7. RESULTS

7.1 RAINFALL ANALYSIS FOR KUTCH

The results of the analysis of annual as well as monthly rainfall data have been shown as follows.

7.1.1 Analysis of Annual Rainfall for the study period of 130 years (1878 to 2007)

7.1.1.1 Rainfall Analysis

Kutch being an arid region, the rainfall pattern is also very erratic, which can be seen from the 130 year rainfall data as shown in Graph 3.1. The maximum rainfall of 996 mm occurs in the year 1959 and the minimum rainfall of 22 mm occurs in the year 1987 for the district. The rainfall ranging from 351 mm to 400 mm occurs 18 times (13.85%) in a span of 130 years. The on an average, the maximum rainfall occurs in Mandvi taluka while the minimum rainfall occurs in Lakhpat taluka.

The results for the rainfall analysis for mean values, minimum values and maximum values of rainfall for the period of 1878 to 2007 have been tabulated in Table 7.1.

Table 7.1 Results of Analysis for Annual Rainfall (mm) for 1878 to 2007

Taluka	Mean	Minimum	Maximum
Anjar	345.83	25.00	1060.00
Bhachau	344.58	0.00	947.00
Bhuj	338.97	5.00	1371.00
Lakhpat	308.52	0.00	1317.00
Mandvi	412.89	3.00	1646.00
Mundra	381.67	0.00	1133.00
Nakhatrana	346.30	0.00	1126.00
Naliya	330.35	0.00	1445.00
Rapar	368.20	2.00	1235.00

7.1.1.2 Results of Rainfall Distribution Analysis (1878 to 2007)

The results of the analysis for rainfall distribution shows that in a span of 130 years, all the talukas have maximum number of years which are rainfall deficit having rainfall values between 151 to 300mm. Thus the percentage distribution of the year being a rainfall deficit year for all the talukas is maximum. The percentage distribution of the number of drought years, number of years with rainfall deficit, the number of years with normal rainfall, the number of years with above average rainfall and the number of years with surplus rainfall over the span of 130 years has been tabulated in Table 7.2.

Table 7.2 Results of Rainfall (mm) Distribution Analysis for 1878 to 2007

Taluka	Drought years	Rainfall deficit years	Normal Rainfall years	Above average rainfall years	Surplus rainfall years
Rainfall in mm	<150	151-300	300-400	400-500	> 500
Bhuj	19.23	33.85	17.69	12.31	16.92
Mandvi	16.15	26.92	11.54	10.77	34.62
Anjar	16.15	34.62	16.92	10.00	22.31
Rapar	12.31	34.62	16.15	11.54	25.38
Naliya	23.85	35.38	10.77	10.77	19.23
Lakhpat	30.00	26.92	10.00	13.08	20.00
Bhachau	16.92	27.69	24.62	7.69	23.08
Mundra	19.23	22.31	16.15	16.92	25.38
Nakhatrana	18.46	30.77	16.15	16.92	17.69
Kutch	14.62	30.00	22.31	13.85	19.23

7.1.1.3 Probability Analysis

The probability of occurrence of rainfall was found out for all the talukas as well as the district.The results of probability analysis for the rainfall of the entire district are tabulated in Table 7.3.

Table 7.3 Probability of Occurrence (%) of Rainfall for All Talukas & Kutch District

Rainfall In Mm	Anjar	Bhachau	Bhuj	Lakhpat	Mandvi	Mundra	Nakha-trana	Naliya	Rapar	Kutch
0-50	1.54	3.85	1.54	10.00	5.38	4.62	3.08	11.54	2.31	1.54
51-100	5.38	5.38	10.77	10.00	1.54	5.38	8.46	5.38	3.85	6.92
101-150	9.23	7.69	6.92	10.00	8.46	9.23	6.92	8.46	6.15	6.15
151-200	9.23	9.23	9.23	8.46	9.23	5.38	8.46	13.08	10.77	6.92
201-251	11.54	6.92	9.23	9.23	8.46	7.69	10.00	10.77	11.54	12.31
251-300	12.31	11.54	15.38	10.00	10.00	9.23	12.31	10.00	12.31	10.77
301-350	10.77	9.23	10.77	4.62	6.15	6.92	7.69	4.62	8.46	8.46
351-400	7.69	15.38	6.15	5.38	5.38	9.23	7.69	6.15	6.92	13.85
401-450	2.31	3.08	4.62	7.69	3.85	7.69	7.69	6.15	6.92	7.69
451-500	7.69	4.62	8.46	4.62	6.92	9.23	10.00	4.62	5.38	6.15
501-550	8.46	5.38	2.31	3.08	6.92	3.85	2.31	2.31	8.46	4.62
551-600	4.62	4.62	3.08	3.08	6.92	5.38	1.54	2.31	3.85	2.31
601-650	1.54	3.08	1.54	0.77	4.62	0.77	1.54	3.85	3.08	1.54
651-700	3.85	3.08	1.54	3.85	3.08	2.31	3.08	1.54	2.31	3.08
701-750	0.00	3.85	3.08	2.31	3.08	0.00	0.00	1.54	3.85	1.54
751-800	1.54	0.77	1.54	1.54	1.54	4.62	1.54	0.77	0.77	2.31
801-850	0.00	0.00	0.77	0.77	3.08	4.62	2.31	0.00	0.77	1.54
851-900	0.00	0.77	0.77	0.00	0.77	1.54	0.00	0.77	0.00	0.77

Rainfall In Mm	Anjar	Bhachau	Bhuj	Lakhpat	Mandvi	Mundra	Nakha-trana	Naliya	Rapar	Kutch
901-950	0.77	0.77	0.77	1.54	0.00	0.00	1.54	0.77	1.54	0.00
951-1000	0.77	0.00	0.00	0.77	0.00	0.77	1.54	1.54	0.00	1.54
1001-1050	0.00	0.00	0.00	0.00	2.31	0.00	0.77	0.00	0.00	0.00
1051-1100	0.77	0.77	0.00	0.77	0.00	0.77	0.77	1.54	0.00	0.00
1101-1150	0.00	0.00	0.00	0.77	0.00	0.00	0.77	0.77	0.00	0.00
1151-1200	0.00	0.00	0.77	0.00	0.77	0.77	0.00	0.77	0.00	0.00
1201-1250	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.77	0.77	0.00
1251-1300	0.00	0.00	0.77	0.77	0.77	0.00	0.00	0.00	0.00	0.00
1301-1350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1351-1400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1401-1450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00
1451-1500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1501-1550	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1551-1600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1601-1650	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00

7.1.2 Analysis of Annual Rainfall for the study period of 19 years (1989 to 2007)

The analysis of the annual rainfall values for the period of 1989 to 2007 shows that the maximum rainfall for most of the talukas has occurred in the year 2003 with Bhuj having the maximum rainfall value of 1371 mm amongst all talukas. The minimum rainfall value of 0 mm has been observed thrice at Lakhpat, twice at Nakhatrana and once at Naliya. Total 19 figures for visual distribution of the annual rainfall pattern have been developed and shown in Chapter 3 in Figures 3.2 to 3.20. The results for the mean values, minimum values and maximum values of rainfall for the period of 1989 to 2007 have been tabulated in Table 7.4.

Table 7.4 Results of Analysis for Annual Rainfall (mm) for 1989 to 2007

	Mean	Minimum	Maximum
Anjar	383.89	107.00	979.00
Bhachau	324.47	0.00	788.00
Bhuj	366.79	45.00	1371.00
Lakhpat	269.37	0.00	1317.00
Mandvi	362.63	29.00	978.00
Mundra	421.95	31.00	1133.00
Nakhatrana	323.21	0.00	1122.00
Naliya	336.58	0.00	970.00
Rapar	418.68	129.00	1091.00

7.1.3 Analysis for Monthly Rainfall (mm) for 1989 to 2007

The analysis of the monthly rainfall values for the period of 1989 to 2007 shows that the maximum rainfall for most of the talukas has occurred in July 2003 with Lakhpat having the maximum monthly rainfall value of 1141 mm amongst all talukas. The minimum rainfall value of 0 mm has been observed for several months for all the talukas. Total 95 figures for visual distribution of the monthly rainfall pattern have been developed and shown in Chapter 3 in Figures 3.22 to 3.116. The results for the mean values, minimum values and maximum values of monthly rainfall for the period of 1989 to 2007 have been tabulated in Table 7.5.

Table 7.5 Results of Analysis for Monthly Rainfall (mm) for 1989 to 2007

Taluka	Mean	Minimum	Maximum
Anjar	31.99	0.00	636.20
Bhachau	27.04	0.00	455.00
Bhuj	30.56	0.00	1087.00
Lakhpat	22.45	0.00	1141.00
Mandvi	30.77	0.00	602.00
Mundra	35.31	0.00	755.00
Nakhatrana	27.17	0.00	837.00
Naliya	27.99	0.00	890.00
Rapar	34.89	0.00	717.00

7.2 SURFACE WATER ANALYSIS FOR KUTCH

7.2.1 Analysis of Annual Runoff (mm)

The runoff for all the watersheds has been calculated using daily rainfall data for the period of 1989 to 2007 using the Soil Conservation Service model (USDA-SCS, 1972. The landuse map was generated using the images derived from Landsat Thematic Mapper (TM) data at 90 m resolution for November 2009 using the photo-interpretation technique. Boundaries of prominent landforms were delineated and mapped and their morphological features, tonal variations and landuse / land cover were interpreted and demarcated. Runoff Curve Numbers (CN) values were determined using the hydrological soil groups (A to D), hydrological cover conditions (poor, fair and good) and five day antecedent rainfall values. The available soil map for the district was used to find the Hydrologic Response Units (HRU) for the region. As there were more than one curve numbers for each catchment, the weighted curve numbers were found out and considered for the estimation of daily runoff. The daily runoff obtained was summed up to find out the annual runoff.

The analysis was done for the annual runoff values for the study period of 1989 to 2007. The analysis shows that a maximum of 610.97 mm of annual runoff was observed at Mandvi in the year 1994. The annual runoff is found to be maximum in most of the talukas in the years 1994 and 2003. The minimum runoff of 0 mm was found in the years 1991 and 1999 for most of the talukas, with Lakhpat having maximum number of years

with 0 mm runoff value. Total 19 figures for visual distribution of the annual runoff pattern have been developed and shown in Chapter 4 in Figures 4.5 to 4.23. The results for the analysis of the annual runoff values have been tabulated in Table 7.6.

Table 7.6 Results of Annual Runoff (mm) Analysis

Taluka	Mean	Minimum	Maximum
Anjar	33.60	0.00	162.95
Bhachau	58.68	1.98	195.97
Bhuj	84.12	0.17	530.23
Lakhpat	51.62	0.00	340.81
Mandvi	71.46	0.00	610.79
Mundra	88.65	0.05	400.32
Nakhatrana	59.76	0.00	302.35
Naliya	83.25	0.00	397.68
Rapar	78.51	1.47	375.34

7.2.2 Analysis of Monthly Runoff (mm)

The daily runoff obtained by procedure as mentioned in analysis of annual runoff was summed up to find out the monthly runoff. The analysis was done for the monthly runoff values for the study period of 1989 to 2007. Total 95 figures for visual distribution of the monthly runoff pattern have been developed and shown in Chapter 4 in Figures 4.25 to 4.119. The results for the analysis of the monthly runoff values have been tabulated in Table 7.7.

Table 7.7 Results of Monthly Runoff (mm) Analysis

Taluka	Mean	Minimum	Maximum
Anjar	3.27	0.00	120.57
Bhachau	5.55	0.00	167.06
Bhuj	8.25	0.00	472.88
Lakhpat	5.72	0.00	332.65
Mandvi	4.62	0.00	247.05
Mundra	8.61	0.00	347.86
Nakhatrana	5.35	0.00	251.49
Naliya	4.95	0.00	302.35
Rapar	4.40	0.00	307.10

7.3 RESULTS OF GROUNDWATER POTENTIAL ANALYSIS

The analysis for the groundwater potential was done for all the talukas. The talukas were further grouped into four groups depending upon the types of soils and geology.

The groundwater levels for a total of 208 wells in all for 19 years have been plotted to obtain the average pre-monsoon and post-monsoon water levels for each taluka for all the years. To judge the groundwater potential, figures for pre-monsoon and post-

monsoon water tables have been developed for visual analysis in Chapter 5 Figures 5.15 to 5.52.

7.3.1 Development of Equation for Draft

The data for the number of wells, rainfall pattern, the total agricultural area and the total geographical area was used for analysis and the equation for obtaining the draft in mm for the district was developed using the technique of multiple regression with the help of the software Statistica. The final equation obtained is as follows:

$$Dr = .0062*W + .0721*P_{m-2} + .0198*P_{m-1} - .0185*P_m + .00047*A_{ag} - 0.0000795*A_t$$

Where, Dr = depth of draft in mm
W = water extracting mechanisms / wells in the taluka
m = number of year
P_{m-2} = Depth of Rainfall two years ago in mm
P_{m-1} = Depth of Rainfall for previous year in mm
P_m = Depth of Rainfall for current year in mm
A_{ag} = Total agricultural area in the taluka in hectares
A_t = Total area of taluka in hectares

Using the above formula, the depth of groundwater draft was calculated for all the talukas. The results for the analysis of the draft for the 19 year data from 1989 to 2007 is tabulated in Table 7.8.

Table 7.8 Results for analysis of Draft Pattern (mm)

Taluka	Mean	Minimum	Maximum
Anjar	54.85	29.65	101.00
Bhachau	37.07	0.94	101.00
Bhuj	46.65	12.44	114.19
Lakhpat	20.01	-20.67	99.71
Mandvi	55.97	31.38	108.00
Mundra	53.94	24.50	112.74
Nakhatrana	44.63	-0.15	106.18
Naliya	29.02	0.51	88.77
Rapar	31.76	3.03	71.95

7.3.2 Total Groundwater Recharge

The values for groundwater recharge due to rainfall and the groundwater recharge due to surface storage have been calculated and the total groundwater recharge is obtained as the sum of the two values. The analysis was done for the values of total annual groundwater recharge in mm for the study period of 1989 to 2007. The results for the analysis of the total annual groundwater recharge values have been tabulated in Table 7.9.

Table 7.9 Results for Annual Groundwater Recharge Values (mm) for 1989 to 2007

Taluka	Mean	Minimum	Maximum
Anjar	64.47	-53.43	239.31
Bhachau	27.21	-49.76	119.64
Bhuj	66.80	-123.30	284.56
Lakhpat	24.27	-12.98	90.00
Mandvi	107.42	-166.51	471.04
Mundra	69.78	-44.41	290.94
Nakhatrn	55.03	-138.83	223.99
Naliya	41.98	-10.59	171.09
Rapar	43.22	-6.33	165.71

7.4 RESULTS OF INTER-RELATIONSHIP

7.4.1 Rainfall-Runoff Relations

The graphs for depth of rainfall and depth of runoff have been developed for each taluka and the equations for relationship between rainfall and runoff have been developed using method of linear regression.

7.4.1.1 Annual Rainfall - Runoff Relations

Graphs 6.1 to 6.9 show the scatter plots for the annual rainfall – runoff relations.
The equations developed for the inter relationship between annual rainfall and runoff for all the talukas have been tabulated as shown in Table 7.10.

Table 7.10 Results for Annual Rainfall – Runoff Relations

Taluka	Equation
Anjar	Q = 0.182P-36.177
Bhachau	Q = 0.245P-20.714
Bhuj	Q = 0.364P-49.371
Lakhpat	Q = 0.215P-6.295
Mandvi	Q = 0.445P-89.991
Mundra	Q = 0.344P-56.392
Nakhatrana	Q = 0.352P-30.369
Naliya	Q = 0.249P-24.030
Rapar	Q = 0.348P-67.236

7.4.1.2 Monthly Rainfall – Runoff Relations

Graphs 6.10 to 6.18 show the scatter plots for the monthly rainfall – runoff relations.
The equations developed for the inter relationship between monthly rainfall and runoff for all the talukas have been tabulated as shown in Table 7.11.

Table 7.11 Results for Monthly Rainfall – Runoff Relations

Taluka	Equation
Anjar	$Q_m = 0.139P - 1.163$
Bhachau	$Q_m = 0.240P - 0.946$
Bhuj	$Q_m = 0.342P - 2.212$
Lakhpat	$Q_m = 0.262P - 0.172$
Mandvi	$Q_m = 0.239P - 2.725$
Mundra	$Q_m = 0.324P - 2.792$
Nakhatrana	$Q_m = 0.253P - 1.476$
Naliya	$Q_m = 0.262P - 2.390$
Rapar	$Q_m = 0.212P - 2.986$

7.4.2 Rainfall – Groundwater Recharge Relations

The graphs for depth of rainfall and depth of groundwater recharge have been developed for each taluka and the equations for relationship between rainfall and depth of groundwater recharge have been developed using method of linear regression. Graphs 6.19 to 6.27 show the scatter plots for the annual rainfall – total groundwater recharge relations. The equations developed for the inter relationship between annual rainfall and total annual groundwater recharge for all the talukas have been tabulated as shown in Table 7.12.

Table 7.12 Results for Annual Rainfall – Groundwater Recharge Relations

Taluka	Equation
Anjar	R=0.231P-24.277
Bhachau	R=0.136P-16.843
Bhuj	R=0.216P-12.204
Lakhpat	R=0.079P+2.946
Mandvi	R=0.524P-82.558
Mundra	R=0.294P-54.043
Nakhatrana	R=0.205P-11.025
Naliya	R=0.163P-12.857
Rapar	R=0.157P-22.514