965	1897	1945	1954
1931	1924	1971	1898	1953	1956
1948	1928	1973	1905	1975	1959
1966	1930	1977	1906	1980	1961
1968	1932	1978	1907	1998	1967
1969	1934	1982	1916	2013	1970
1972	1935	1983	1929		1979
1974	1936	1990	1941		1988
1985	1937	1995	1952		1989
1986	1938	1997	1964		1992
1987	1939	2000	1976		1994

1991	1940 2001	1981		2003
1993	1942 2008	1984		2006
1996	1943 2014	1999		2007
2002		2012		2009
2004				2010
2005				2011
				2015
Total 26 Years	Total 46 Years	Total 24 Years	Total 15 Years	Total 27 Years

5.1.4.3 Talukawise comparison of rainfall with water level (Bhuj)

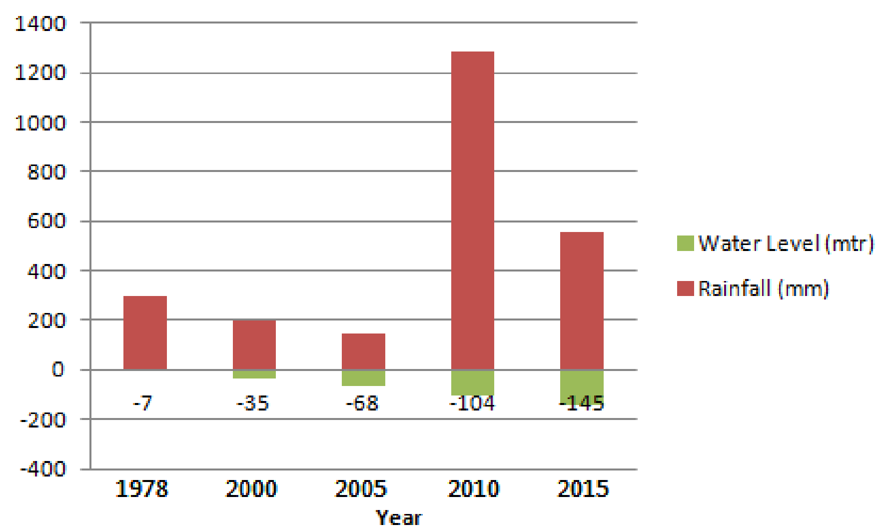

Fig. 5.18 Rainfall Vs SWL Graph Gandher Village, Bhuj

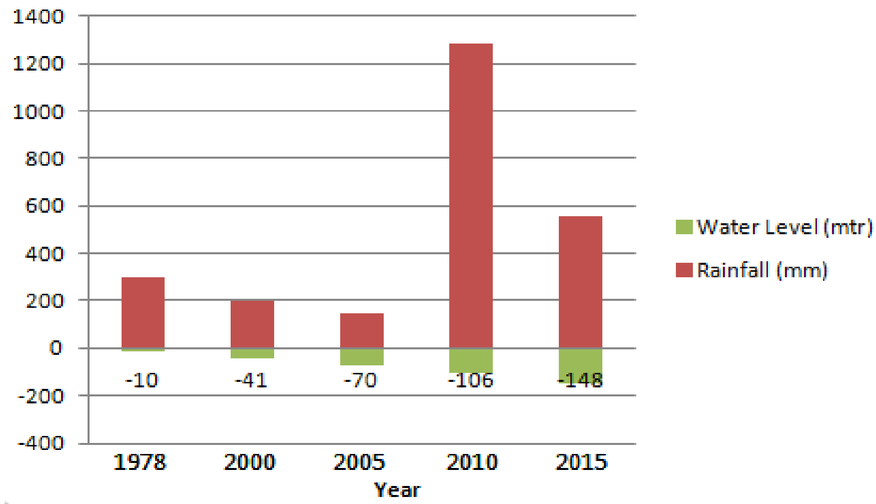

Fig. 5.19 Rainfall Vs SWL Graph for Chubdak Village, Bhuj

5.1.5 Rainfall Pattern Analysis for Gandhidham

The average annual rainfall for Gandhidham taluka is 414.44 mm based on available 18 years data. During period 1998 to 2013 the highest annual rainfall amounting to 852 mm which occurred in the year 2003. Fig. 5.20 shows the bar graphs and 5 year moving mean graphs for Gandhidham taluka.

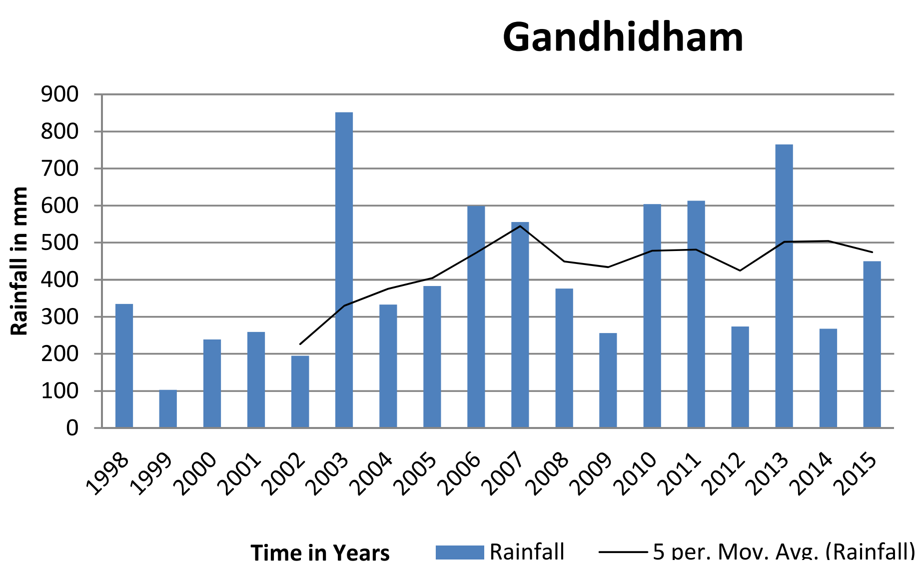

Fig. 5.20 Annual Rainfall Pattern for Gandhidham Taluka and 5 Years Moving Average

5.1.5.1 Probability Analysis for Gandhidham

Based on the above data, the probabilities of occurrence of different magnitudes of rainfall have been found out for Gandhidham taluka. The probability for rainfall occurring between 251 to 300 mm for Gandhidham taluka is maximum. Fig. 5.21 shows the probability of occurrence of rainfall for Gandhidham taluka.

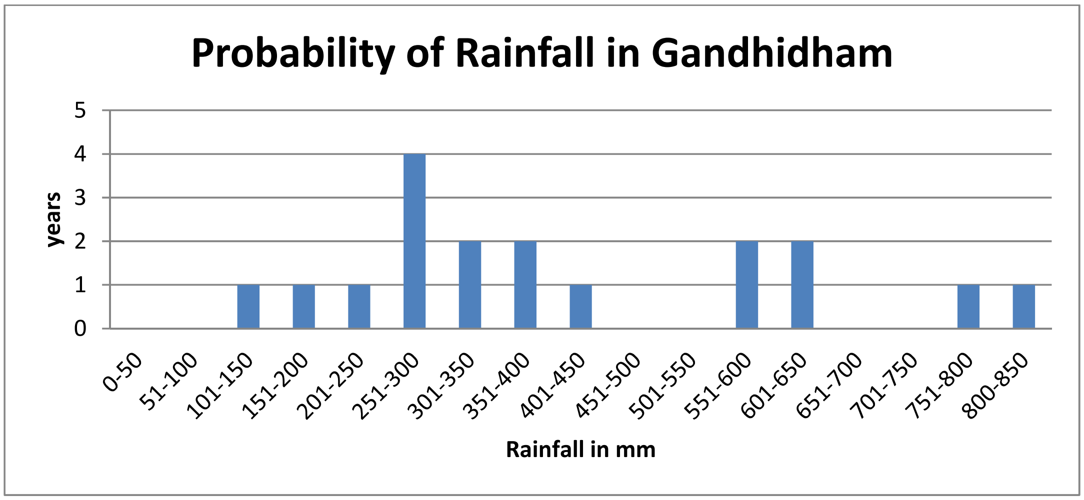

Fig. 5.21 Graph of Probability of Occurrence (Gandhidham)

Table 5.9 Probability of Occurrence (Gandhidham)

Rainfall	Probability of Occurance	Percentage
0-50	0	0.00%
51-100	0	0.00%
101-150	1	6.25%
151-200	1	6.25%
201-250	1	6.25%
251-300	4	25.00%
301-350	2	12.50%
351-400	2	12.50%

401-450	1	6.25%
451-500	0	0.00%
501-550	0	0.00%
551-600	2	12.50%
601-650	2	12.50%
651-700	0	0.00%
701-750	0	0.00%
751-800	1	6.25%
800-850	1	6.25%
Total	18	112.50%

5.1.5.2 Distribution of Rainfall in Gandhidham

The analysis shows that of the total study period of 18 years, there have been 1 (5.56 %) drought years, 6 (33.33 %) rainfall deficit years, 4 (22.22 %) years having normal rainfall, 1 (5.56%) years having above average rainfall and 6 (33.33 %) years having surplus rainfall.

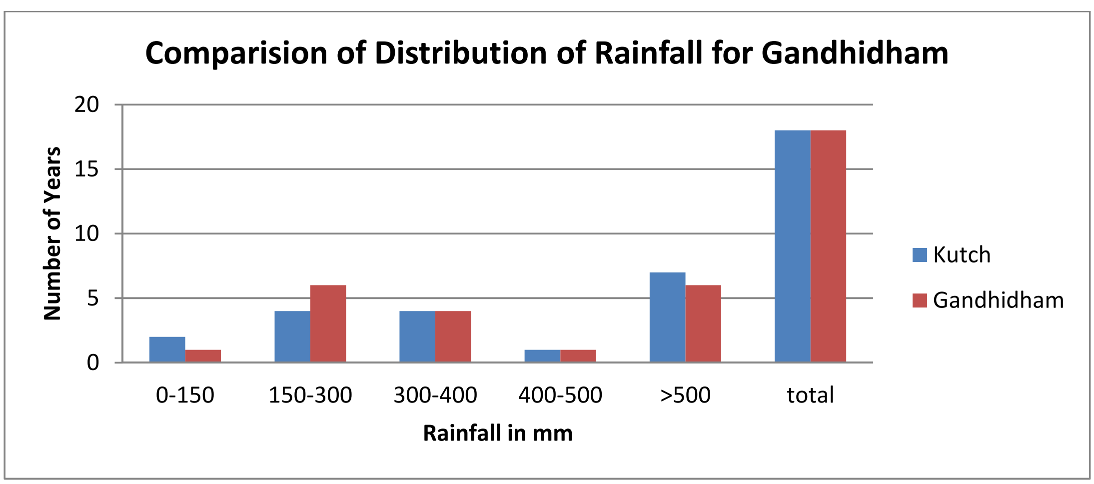

Fig. 5.22 Comparison of Distribution of Rainfall for Gandhidham Taluka with Kutch District for last 18 years

Table 5.10 Rainfall in Gandhidham

	Draught Years	Rainfall Deficit Years	Normal Rainfall	Above Average Rainfall	Surplus Rainfall
Rainfall in mm	0-150	150-300	300-400	400-500	>500
Occurrences of Events	1	6	4	1	6
Percentage	5.56%	33.33%	22.22%	5.56%	33.33%

Table 5.11 Distribution of Rainfall for Gandhidham Taluka

Drought years	Rainfall Deficit years	Normal Rainfall Years	Above Average rainfall years	Surplus Rainfall Years
<150	151-300	301-400	401-500	>500
1999	2000 2001 2002 2009 2012 2014	1998 2004 2005 2008	2015	2003 2006 2007 2010 2011 2013
Total 1 Years	Total 6 Years	Total 4 Years	Total 1 Years	Total 6 Years

5.1.5.3 Talukawise comparison of rainfall with water level (Gandhidham)

Since there are no deep tubewells with desirable or permissible water quality is available in the Gandhidham taluka due to its close proximity to the gulf of kutch, this analysis is not done for Gandhidham.

5.1.6 Summary

5.1.6.1 Anjar

The rainfall is Anjar is very erratic. From the results it can be said that there were 21 drought periods in Anjar. There were no drought periods after 2002. There were 48 rainfall deficit year and 6 after year 2000. There were 22 normal rainfall years and only one after 2000. There 14 above average rainfall year with 2 after 2000. There were 33 total surplus rainfall years and 4 after 2000.

From this we can say that after the year 2000 there was one year of normal rain while two above average and four surplus rainfall years giving a total of 7 years of good amount of rainfall out of the total of last 16 years i.e. 2000 – 2015. This is almost 50 % of the total period.

5.1.6.2 Bhuj

There were 26 drought periods in Bhuj which counts to 18.84% of total years under consideration and none after 2005. There were 46 (33.33%) of rainfall deficit year and 24 (17.39%) of normal rainfall years. The total rainfall years above the normal rainfall years are 42 or 30.43 % out of which 10.87 % was above the average rainfall while 27

(19.56%) was surplus rainfall years. It is worth noting that there were 6 surplus rainfall years (2006, 2007, 2009, 2010, 2011, 2015) in the last decade e.g. after 2005

5.1.6.3 Gandhidham

The rainfall data for Gandhidham was available only from 1998 i.e. for the period of 18 years. Out of these 18 years there was 1 drought year i.e. in 1999, 6 rainfall deficit years, 4 normal rainfall years, 1 above average rainfall year and 6 surplus rainfall years (33.33%) out of which 5 were in the last decade i.e. after 2005.

This analysis was helpful to understand the trend of rainfall in study area and its impact on the groundwater regime. This data was later correlated with the SWL data to understand the changes in the water level fluctuation with respect to the total precipitation during a particular year.

SWL of five different years was considered for correlation with the rainfall data with a time gap of 5 years with an exceptional year of 1978. These years were 1978, 2000, 2005, 2010 and 2015. The tubewells for the observation were selected judicially in such a way that atleast one falls in each village covered under the study area.

From the observations it can be said that even though there was more than 50% of good rainfall years (including normal rainfall years) observed in Anjar taluka and around 48 % in Bhuj taluka out of total 138 years and more than 60% in Gandhidham taluka out of total 18 years, there was a consistent fall in the water levels observed at almost all the villages of study area. The drop of water level can be generalized to 25-40 meters every 5 years. This means that every year there is a depliction of nearly 5 to 8 meters in the water level of study area. From this it can be said that there is 0.4 to 0.6 mtrs or 1.5 to 2.5 feets of drop in the water level every month. This can be considered as a critical issue which needs to be addressed at the earliest.

5.1.7 Conclusion:

From this we can conclude that there is a depliction in the water level within the study area even when there is a normal rainfall or a surplus rainfall for few years. The reason for this can be understood by the daily rainfall patterns studies. From the data collected it was observed that the most of the rain in study area occurs only with in few days of the total monsoon seasons. Hence there are more chances of rainfall runoff rather than a recharge if this rain water is not properly managed.

The requirement for the groundwater recharge can be clearly understood from the above analysis.

5.2 RAINFALL – RUNOFF MODELLING

5.2.1 Introduction

Kutch district has been subject to many land cover change since 2000. Due to urbanization many different categories of landuse like agricultural activities, human settlements and industries, wastelands, forest lands and other land uses have changed over the period of time. Urbanization tends to decrease groundwater recharge and increase rainfall runoff. With changes in the socio-economic activities alteration of natural land cover is inevitable.

This study aims to analyze the impact of these changes in land cover change on runoff between 2000 and 2015 in sakar and sang catchment area. Kutch district has a complex geo-morphology and lots of variation in soil surface which are directly related with runoff. Due to the presence of various hills / rocky terrain some areas will have higher slope and hence higher rate of runoff then other areas. Over all there is a gradual slope towards the sea side since the study area is closer to the coast. Higher slopes have higher solar radiation that lead to higher evapotranspiration rates and therefore lower available vegetation, moisture and lower organic matter in the soil. (J R Julius, 2013)

SCS curve number method is one of the widely used method for surface runoff among several other methods. Determination of CN depends on the watershed's soil and cover conditions, which the model represents as hydrologic soil group, cover type, treatment, and hydrologic condition. This study attempts to make use of GIS to predict the runoff based on SCS curve number method developed by National Resources Conservation Service (NRSC).

5.2.2 Factors Affecting Runoff

5.2.2.1 Rainfall

Rainfall is the major component of the hydrologic cycle and is the primary source of runoff (Beven, 2001). These data are usually collected using rain gauges, and therefore they are point precipitation data. However, the application of a single rain gauge as precipitation input carries lots of uncertainties regarding estimation of runoff (Faur`es et al., 1995 and Chaubey et al., 1999). The annual rainfall data was obtained for all talukas from the State Water Data Centre, Gandhinagar for a period of 138 years from 1878 to 2015. Daily rainfall data was obtained for the period of 1989 to 2015. An average of 449.7 mm of rainfall was calculated based othe these available data.

5.2.2.2 Watershed Area

The area of watershed was determined using a toposheet and available SRTM/ASTER data and available satellite images from google earth and Landsat images from USGS website. This followed by field verification to an extent possible for locating manmade features that might have taken a role to divert the flow of water

5.2.2.3 Soils

Soil texture is very important for hydrologic soil group determination. Soils were classified according to recommendations of Natural Resource Conservation Service into four hydrologic soil groups A, B, C and D based on the infiltration characteristics where A generally has the lowest runoff potential and D has the highest. In general, rainfall runoff is lower when there is higher infiltration rate which mostly found in the coarse-textured soils like sand. Fine-textured soils or clay have a higher rate of runoff. Infilterometer was also used to determine the infilteration rate of the soils in different area with different soil types.

5.2.3 Methodology

5.2.3.1 Infiltration Rate Methodology:

Infiltration is a process of water entering into the soil. The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores. (NRCS, 1998)

At first our Experimental setup was placed in the barren area we measured the infiltration depth for 2, 3, 5, 10 and 20 mins. The table for infilteration rate test sheet is shown in table 5.12. A general methodology for the double ring infilterometer test is presented below.

It consists of thin metal cylinder with diameter of 15cm and 30cm and the 60cm long and this cylinders were driven into ground and 10-12cm of the cylinder must be above the ground level. And water is poured from the top and we should note the volume of water added to the ring to find the Incremental Infiltration velocity. We should also note the infiltrated water depth for 5,10,20mins until we get the constant infiltration depth A graduated jar was used to add water and scale was used to measure the depth of water infiltrated. To overcome the results of single ring here we use a set of concentric rings with same length are used.

Steps:

Step 1: Hammer the 30 cm diameter ring at least 15 cm into the soil. Use the timber to protect the ring from damage during hammering. Keep the side of the ring vertical and drive the measuring rod into the soil so that approximately 12 cm is left above the ground.

Step 2: Hammer the 60 cm ring into the soil or construct an earth bund around the 30 cm ring to the same height as the ring and place the hessian inside the infiltrometer to protect the soil surface when pouring in the water (Fig. 5.23).

Step 3: Start the test by pouring water into the ring until the depth is approximately 70-100 mm. At the same time, add water to the space between the two rings or the ring and the bund to the same depth. Do this quickly.

The water in the bund or within the two rings is to prevent a lateral spread of water from the infiltrometer.

Step 4: Record the clock time when the test begins and note the water level on the measuring rod.

Step 5: After 1-2 minutes, record the drop in water level in the inner ring on the measuring rod and add water to bring the level back to approximately the original level at the start of the test. Record the water level. Maintain the water level outside the ring similar to that inside.

Step 6: Continue the test until the drop in water level is the same over the same time interval. Take readings frequently (e.g. every 1-2 minutes) at the beginning of the test, but extend the interval between readings as the time goes on (e.g. every 20-30 minutes).

Note that at least two infiltration tests should be carried out at a site to make sure that the correct results are obtained.

Double-Ring Infiltrometer

Double-ring infiltrometer is well known technique for measuring or estimating the infiltration rate of soils. Double ring infiltrometer are developed in reaction to fact that single-ring infiltrometer tends to estimate the over infiltration rates. This has been ascribed the fact that liquid in the cylinder is not purely vertical but it also diverges laterally. Double ring infiltrometer understate the standard errors affiliated with the single-ring infiltrometer because the water in the outer ring forces vertical infiltration of water inside the inner ring. We should take care of a ring while it is driving into the ground there may be chance of having hapless connections between the thin wall of a ring and soil.

A typical Double-ring infiltrometer consists of 45cm diameter inner ring and 60cm diameter outer ring. Whereas there are two techniques used in double-ring one is constant head method and the other is falling head method. In constant head method water is systematically added to both the inner and outer rings. The volume of water wanted to maintain the constant level of inner-ring is measured. For measuring the depth of water in ring we need hook gage, steel tape or scale.

Fig. 5.23 Double-Ring Infiltrometer (Field Test)

Table 5.12 Field Log of Infilteration rate (Sample)

Reading on the clock (hr:min)	Time Difference (min)	Cumulative time(min)	Water level reading (mm)		Infilteration (mm)	Infilteration rate(mm/min)	Infilteration rate (mm/hr)	Cumulative infilteration rate (mm)
	Start time = 0	Start time = 0	Before filling	After filling				
08: 02	2	2	90	103	13	6.5	390	13
08: 05	3	5	103	116	13	4.3	258	26
08: 10	5	10	116	130	14	2.8	168	40
08: 20	10	20	130	158	28	2.8	168	68
08: 30	10	30	158	188	30	3.0	180	98
08: 40	10	40	188	204	16	1.6	96	114
09: 00	20	60	204	228	24	1.2	72	138
09: 20	20	80	228	253	25	1.25	75	163
09: 40	20	100	253	278	25	1.25	75	188
10: 00	20	120	278	293	15	0.75	45	203
10: 20	20	140	293	308	15	0.75	45	218

Details of Table 5.12

- Column 1 indicates the readings on the clock in hours, minutes and seconds.
- Column 2 indicates the difference in time (in minutes) between two readings.
- Column 3 indicates the cumulative time (in minutes); this is the time (in minutes) since the test started.
- Column 4 indicates the water level readings (in mm) on the measuring rod: before and after filling (see step 5).
- Column 5 indicates the infiltration (in mm) between two readings; this is the difference in the measured water levels between two readings. How the infiltration is calculated is indicated in brackets.
- Column 6 indicates the infiltration rate (in mm/minute); this is the infiltration (in mm; column 5) divided by the difference in time (in minutes, column 2).
- Column 7 indicates the infiltration rate (in mm/hour); this is the infiltration rate (in mm/minute, column 6) multiplied by 60 (60 minutes in 1 hour).
- Column 8 indicates the cumulative infiltration (in mm); this is the infiltration (in mm) since the test started. How the cumulative infiltration is calculated is indicated in brackets.

5.2.3.2 RAINFALL RUNOFF (SCS RUNOFF CURVE NUMBER METHOD)

The SCS Curve Number method is used to relate a calculated Runoff Curve Number (CN) to runoff, responsible for initial abstraction losses and infiltration rates of soils. The SCS Runoff Curve Number (CN) method is applied by using the

SCS runoff equation

The Equation is

Q= (P-Ia)2 / (P-Ia)+S [Eq.1]

where,

Q = runoff,

P = rainfall,

S = potential maximum retention after runoff starts, and

Ia = initial abstraction.

(Ia) means all the losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, Ia was found to be approximated by the following empirical equation:

Ia = 0.2S [Eq. 2]

By removing Ia as an independent parameter, this approximation allows the use of a combination of S and P to produce a unique runoff amount.

Substituting equation [Eq.2] into [Eq.1] gives

Q = (P-0.2S) 2 / (P+0.8S) [Eq. 3]

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by

S = (1000 / CN) - 10 [Eq.4]

5.2.4 Soils:

Soils are classified into hydrologic soil groups (HSGs) as an indicator of infiltration rate. The HSGs are A, B, C and D, with A characterized by the highest infiltration rate and D with the lowest, as defined in the USDA Manual, Urban Hydrology for Small Watersheds, Technical Release 55 (TR – 55) (USDA NRCS 1986). Both the HSG and land cover are used in deciding the CN value. Table 5.14 for summary of soils and associated HSGs typically found in the study area.

Table 5.13 Standard Hydrologic Soil Group (HSG)

Soil Name	**HSG**
Clay	D
Clay loam	D
Loam	A
Loamy sand	A
Sand	A
Sandy clay	C
Sandy clay loam	C
Sandy loam	A

Table 5.14 Hydrologic Soil Group (HSG) for Soils in the study area

Soil Type	Description (Brief)	Group Code
Typic Camborthids with Typic Calciorthids	Moderately deep, excessively drained, coarse loamy soils on very gently sloping pediment	A
Typic Torripsamments with Typic Calciorthids	Moderately deep, excessively drained, calcareous, sandy soils on very gently sloping pediment (with isolated hillocks) with moderate erosion	B
Lithic Torriorthents with Lithic Camborthids	shallow, excessively drained, sandy soils on undulating pediment (with isolated hillocks) with severe erosion and moderate stoniness	B
Lithic Torriorthents with Lithic Camborthids	shallow, excessively drained, sandy soils on undulating pediment (with isolated hillocks) with severe erosion and moderate stoniness	B
Ustochreptic Camborthids with Typic Calciorthids	Moderately deep, well drained, loamy soils on very gently sloping arid plain with moderate erosion	B
Typic Camborthids with Lithic Camborthids	Moderately shallow, well drained, fine loamy soils on undulating pediment (with isolated hillocks) with moderate erosion	C
Typic Calciorthids with Ustertic Camborthids (Clay Dominated)	Moderately deep, well drained, fine loamy soils on very gently sloping arid plain with slight erosion and moderate salinity	C
Lithic Torriorthents with Typic Camborthids (Hilly Terrain)	Shallow, well drained, loamy soils on very gently sloping elongated ridges with moderate erosion and moderate stoniness	D

In areas where the soil profiles are disturbed, the HSG should be adjusted up one level (i.e., from A to B, B to C, or C to D), unless reestablishing the predevelopment soil profile.

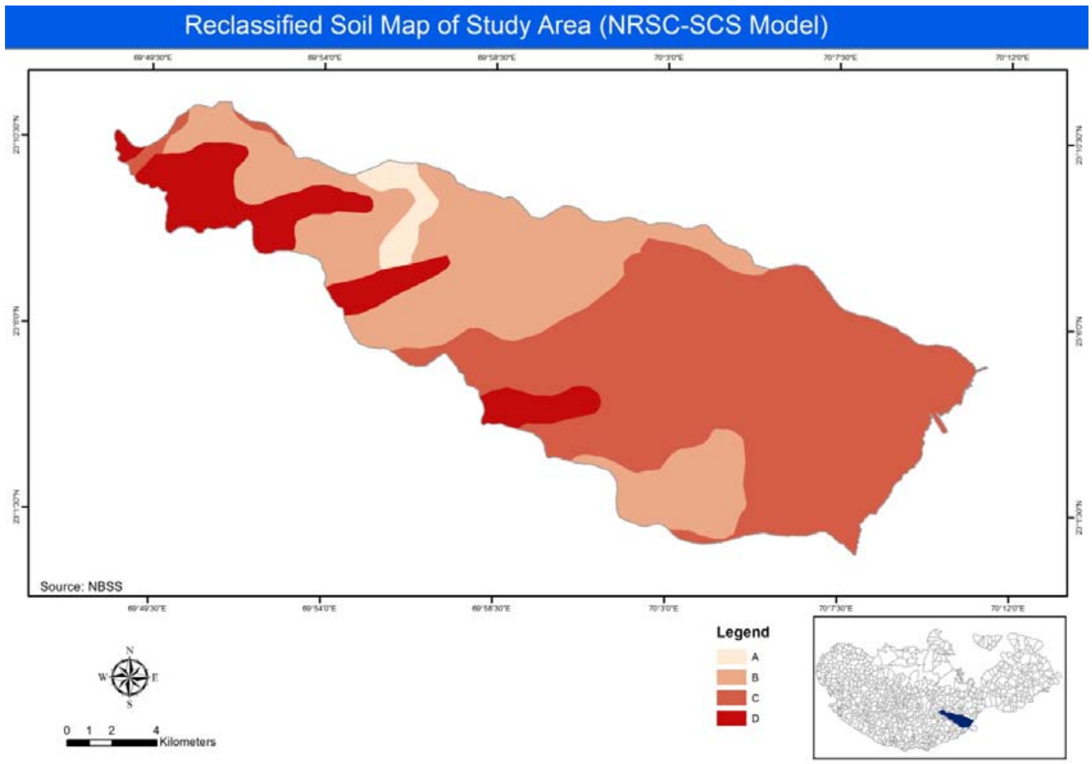

Fig. 5.24 Reclassified Soil Map of Study Area

5.2.5 Land Cover and Land Use

The determination of the CN value for a watershed is a function of soil characteristics, hydrologic condition and land cover or land use. CN values for undeveloped and developed areas are given in Tables 5.16 and 5.17 respectively.

For watersheds characterized by multiple soil types or land uses, an area weighted CN is calculated which is represented in table 5.15.

Table 5.15 Runoff Curve Number (CN) Values for Study Area

Legends (Landuse)	Soil Group	SCS Curve Number	Area (SqKm)
Cultivated Land	A	67	1.630
Cultivated Land	B	78	32.554
Cultivated Land	C	85	8.114
Cultivated Land	D	89	1.888
Floodplains	C	91	0.044
Floodplains	D	94	0.016
Industries	B	88	0.378
Industries	C	91	17.638
National HW	B	98	0.060
National HW	C	98	0.573
Quarry	B	98	0.006
Quarry	C	98	3.963
Quarry	D	98	0.519
River	A	77	0.243
River	B	86	1.445
River	C	91	2.531
River	D	94	0.178
Roads	A	98	0.016
Roads	B	98	0.414
Roads	C	98	1.307
Roads	D	98	0.082
Rocky Terrain	A	98	0.991
Rocky Terrain	B	98	7.778
Rocky Terrain	C	98	3.400
Rocky Terrain	D	98	18.877

Saline Lands	B	86	0.434
Saline Lands	C	91	3.087
Saline Lands	D	94	0.046
Saltpans	C	91	2.803
Settlements	A	46	0.036
Settlements	B	65	4.686
Settlements	C	77	32.279
Settlements	D	82	0.125
State HW	B	98	0.238
State HW	C	98	0.627
State HW	D	98	0.005
Treeclad Areas	B	60	0.013
Treeclad Areas	C	73	0.033
Treeclad Areas	D	79	0.091
Uncultivated Land	A	76	3.888
Uncultivated Land	B	85	45.700
Uncultivated Land	C	90	51.157
Uncultivated Land	D	93	6.342
Wastelands	A	63	0.513
Wastelands	B	77	12.866
Wastelands	C	85	39.730
Wastelands	D	88	7.602
Waterbodies	A	77	0.023
Waterbodies	B	86	3.691
Waterbodies	C	91	2.593
Waterbodies	D	94	1.001
Grand Total	-	-	324.252

Table 5.16 Runoff Curve Number (CN) Values for Undeveloped Lands

Cover Description	Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	A	B	C	D
Idle lands (not yet developed)				
Pasture, grassland or range-condition forage for grazing : Good condition (ground cover > 75% and only occasionally grazed)	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay	30	58	71	78
Woods-grass (50%-50%) combination, orchard or tree farm Other combinations can be calculated as composite of pasture and woods Good Condition	32	58	72	79
Farmsteads – buildings, lanes, driveways and surrounding lots	59	74	82	86

Source: USDA NRCS (1986)

Table 5.17 Runoff CN Values for Fully Developed & Developing Urban areas

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) :					
Good Condition (grass cover > 75%)		39	61	74	80
Fair Condition (grass cover 50% > 75%)		49	69	79	84
Poor Condition (grass cover less than 50%)		68	79	86	89
Impervious areas : Paved parking lots, roofs, driveways, compacted gravel, etc. (excluding right-of-way)		98	98	98	98
Small open spaces within developments		72	82	87	89
Streets and roads :					
Paved; curbs and storm sewers (including right-of-way)		90	93	95	97
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Urban districts :					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size :					
1/8 acre or less (townhouses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas : Newly graded areas (previous areas only, no vegetation)		77	86	91	94

Source: USDA NRCS (1986)

Landsat multispectral satellite image through a combination of satellite images layers from Google Earth Pro for the year 1990 (not available in Google Earth Pro), 2000 and 2015 was used for preparation of Landuse map which was reclassified based on values for Runoff Curve Number from USDA NRCS (1986). The same has been presented below:

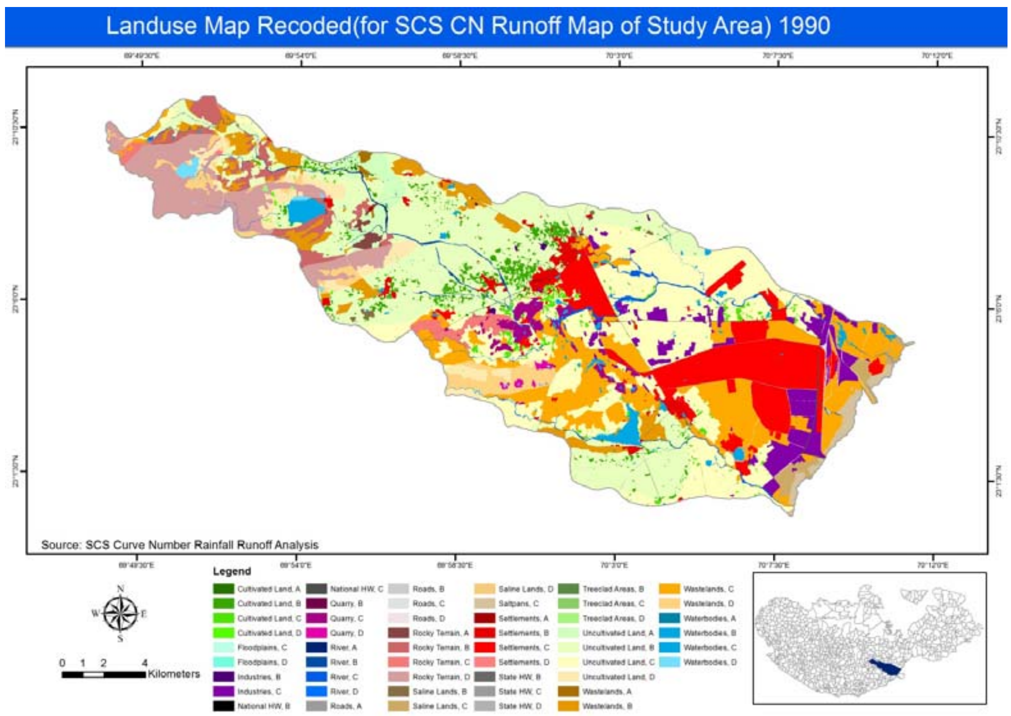

Fig. 5.25Reclassified Land use Map of Study Area (1990)

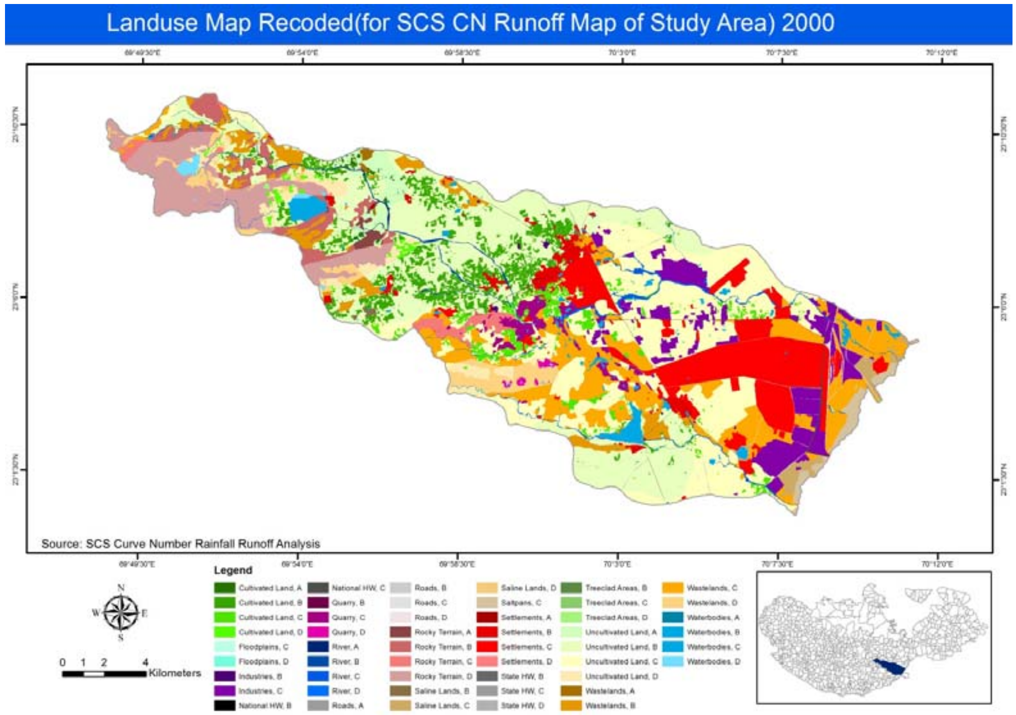

Fig. 5.26 Reclassified Land use Map of Study Area (2000)

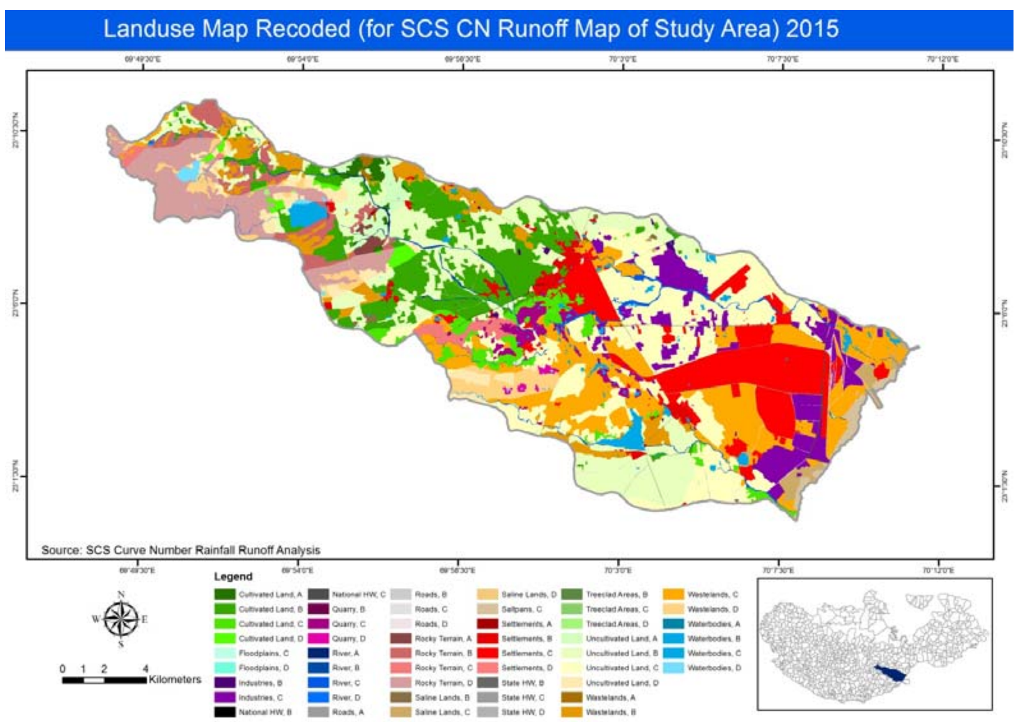

Fig. 5.27 Reclassified Land use Map of Study Area (2015)

5.2.6 Analysis and Result of runoff for the year 1990, 2000 and 2015

Rainfall run-off analysis was conducted for the years 1990, 2000 and 2015. Over these period it was noted that there has been some significant changes in the landuse of the area. The gap of 10 or more years was considered for these analysis which helped us give a better picture to understand the impact of the landuse and meteriological changes on the runoff within the study area. Table 5.18 shows the increase in the area of run-off on the basis of SCS curve number method through the period of time. The same has been represented in the Fig. 5.28, Fig. 5.29 and Fig. 5.30.

Table 5.18 Run-off Based on SCS CN method

Year	**Run-off Based on SCS CN method**		
	<14	**<16**	**<18**
1990	122.105	154.606	47.354
2000	83.0156	192.815	48.235
2015	75.636	198.587	49.843

Urbanization can be one of the major reasons for the increase in rainfall runoff. Due to urbanization and/or industrialization there is increase in the impervious areas like roads, pavement, built-up land etc. which acts as hindrance and does not allow enough infiltration of the water to the ground. Due to this surface water is forced to flow over the surface, which can also create the situation of flooding. This water later gets merged into the streams causing soil erosion or siltation. Hence this increased runoff can also be a reason for lesser groundwater recharge within the study area, thus lowering the water table. This is seen to be directly affecting the agriculture production of the farmers.

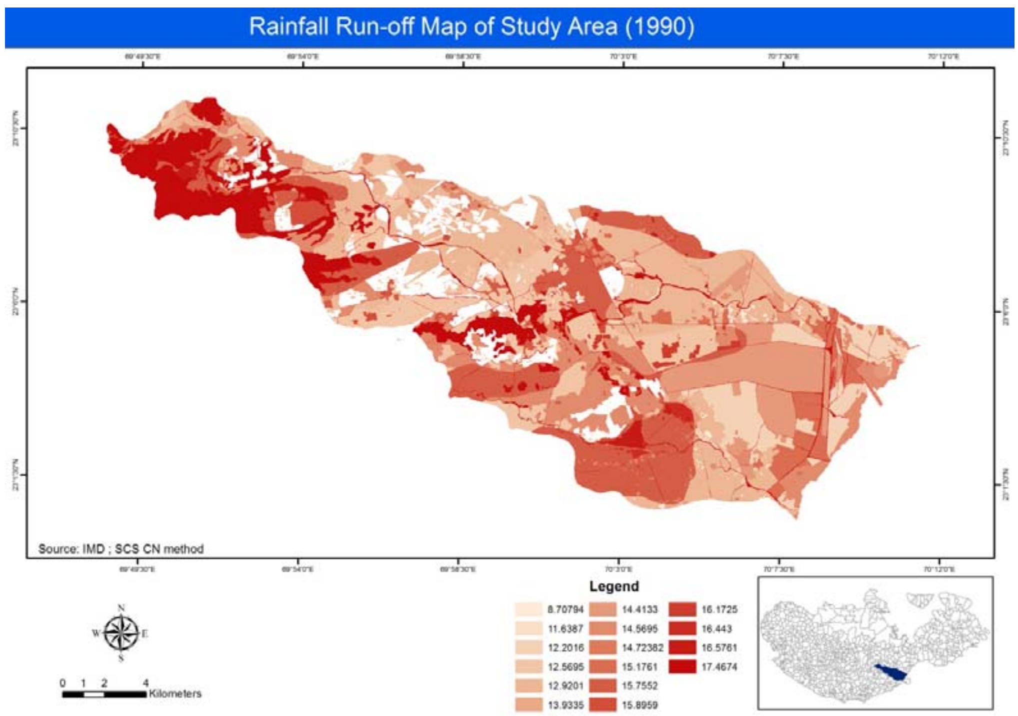

Fig. 5.28 Rainfall Runoff Map of Study Area (1990)

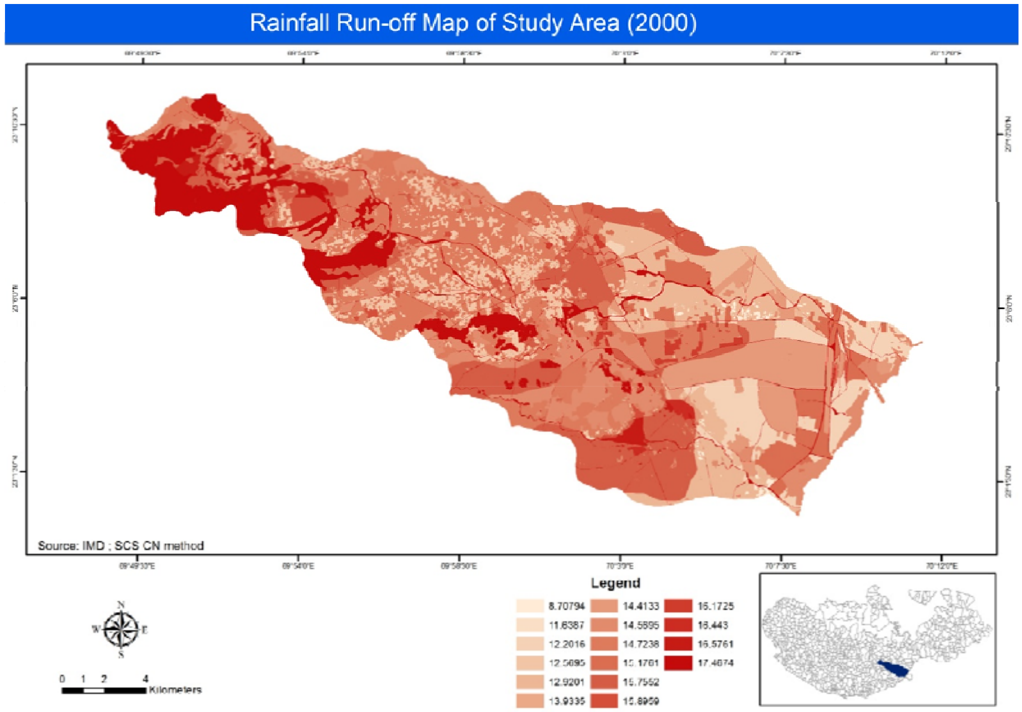

Fig. 5.29 Rainfall Runoff Map of Study Area (2000)

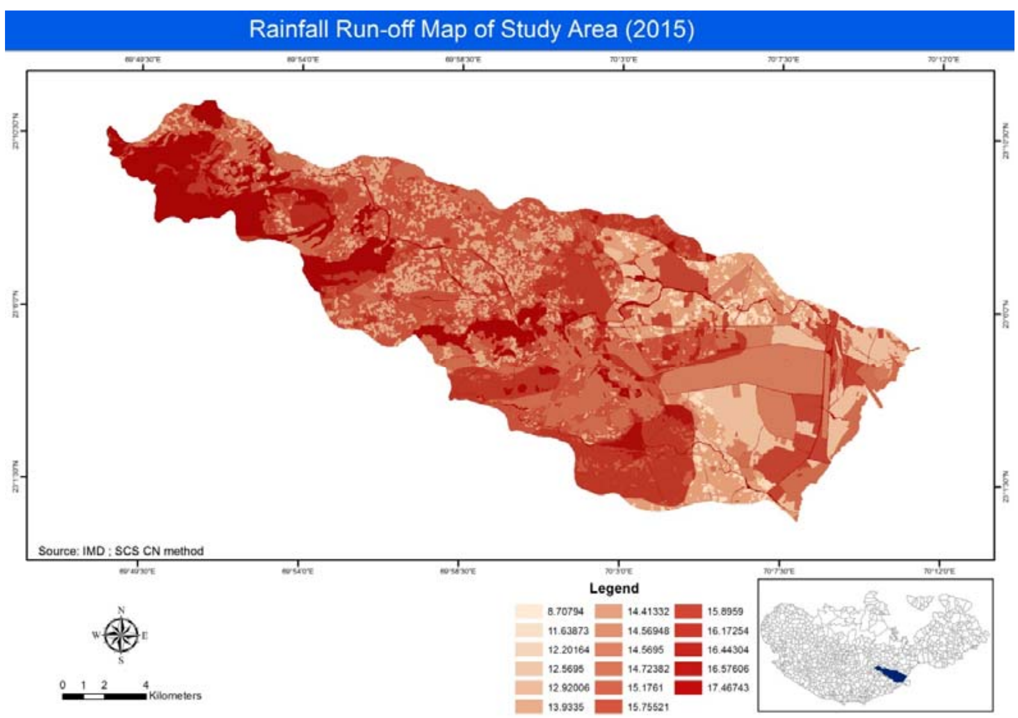

Fig. 5.30 Rainfall Runoff Map of Study Area (2015)

5.2.7 Conclusions:

The SCS-model analysis in the study area based on Hydro-Geological parameters supports in proving that urban development has also contributed to increase in the runoff while acting as a barrier between the surface and the subsurface aquifers lowering the groundwater tables.

In the last few decades, Anjar, Bhuj and Gandhidham taluka has experienced an increase in urban area while reducing the overall agriculture land. Due to this rapid expansion and ignorance of Humans to tackle the future groundwater problems has affected the local water environment. Increased pollution in Water is another problem that can be considered as a byproduct of this urbanization process.

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