Chapter 6
Hydrological Characteristics

CHAPTER – 6

HYDROLOGICAL CHARACTERISTICS

Hydrology is the study of the flow of the earth's waters through the hydrologic cycle. This involves precipitation of water onto the earth's surface, evaporation back into the atmosphere, runoff of water from the land surface to the oceans, and flow of water in soil and groundwater aquifers. Associated with the flow of water is the transport of the constituents, including sediment, dissolved chemicals, and microorganisms such as bacteria. Thus, hydrology is not limited to the study of water quantity issues, but also deals with water quality and environmental concerns.

6.1 Hydrologic Cycle

The hydrologic cycle is a vast flow of water, powered by gravity and solar energy, which circulates water through the earth's system. The cycle exists both over the oceans and over the land surface. The approximate annual volumes of water moved through the hydrologic cycle are shown in the attached graphic (figure. 6) in units relative to the annual volume of precipitation on the land surface, which is taken as 100 units. Thus, evaporation from the land surface is 61 units, or 61% of the precipitation on the land surface. Of the remaining 39%, 38% flows from the land surface to the oceans as surface runoff in rivers and 1% is discharged directly to the oceans by groundwater systems which discharge below the ocean surface. These 39 units going from the land surface to the oceans as runoff are replaced by an equal flow of 39 units coming from the oceans to the land surface as atmospheric moisture. The accounting of inflows and outflows of water depicted in the hydrologic cycle is called a water balance.

Water moving through the hydrologic cycle can be divided into several phases: atmospheric water, which is water moving in atmospheric circulation as water vapor or water droplets in clouds; surface water, which is water moving through streams, rivers and lakes on the land surface; soil water, which is water resident in surface soil and readily accessible to plants, and groundwater, which is water in groundwater aquifers deeper in the subsurface. Spatial hydrology can be applied to represent the water balance of each phase of the hydrologic cycle separately, and to quantify the exchange of water between phases of the hydrologic cycle.

6.2 Sources of Water

There are three major sources of water on the earth,

1. Precipitation.
2. Surface Water.
3. Groundwater

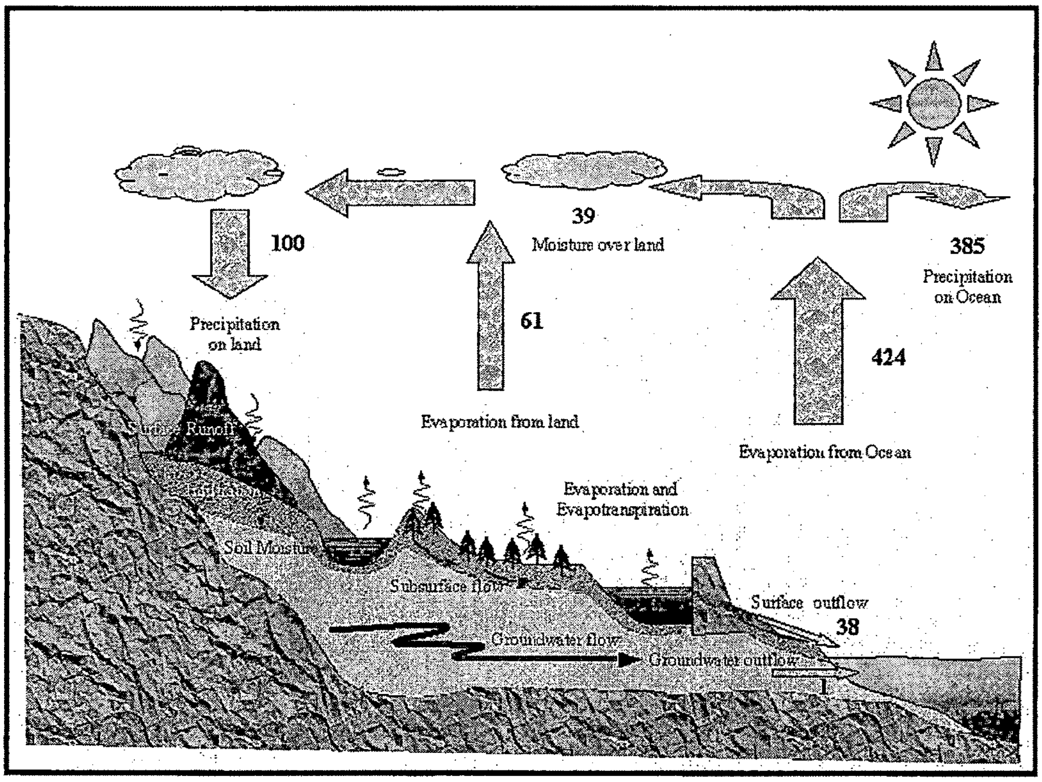


Figure. 6.1 Movement of water through the hydrologic cycle (adapted from: Singh, V.P. (1992), Elementary Hydrology)

Growth and development are primarily governed by the environmental conditions of the soil and climate. The success or failure of farming is intimately related to the prevailing weather conditions. The modification of weather, except on a very limited scale, is yet in the realm of experimentation. It is, nevertheless, possible to optimise farm production by adjusting cropping patterns and agronomic practices to suit the climate of a locality.

Weather assumes significance in nearly every phase of agricultural activity from the preparatory tillage to harvesting and storage. Even after the produce is stored, weather continues to affect the fortunes of the farmers, as the reports of good or bad weather elsewhere tend to upset the price trends.

As weather is the single major limiting factor in crop production successful farming calls for appropriate decisions in the light of weather conditions in the matter of the time of sowing, transplanting, scheduling of irrigation, timing of fertilizer application, using of pesticides, etc.

A sound knowledge of the climatic factors and an understanding of the complex processes of interaction between the climate and the biological processes of the plants are essential to a scientific approach to farming, based on planned cropping patterns and improved land and water-management practices.

India is a land of many climates and varieties of soils affording scope for much diversity in agriculture. The geographic location and the physical features largely determine the climate of the country.

The pattern of rainfall all over India reflects the climatic variations in the different parts of the country. It varies from per-humid in north-east India to arid in Rajasthan. A belt of arid or semi-arid climates extends from the north to the south, dividing the humid climates of the west coast & the central and eastern parts of the country, where the annual rainfall is generally less than 1,000 mm.

More then any other factor, the climate plays a dominant role in the development of the pattern and character of land use. The type of bio-mass, the human settlements, the types and pattern of general and cropland use etc, in one or the other way reflect "a major exploitation of climatic resources" (Peacock and Shelly 1974)

The study area is a macro climatic zone in the vast monsoonal realm of the Indian sub continent. The climate in this area represents the salient characteristics of the south-west monsoon, partly modified by the marine influences, being situated between the estuaries of Mahisagar in the north, Dhadhar to the south of Mahisagar, the Gulf of Khambhat in the west and Narmada in the south. The climate of the study area is moderated by the presence of these water bodies. There are seasonal rhythms but rarely reaching the extremes as experienced in the interior part of the country.

6.2.1 Rainfall Pattern in Study Area

15th June is considered to be the date of "onset" of monsoon rains, but it rarely comes on this date. It commences either earlier or later than this date. Similarly, the departure date is 15th October, but it hardly stays up to this date. The words that can explain nature of these seasonal rains are precarious, irregular, unreliable, scanty, erratic, and excessive. The late arrival and early departure prove disastrous and equally disastrous are unabated spells for long durations.

The actual rainy months are the latter half of June, July and the first half of August. July is the rainiest month. The force of monsoon starts winding up from mid August and practically disappears by mid September. Occasional showers are received during October only in the event of a good season.

The data required for the present study include rainfall data and stream flow records. Forty-five (for year 1981 to 1990) and forty-six (for the year 1991 to 2000) rain gauge stations are selected for analysis purpose. The daily, monthly and Yearly rainfall data of twenty years have been collected from State Water Data Centre, Gandhinagar and River Gauaging Department, Vadodara. The data are available from 1981 onwards to year 2000.

The following are some of the highlights regarding the rainfall pattern within the study area.

Years: 1981 – 90 (10 Years)

- Average rainfall in the study area during these 10 years was 78.75 cm.
- Year 1990 – Received an average rainfall of 105.96 cm, which was highest in 10 years.
- Year 1987 - Received an average rainfall of 38.41 cm, which was lowest 10 years.
- Highest annual rainfall recorded – 214.3 cm at Devhat (Region – I) in year 1988.
- Lowest annual rainfall recorded – 18.7 cm at Dahej (Region – IV) in year 1982.
- The monthly averages were 97 cm in June, 253 cm in July, 316 cm in August, 14 cm in September and 23 cm in October.
- Monthly average was thus highest in August.
- Highest monthly rainfall recorded – 492.72 cm at Devhat (Region – I), in the month of August.
- Lowest monthly rainfall recorded – 0.4 cm at Muler (Region – IV), in the month of October.
- Average No of rainy days in the study area were 32 days for 10 years.
- Year 1981 received rainfall for 44 days. This was highest in 10 years.
- Year 1987 received rainfall for 16 days. This was lowest in 10 years.
- Highest No of Rainy days recorded was in the month of August - 124 days.

- Lowest No of Rainy days recorded was in the month of October – 6 days.
- Rajpipla (Region – I) in the month of July received rainfall for 195 days, which was highest in 10 years.
- Vagra (Region – IV) in the month of October received rainfall for 01 day, which was lowest in 10 years.

Years: 2000 – 01 (10 Years)

- Average rainfall in the study area during these 10 years was 81.92 cm.
- Year 1994 – Received an average rainfall of 116.17 cm, which was highest in 10 years.
- Year 2000 - Received an average rainfall of 39.25 cm, which was lowest 10 years.
- Highest annual rainfall recorded – 207.7 cm at Tarol (Region – I) in year 1996.
- Lowest annual rainfall recorded – 14.6 cm at Padra (Region – II) in year 1999.
- The monthly averages were 118 cm in June, 380 cm in July, 183 cm in August, 159 cm in September and 21 cm in October.
- Monthly average was thus highest in July.
- Highest monthly rainfall recorded – 423.8 cm at Tarol (Region – I), in the month of July.
- Lowest monthly rainfall recorded – 5.6 cm at Padra (Region – II), in the month of October.
- Average No of rainy days in the study area were 40 days for 10 years.

- Year 1994 received rainfall for 61 days, this was highest 10 years.
- In year 2000 received rainfall for 25 days, this was lowest 10 years.
- Highest No of Rainy days recorded was in the month of July – 142 days.
- Lowest No of Rainy days recorded was in the month of October – 17 days.
- Rajpipla (Region – I) in the month of July received, rainfall for 194 days, which was highest in 10 years.
- Sinor (Region – II) in the month of October received rainfall for 02 days which was lowest in 10 years.

There has been an increase in, the average rainfall from 78.75 cm in

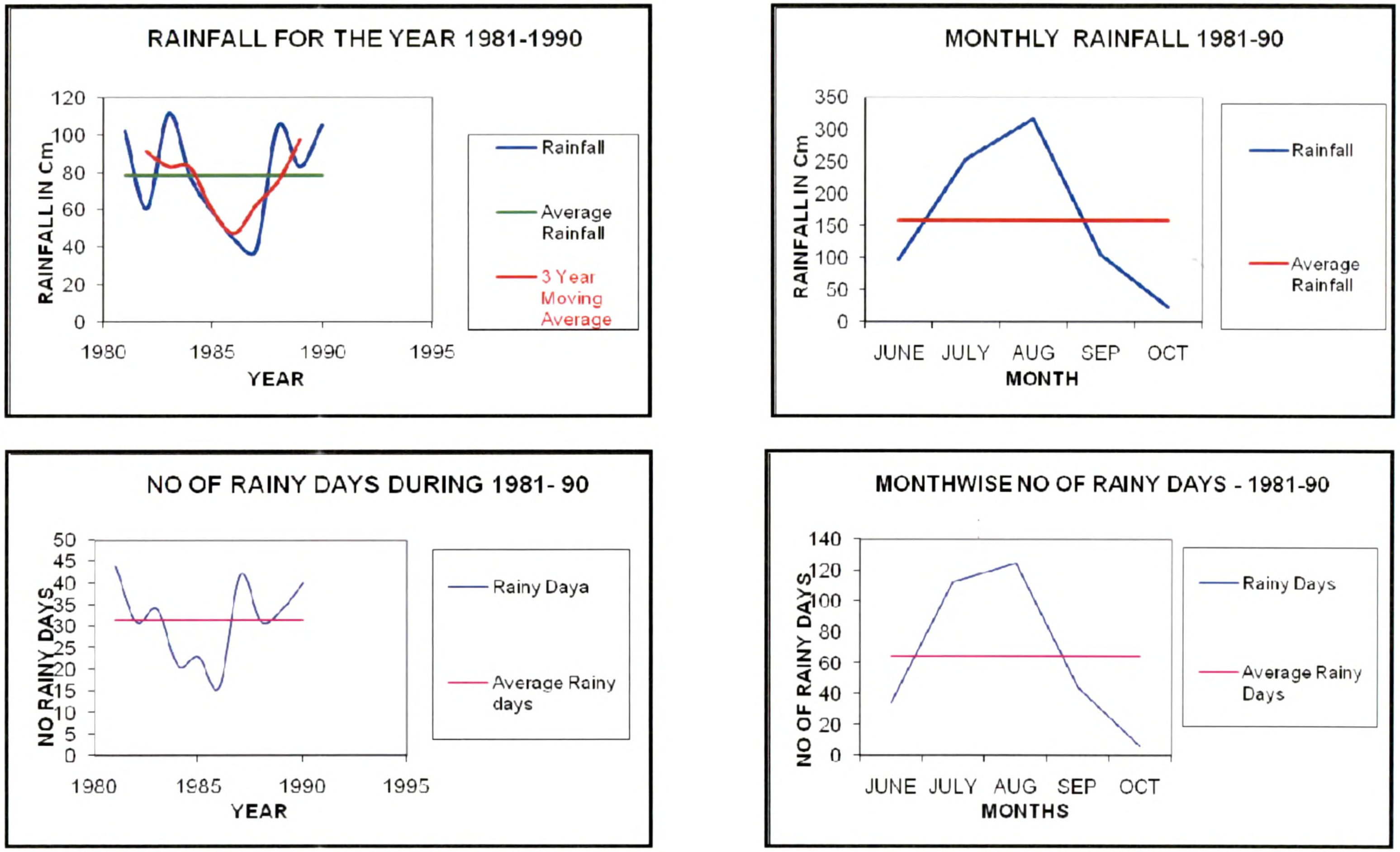

RAINFALL FOR THE YEAR 1981-1990
RAINFALL IN Cm
120
100
80
60
40
20
0
1980
1985
1990
1995
YEAR
Rainfall
Average Rainfall
3 Year Moving Average
MONTHLY RAINFALL 1981-90
RAINFALL IN Cm
350
300
250
200
150
100
50
0
JUNE
JULY
AUG
SEP
OCT
MONTH
Rainfall
Average Rainfall
NO OF RAINY DAYS DURING 1981- 90
NO RAINY DAYS
50
45
40
35
30
25
20
15
10
5
0
1980
1985
1990
1995
YEAR
Rainy Daya
Average Rainy days
MONTHWISE NO OF RAINY DAYS - 1981-90
NO OF RAINY DAYS
140
120
100
80
60
40
20
0
JUNE
JULY
AUG
SEP
OCT
MONTHS
Rainy Days
Average Rainy Days

Figure 6.2

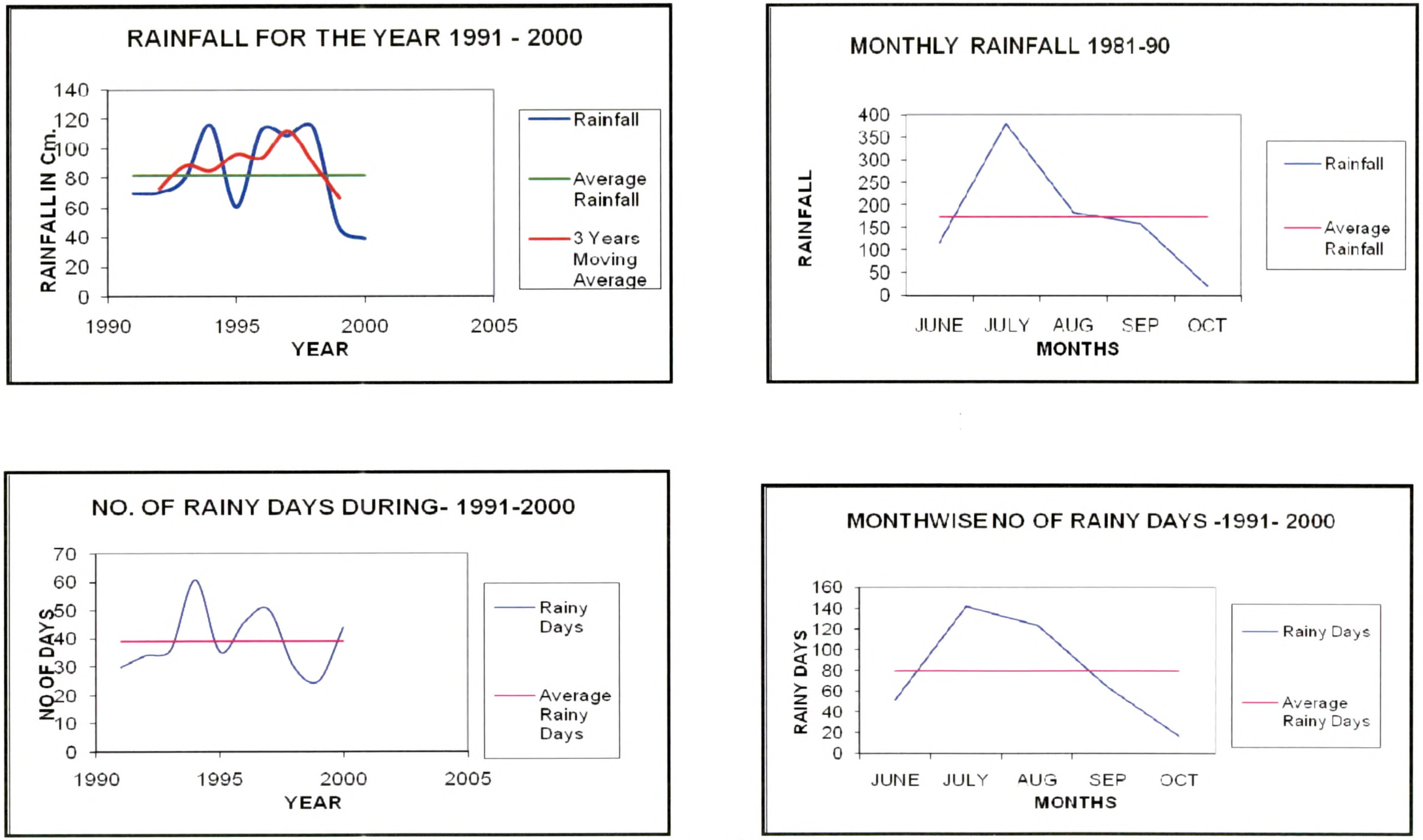

RAINFALL FOR THE YEAR 1991 - 2000
RAINFALL IN Cm.
140
120
100
80
60
40
20
0
1990
1995
2000
2005
YEAR
Rainfall
Average Rainfall
3 Years Moving Average
MONTHLY RAINFALL 1981-90
RAINFALL
400
350
300
250
200
150
100
50
0
JUNE
JULY
AUG
SEP
OCT
MONTHS
Rainfall
Average Rainfall
NO. OF RAINY DAYS DURING- 1991-2000
NO OF DAYS
70
60
50
40
30
20
10
0
1990
1995
2000
2005
YEAR
Rainy Days
Average Rainy Days
MONTHWISE NO OF RAINY DAYS -1991- 2000
RAINY DAYS
160
140
120
100
80
60
40
20
0
JUNE
JULY
AUG
SEP
OCT
MONTHS
Rainy Days
Average Rainy Days

Figure 6.3

1981-90 to 81.92 cm in 1991-2000. The yearly trends during this 20 years period shows that almost every third year drought, like situation has occurred. The reliable month for maximum precipitation has shifted from August to July. The average number of rainy days has increased from 32 days to 40 days, which is good for agriculture (Figure 6.2 & 6.3)

6.2.2 Estimating Water Availability

Various phases of hydrologic cycle such as rainfall, runoff, evapotranspiration and transpirations are all not uniformly distributed both in time and space. Further, practically all-hydrologic phenomena are complex and at the present level of knowledge, they can be best interpreted with the aid of probability concepts. Hydrological events are treated as random processes and the historical data related to event are analyzed by statistical methods to obtain information on probabilities of occurrence of various events. The probability analysis of hydrologic data is an important component of present day hydrological studies and enables the researcher to take suitable decisions consistent with economic and other criteria to be taken in a given project.

(A) Data Collection

The data required for present study are rainfall data and stream flow records. Forty-five (for year 1981 to 1990) and forty-six (for the year 1991 to 2000) rain gauge stations are selected for analysis purpose. The daily, monthly, yearly rainfall data of twenty years have been collected from

State Water Data Centre and River Gauging Department. The data are available from 1981 onwards to year 2000.

(B) Methodology

i) To check consistency of data: The complete database of all forty-five rain gauges is very much necessary for carrying out the rainfall analysis of the study area. Before using the rainfall records of stations, the consistency and continuity of data has been checked. The continuity of a record has been broken with missing data for three (3) the rain gauge stations. The missing data have been estimated by using the data of the neighboring stations.

ii) Estimation of Missing Rainfall Data

The daily rainfall data have been collected for 43 rain gauge stations. At rain gauge stations, the daily rainfall data for time period 1981 to 2000 have been observed. In order to fill the missing rainfall data at these rain gauge stations, spatial homogeneity test has been carried out with the help of HYMOS software.

iii) Spatial Homogeneity Test

The test is applicable to quantity and quality parameter with a spatial character, like rainfall, temperature, and evaporation etc. but sampled at a number of stations. (Point measurement) This test works on the concept of distance power method. This method weights neighbouring stations on the basis of their distance from the station under consideration, on the assumption that closer stations are better correlated than those further away. Spatial interpolation is made by weighing the adjoining station rainfall as inversely proportional to some power of the distances from the station under consideration.

In this method four quadrants are delineated by north-south and east-west lines passing through the rain gauge station under consideration. A circle is drawn of radius equal to the distance within which significant correlation is assumed to exist between the rainfall data, for the time interval under consideration

iv) Selection of Adjoining Stations

The adjoining stations must lie within the specified radius having significant spatial correlation with one-another. A maximum number of 8 adjoining stations are sufficient for estimation of spatial average. In adverse condition, 3 adjoining stations are also considered valid. An equal number of stations from each of the four quadrants are preferred for minimizing any directional bias. The spatial interpolated estimate of the rainfall at station under consideration is obtained as:

$$P_{est,j} = \left(\sum_{I=1}^{Mbase} P_{i,j} / D_i^{B} \right) / \left(\sum_{I=1}^{Mbase} 1/D_i^{B} \right)$$

Where:

Pest, j = estimated rainfall at the test station at time j

Pi, j = observed rainfall at the neighbour station i at time j

Di = distance between the test and neighbouring station i

Mbase	=	number of neighbouring stations taken into account
B	=	Power of distance D used for weighting rainfall values at Individual station.

Thus the missing rainfall data are obtained by using spatial homogeneity test. After getting the complete database for 45 rain gauge stations, the daily rainfall data are converted into values of rainfall data.

v) Estimation of Areal Rainfall

Rain gauges generally measure rainfall at individual points. The present study requires the average depth of rainfall occurring over an area. Since rainfall is spatially variable and the spatial distribution varies between events, point rainfall does not provide a precise estimate or presentation of areal rainfall. The areal rainfall will always be an estimate and not the true rainfall depth irrespective of method.

There are number of methods which can be employed for estimation of rainfall.

a) Arithmetic mean method.

b) Thiessen polygon method.

c) Isohyetal method.

In present study, the Thiessen polygon method has been used for estimation of areal rainfall due to its advantages over other methods.

6.2.3 Thiessen Polygon Method

The Thiessen mean method calculates the weighted average of the precipitation data based on the weightage given to the area closest to the gauging station. This technique has the advantage of being quick to apply for multiple storms because it uses fixed sub-areas. Consider the watershed shown in fig. In this watershed, there are 45 stations that are joined together forming a network of triangles. Perpendicular bisectors of each of the sides of the triangles are drawn and joined together forming a polygon around each gauging station. Wherever the watershed boundary cuts the bisectors, it is taken as the outer limit of the polygon. The areas of the bounding polygons are measured by planimeter or by overlay grid method.(GIS Method) The average rainfall of watershed is then determined as follow (Figure. 6.4 & 6.5).

$$P = (P1A1+P2A2+\ldots+PmAm / A1+A2+\ldots+Am)$$

$$= PiAi / A$$

$$= Pi\,(Ai/A)$$

Where,

P = average rainfall over the Catchment.

P1, P2,... Pm = respective rainfall magnitude recorded by stations 1, 2, ..., m Respectively.

A1, A2,..., Am = respective areas of 1, 2,..., m Thiessen polygons

A = total area of watershed (A1+A2+...+Am)

Ai/A = weightage factor for each station.

Advantages of the Thiessen Mean Method

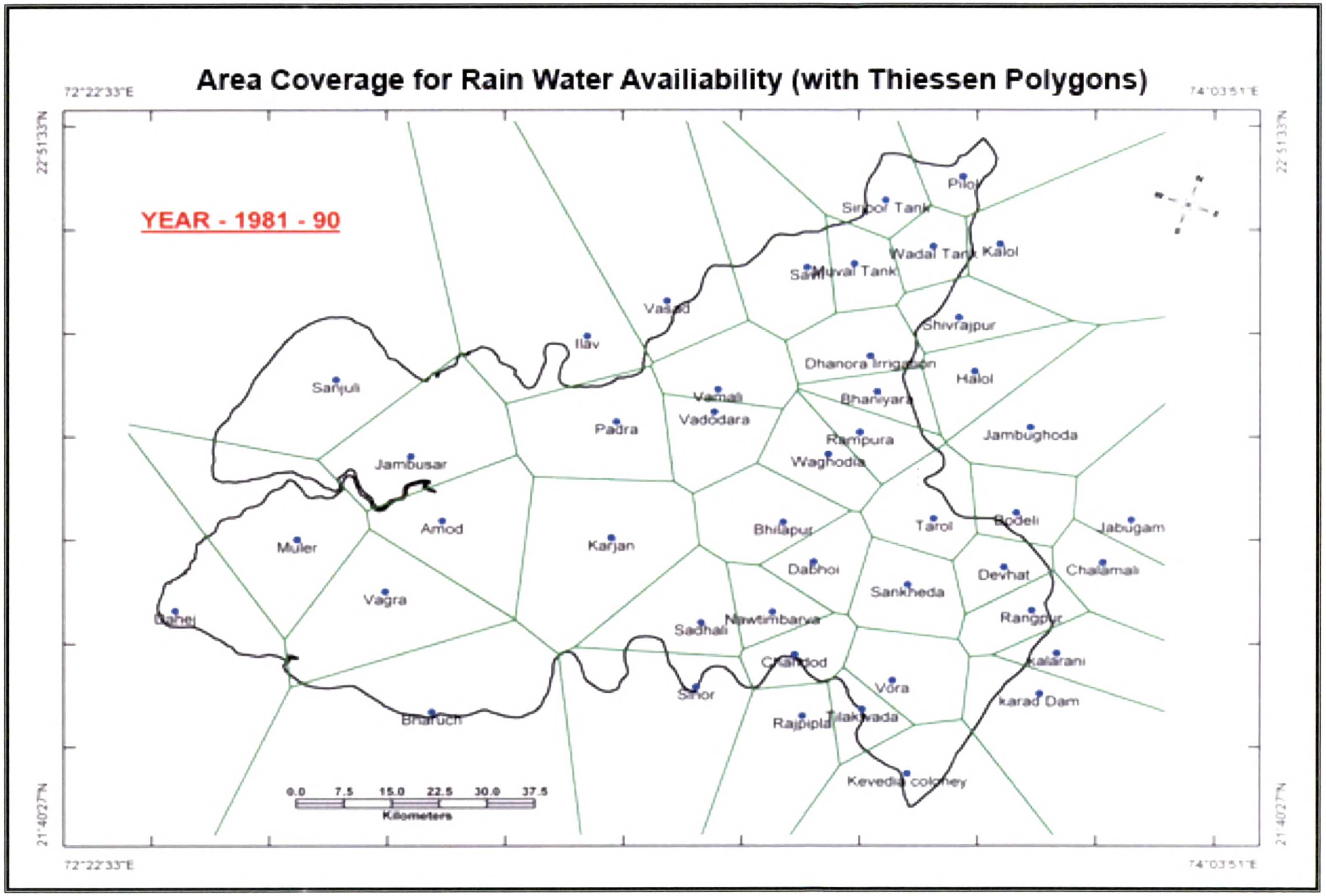
- The method also makes use of data from nearby stations located outside the watershed.
- It allocates importance of measurement according to station spacing.
- It is easily adopted on computers.
- Station weights remain constant when the same number of stations is used.

Disadvantages of Thiessen Mean Method

The method ignores the orographical effects. Whenever a new station is added, it leads to changes in the areas of polygons.

Construction of Thiessen Polygon Using GIS and Obtaining the Mean Rainfall for the Study Area:

- The nearest rain gauge stations located on the map have been first joined together for creating triangles.
- Then the bisectors of each triangle are drawn and the Thiessen polygons are created surrounding the each rain gauge station.
- The polygon areas obtained are then used for getting the weightage factors.



Area Coverage for Rain Water Availiability (with Thiessen Polygons)
YEAR - 1981 - 90
72°22'33"E
74°03'51"E
22°51'33"N
21°40'27"N
Piloj
Sinbor Tank
Wadal Tank
Kalol
Muval Tank
Vasad
Ilav
Sanjuli
Shivrajpur
Halol
Bhaniyara
Vamali
Vadodara
Padra
Rampura
Waghodia
Jambughoda
Jambusar
Amod
Muler
Vagra
Karjan
Bhilapur
Taroi
Bodeli
Jabugam
Dabhoi
Devhat
Chalamali
Sankheda
Rangpur
Sadhali
Chandod
Sinor
Vora
Rajpipla
Bharuch
Dahej
karad Dam
Kevedia colony
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers

Figure. 6.4

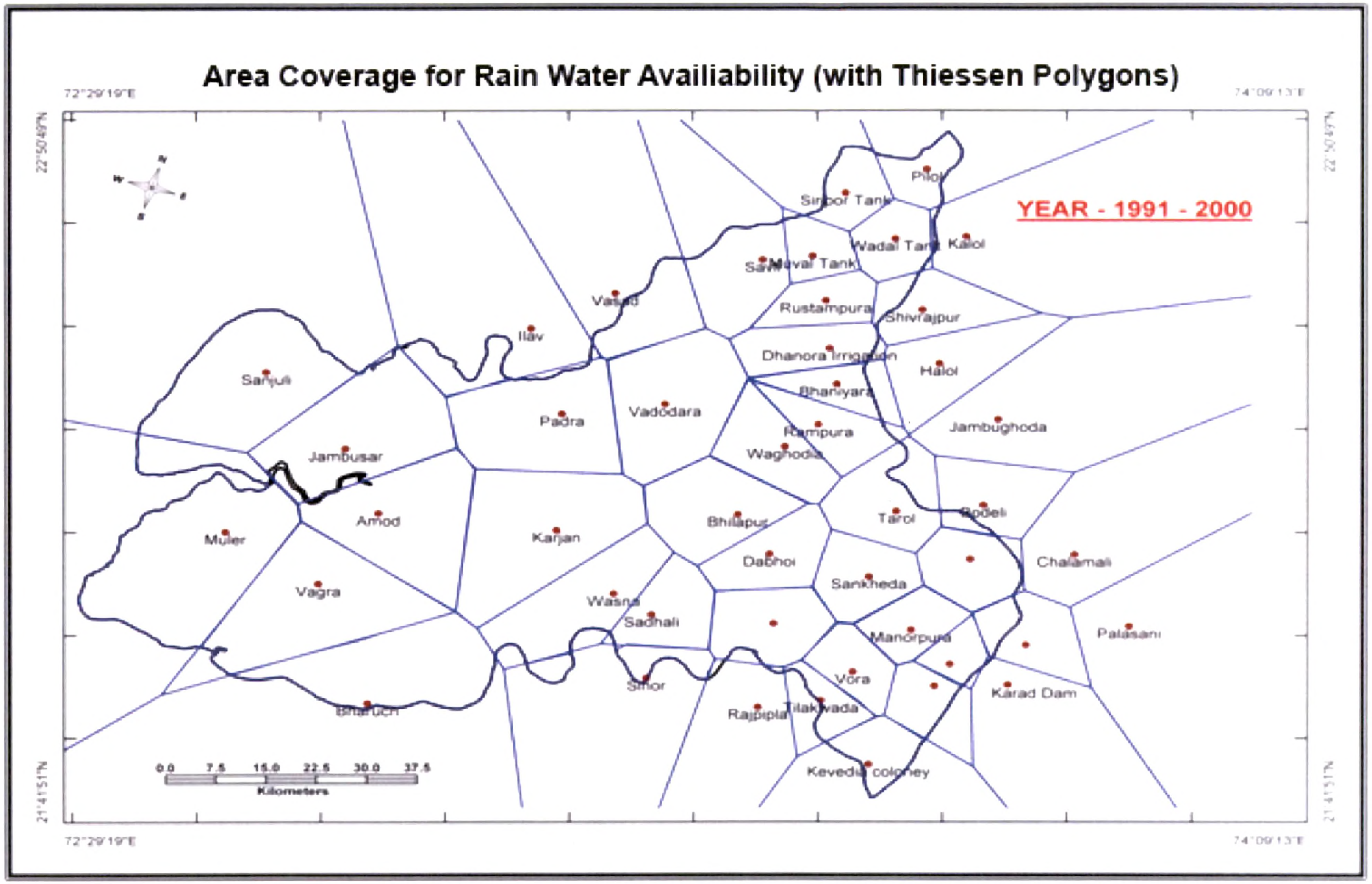

Area Coverage for Rain Water Availiability (with Thiessen Polygons)
YEAR - 1991 - 2000
72°29'19"E
74°09'13"E
22°50'49"N
21°41'51"N
Pilol
Kalol
Wadali Tank
Meval Tank
Rustampura
Shivrajpur
Dhanora Irrigation
Halol
Bhaniyara
Rampura
Waghodia
Jambughoda
Vasad
Ilav
Sanjuli
Padra
Vadodara
Jambusar
Amod
Muler
Karjan
Bhilapur
Dabhoi
Tarol
Bodeli
Chalamali
Sankheda
Vagra
Wasna
Sadhali
Manorpura
Palasani
Vora
Karad Dam
Sinor
Rajpipla
Tilakwada
Bharuch
Kevedia coloney
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers

Figure. 6.5

- The weightage factors obtained are then multiplied with the 10 daily rainfall data (Pi) of each rain gauge stations and then by summing up these Pi values, aerial rainfall (P) has been obtained for ten days for ten years (1981 to 2000).

By using Thiessen Polygon method the area of each rain gauge is calculated. Finally the total area of each rain gauge station is computed and the total volume of rainfall is achieved. (Figure 6.2 & 6.3)

The total volume of water (rainfall) from year 1981 to 1990 is 62118.13 Mm3. and for the year 1991 to 2000 was 63331.85 Mm3.

The total runoff estimated is 10288.29 Mm3 for the years 1981 to 1990 and for the years 1991 to 2000 is 11823.12 Mm3.

6.3 Ground Water Resources

Groundwater is a precious and the most widely distributed resource of the earth and unlike any other mineral resource, it gets its annual replenishment from the meteoric precipitation.

It is the largest source of fresh water on the planet excluding the polar icecaps and glaciers. The amount of ground water within 800m from the ground surface is over 30 times the amount in all fresh water lakes and reservoirs and about 3000 times the amount in stream channels at any one time. At present nearly one fifth of all the water used in the world is obtained from ground water resources. Agriculture is the greatest user of water accounting for 80% of all consumptions. It takes, roughly speaking 1000 tons of water to grow one ton of grain and 2000 tons to grow one ton of rice.

Some 15% of world's cropland is irrigated by groundwater. The present irrigated area in India is 60 million hectares of which about 40% is irrigated by ground water.

The average annual rainfall of India is around 114cm. Based on this Dr. K.L. Rao has estimated that the total annual rainfall over the entire country is of the order of 370 Mha-m and one third of this is lost in evaporation. Of the remaining 247 Mha-m of water 167 Mha-m goes as runoff and the rest of the 80 Mha-m goes as sub-soil water. Out of this 80 Mha-m of sub-soil water that seeps down annually in to the soil, about 43 Mha-m gets absorbed in the top layer, thereby contributing to the soil moisture, the balance of 37 Mha-m is the contribution to ground water from rainfall. The average annual ground water recharge from rainfall and seepage from canals and irrigation system is of the order of 67 Mha-m, of which 40% i.e. 27 Mha-m is extractable economically. The National Commission for Integrated Water Resource Development Plan in their report published during September 1999 have found that the over all availability and requirement of water for different uses in the country projected up to 2050 A.D will broadly match each other at the National level but, acute scarcity. The commission has estimated the available water resource for the country as 1953 km^3 (1521 km^3 surface water + 432 km^3 ground water). Out of this water we have used up till now 600 km^3. The commission has estimated the requirement of water for all uses up to 2050 A.D as 1189 km^3 (807 km^3 for Irrigation, 111 km^3 for domestic water supply, 81 km^3 for industrial use and 70 km^3 for power generation). In the country at present 3596 irrigation works are completed and 695 are under execution to provide 250 km^3 of water storage. New projects to store additional 130 km^3 of water are under consideration. It is necessary to increase the irrigation potential from the level of 80.76 Mha (1997) to the ultimate level of 140 Mha to provide food and fodder by 2050 A.D.

In terms of total quantum of rainfall, south and central Gujarat receive the highest amount of rainfall with mean annual precipitation of 51.95 $km^{3;}$ Saurashtra follows this with 36.514 km^3 and north Gujarat with 24.53 $km^{3.}$ Kachchh receives a total of 17.21 km^3 of water as the mean rainfall. Thus 40 percent of the total rainfall (130.205 km^3 or 13.205 M h) is in south and central Gujarat is 2334 MCm. The total ground water resources in the study area is given in table. 6.1.

In recent years there has been an increasing tendency towards drilling deep wells as well as towards revitalization of existing open wells. With the economic and technical help of various agencies the poor and marginal farmers have accelerated the pale of ground water development and bringing more land under intensive irrigation.

With the increasing use of groundwater for agricultural, domestic and industrial needs, the annual extractions of ground water are far in excess of net average recharge from natural sources. Consequently groundwater is being withdrawn from storage and water levels are declining resulting in crop failures, adverse salt balance, seawater intrusion in coastal aquifers and land subsidence in areas where drafts result in compaction of sediments.

Table 6.1: Ground Water Resources Assessment in S.S.P. Command Area Phase - I

Sr. N0	Region	Taluka	District	GCA IN Sq Km.	Alluvial area Suitable for G.W.D in Sq.Km.	Hard rock area suitable for Dug well Sq. km.	Saline area unsuitable for G.W.D. in Sq.Km.	A	B	Gross Annual Draft in MCM	C	Balance ground water available for further development in MCM.
1.		Nandod	Bharuch	97.52	--	97.53	--	15.98	13.58	1082	1.27	12.31
2.		Naswadi	Vadodara	110.48	--	110.48	--	13.45	11.43	1.62	1.62	9.81
3.		Sankheda	Vadodara	498.59	72.26	426.33	--	76.13	64.71	9.27	9.27	55.44
4.		Tilakwada	Vadodara	255.77	122.30	133.47	--	36.98	31.43	1.43	1.43	30.00
5.		Pavi Jetpur	Vadodara	38.37	--	38.37	--	5.49	4.67	0.89	0.89	3.78
6.		Waghodia	Vadodara	544.64	--	347.06	--	49.33	41.93	5.80	5.80	36.13
7.		Savli	Vadodara	795.63	--	637.23	--	89.26	75.87	11.07	11.07	64.13
8.		Halol	Panchmahal	49.78	--	49.78	--	7.84	6.58	0.65	0.65	5.93
9.		Kalol	Panchmahal	84.66	--	84.66	--	11.11	8.44	2.31	2.31	7.13
10.		Godhara	Panchmahal	49.78	--	49.78	--	6.23	5.30	1.01	1.01	4.29
11.		Jambughoda	Panchmahal	5.26	--	5.26	--	0.79	0.67	0.16	0.16	0.51
TOTAL →				2530.49	550.54	1979.95	--	312.49	265.62	35.48	35.48	230.14
12.	II	Karjan	Vadodara	601.78	601.78	--	--	152.75	129.84	18.24	18.24	11.60
13.	II	Sinor	Vadodara	293.00	293.00	--	--	51.45	43.73	7.43	7.43	36.30
14.	II	Padra	Vadodara	525.70	418.86	--	106.84	93.44	79.42	13.80	13.80	65.62
15.	II	Vadodara	Vadodara	668.15	502.50	--	165.65	107.02	90.97	21.32	21.32	69.65
16.	II	Dabhoi	Vadodara	641.85	641.85	--	--	179.21	152.33	15.50	15.50	136.83
TOTAL →				2730.48	2457.99	--	272.49	583.87	496.29	76.29	76.29	420.00
17.	III	Amod	Bharuch	346.60	255.69	--	9091	42.74	36.32	11.06	11.06	25.26
18.	III	Vagra	Bharuch	152.07	--	--	152.07	--	--	--	--	--
19.	III	Jambusar	Bharuch	379.05	--	--	379.05	--	--	--	--	--
20	III	Bharuch	Bharuch	653.99	266.20	--	387.79	39.55	33.62	8.71	8.71	24.91
TOTAL →				1531.71	521.89	--	1009.82	82.99	69.94	19.77	19.77	50.17
21.	IV	Amod	Bharuch	116.78	--	--	116.78	--	--	--	--	--
22.	IV	Vagra	Bharuch	524.18	--	--	524.18	--	--	--	--	--
23.	IV	Jambusar	Bharuch	472.03	--	--	472.03	--	--	--	--	--
TOTAL →				1112.99	--	--	1112.99	--	--	--	--	--
SUM OF ALL REGION				7905.67	3530.42	1979.95	2395.30	978.65	831.85	188.50	131.54	700.31

A. GROSS ANNUAL RECHARGE BY RAINFALL & PRESENT IRRIGATION IN AREA SUITABLE FOR GROUND WATER DEVELOPMENT (G.W.D) IN MCM.
B. RECOVERABLE RECHARGE 85% OF COLUMN – 9.
C. ANNUAL DRAFT IN MCM (70% OF COL. – 11)
Source: GWRDC, Gandhinagar.

Artificial recharge is one method of modifying the hydrological cycle and thereby providing ground water in excess of that available by natural processes. It is accomplished by augmenting the natural infiltration of precipitation or surface water into underground formations by some method of construction, by pounding or spreading of water or by artificially changing the natural conditions or injecting the surface water into the ground aquifers.

There is a big gap between what is available and what can be used. The water resources availability therefore needs to be increased by adopting appropriate strategy.

6.3.1 Methods of Ground Water Conservation

- The water falling in the form of rain has to be prevented form going to sea to the extent possible. The farm ponds, the percolation tanks, surface check dams, underground check dams, and minor and major surface reservoirs are the means to be adopted for this.
- Measures for charging the ground water to increase ground water availability need to be taken up. Schemes like recharge wells and spreading channels are found to be very expensive. However by proper location of rain harvesting structures the ground water recharge can be enhanced without extra cost. Favourable geological features like fractures, faults and contact zones between two rock types are potentially very good locations where the recharge can take place. Such sites can be easily identified with help of satellite imageries. These are more significant for recharge of drinking water sources as it increases the dependability.

- Conservation of water stored in reservoirs and reduction of evaporation losses is important. This loss is proportionate to the water spared. Normally with full reservoir the total loss in a year would be of the order of 20 % whereas when the reservoir is low, the loss would be as high as 75 %. Since water is more precious in years when the replenishments are less special measures need to be considered. Evaporation can be considered. Evaporation can be partially prevented by using evaporation control measures like fatty alcohols. Such measures are being successfully used during drought conditions and the water so saved is of the order of 25 % of the normal evaporation loss.
- Technique for compartmentation is an effective tool for water saving. In this method, a small reservoir is constructed within the main reservoir and the water transferred to this small reservoir. This has been successfully used in Gujarat in 1988 drought. The results of this technique have been quite encouraging. The cost of constructing the compartment was within Rs. 20 lakhs. This reduced the evaporation substantially. The cost of water so saved would have Rs. 150 lakhs for bringing by tankers.
- Water use efficiency is a significant factor, which influences the water availability. The requirement for domestic and industrial uses is less than 15 % of the total water used in irrigation. If therefore irrigation can be made more efficiently, sufficient quantity of water can be saved for domestic and industrial uses.
- Adoption of conjunctive use of surface and ground water on irrigation systems is another way of increasing the area under irrigation. A number of projects in the country are now planning use of ground water by

mixing with surface water or independently using the same. This helps in bringing down the drainage problems also.

- Control of pollution is of vital importance, since it pollutes good water. Industrial effluents, as also effluents from the domestic sewage, need to be properly treated before they are discharged into streams. Recycling of the treated effluent is yet another way for conserving water. An impression exists that the treatment could be very expensive. A recent study has however shown that the cost of treating the domestic effluent to make it suitable for use in boiler feed and gardening is substantially less than getting water from distant sources by pipeline.
- Legislative measures for control on use of ground water. Unchecked and unplanned exploitation of ground water, in some parts of the country, has resulted into problems of salinity intrusion on the seacoast and high salinity in other areas. Sometimes these are associated with higher level of fluorides, and chlorides, which are harmful not only for, direct consumption, but also for use in irrigation. It is therefore necessary that by proper legislative measures ground water exploitation is checked in such areas and withdrawal in excess of the annual recharge is not permitted under normal circumstances.
- Reserve static ground water reserves for meeting domestic needs. The ground water forms a significant portion of the total water resources. This being more dependable, it has to be preferred for priority areas like domestic needs. A deliberate policy of reserving the static reserves for domestic requirements and permitting dynamic zone only to be used for agriculture need to be adopted. Both irrigation and

drinking water wells are so far planned on dynamic reserves. Irrigation being a strong competitor draws more water from these reserves and domestic requirements suffer, more particularly in drought years. A deliberate attempt has therefore to be made to tap the domestic water from greater depth as compared to the irrigation sources.

6.3.2 People's Participation and Role Of NGOs in Water Management

The need for community participation or the beneficiaries' participation in the water management has been realised sufficiently. The second Irrigation Commission in its report in the year 1972 has first recommended setting up of water users societies. However little progress was been made achieved in forming such societies. Water management especially in Irrigation Project will be successful only when the beneficiary farmers are fully associated in the day-to-day management of the water resources.

Experience on some of the irrigation projects have indicated that saving in water of more than 20 % is possible by use of these methods. The yields have also improved by 20 to 50 %. Now, in many parts of India where groundwater is under worst threat of depletion- there is a growing involvement of the community in rainwater harvesting and local groundwater recharge. At the frontline of this movement are regions like Rajasthan and Gujarat, where untold havoc and misery have resulted from depleting ground water. Here, rather than waiting for governments and high science to come to their rescue, ordinary people, communities, NGOs and religious movements have made groundwater recharge an community responsibility.

6.3.3 The Ground Water Recharge Movement in Gujarat

Saurashtra and North Gujarat are the two most drought prone regions of Gujarat state in Western India. In the decade of 80's, most part of these regions experienced 6-7 years of draught of varying intensity. In the regions that are fully dependent on rain fed or ground water irrigation sufficiency of ground water is basic to sustainable agriculture for water availability has deep socio-economic and political consequences. The popular movement has adopted two basic approaches. First- recharge of open wells by directing the surface runoff through a percolation cum filter pit directly in to the wells and second collecting the surface runoff at points convenient through a series of check dams build on streams, either natural or artificial and allow the collected runoff to seep in to recharge to ground water table.

Open well recharging method was popularize by Swadhyayee Parivaar They have recharged more than one lakh open wells from 1987 to 2002 only by people's contribution. This method was also well adopted by Saurastra Lok Manch they have created awareness among the farmers about the well recharging technique and urging them to find their own solutions to the recurring water problem.

Another example to emulate has been that of the work carried out by Tarun Bharat Sangh (TBS) in Alwar District of Rajasthan. Through a series of check dams the TBS has been able to raise water table in wells of 660 villages, have revived 5 seasonal rivers in to a perennial rivers. They have provided a low cost permanent solution to the problems of water scarcity and environmental degradation. (http://www.tarunbharatsangh.org)

6.4 Quality of Ground Water

Fresh water being one of the basic necessities for sustenance of life, the human race through the ages has striven to locate and develop it. Water, a vital source of life in its natural state is free from pollution but when man tampers the water body it loses its natural conditions. Ground water has become an essential resource over the past few decades due to the increase in its usage for drinking, irrigation and industrial uses. The quality of ground water is equally important as that of quantity. Remote sensing and GIS are effective tools for water quality mapping and land cover mapping essential for monitoring, modeling and environmental change detection

GIS can be a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale, keeping this in view, Integrated GIS and field studies for the evaluation of the impacts of ground water quality on the land use change. GeoMedia Professional and GeoMedia Environment GIS software was used to map, query, and analyze the data in these studies.

Applications of geostatistics can be found in different disciplines ranging from the classical fields of mining and geology to soil science, hydrology, meteorology, environmental sciences, agriculture, and even structural engineering. Kriging is used widely in geology, hydrology, environmental monitoring, and other fields to interpolate spatial data (Stein 1999 & Muralidhara 2002). For the current study Kriging method is used for interpolating well data.

The ground water data was collected for 2058 open wells from Sardar Sarovar Narmada Nigam Limited (SSNNL) and Gujarat Water resources development corporation (GWRDC). The data comprised sub-surface water level, electric-conductivity (EC) and pH (Alkalinity) for the year 1981 (pre and post monsoon), 2000 (pre and post Monsoon) and 2001 (pre monsoon). The researcher had collected ground water samples for 258 open wells from the study area for the year 2003 (Pre & Post Monsoon). The water samples were analysed for EC, pH.

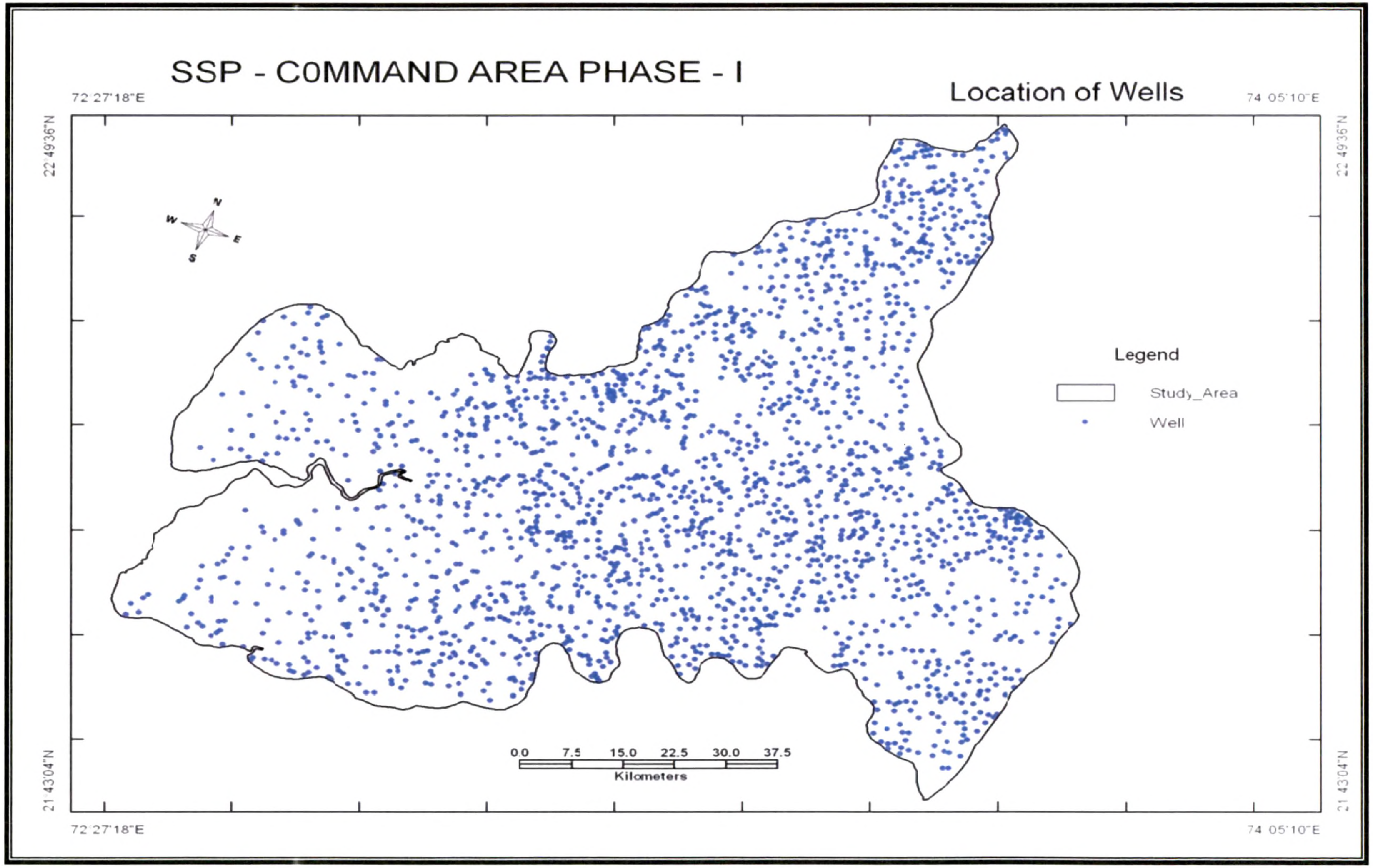

SSP - COMMAND AREA PHASE - I
Location of Wells
72°27'18"E
74°05'10"E
22°49'36"N
21°43'04"N
N
W
E
S
Legend
Study_Area
Well
0.0
7.5
15.0
22.5
30.0
37.5
Kilometers

Figure 6.6

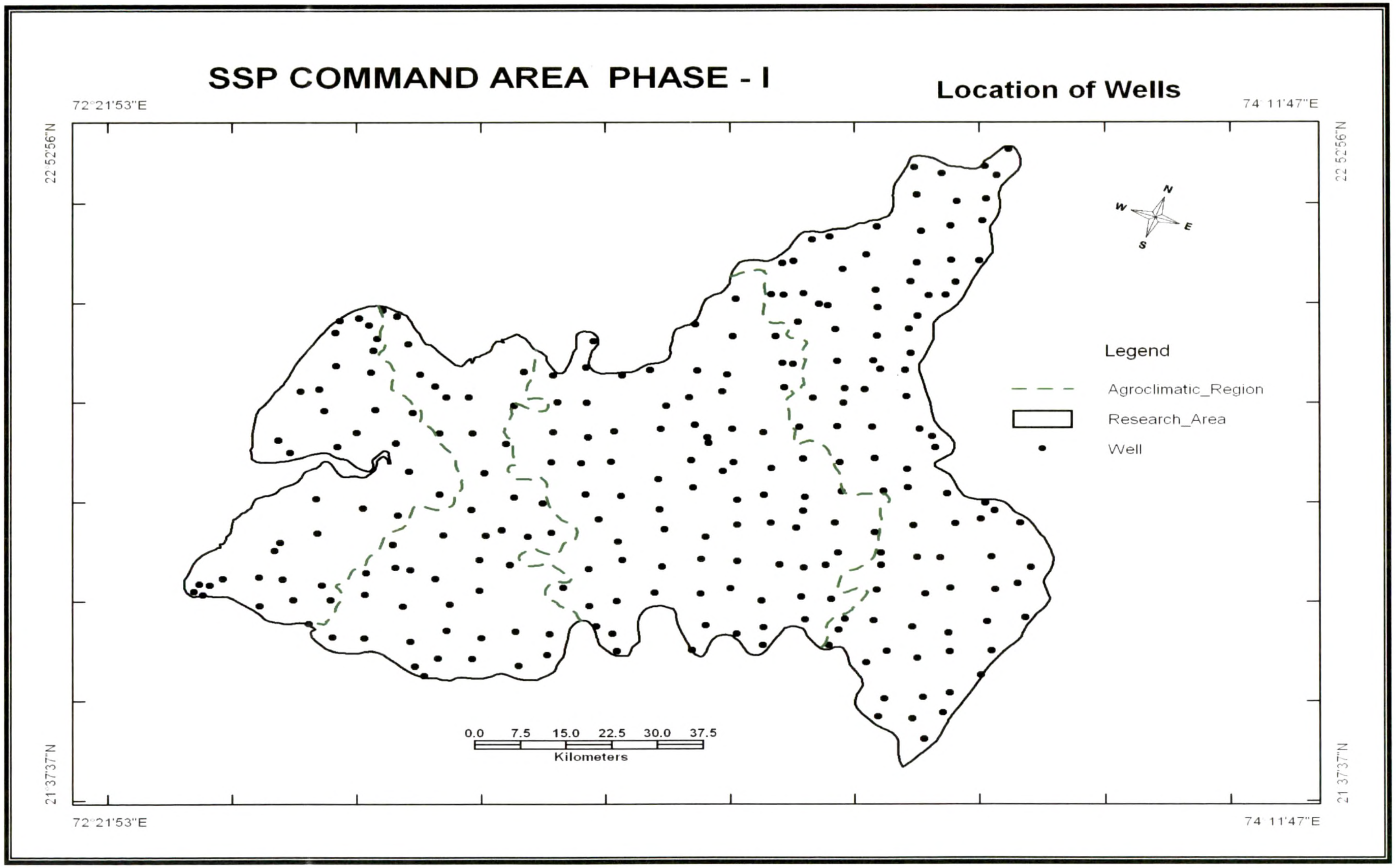

SSP COMMAND AREA PHASE - I
Location of Wells
72°21'53"E
74°11'47"E
22°52'56"N
21°37'37"N
N
E
S
W
Legend
Agroclimatic_Region
Research_Area
Well
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers

Figure 6.7

and different salts like Ca (calcium), Mg (Magnesium), Na (Sodium) K (Potassium). For selection of samples well, the entire study area was divided in grid of 6 x 6 km and one well was selected from each grid (Figure. 6.6 & 6.7).

Making use of ground water data of sub surface water levels, hydroisobath were plotted for the year 1981 and 2000 for pre and post monsoon. Contours were plotted for EC and ph data using Kriging method. The thematic maps thus generated, reveals the state of quality of ground water and the levels in the study area, before and after the monsoon (Figures 6.8 to 6.15).

The samples were collected to study characteristics of ground water. The water samples collected in the month of May represent the quality of groundwater in pre-monsoon and those in October represent the quality of ground water during post-monsoon.

Based on the chemical analysis results, various plans showing salinity distribution in the area during pre-monsoon and post-monsoon period are drawn and discussed. The main objective of the study and analysis of water samples was to observe the seasonal change in the quality of groundwater. In the post monsoon period because of rainfall recharge inputs and its dilution impact the salinity in groundwater reduces and the same is marginally higher during pre-monsoon period. There are few locations where such seasonal changes do not. Occur since the aquifer being in hydraulic continuity with surface water body, the behaviour becomes independent of seasonal change.

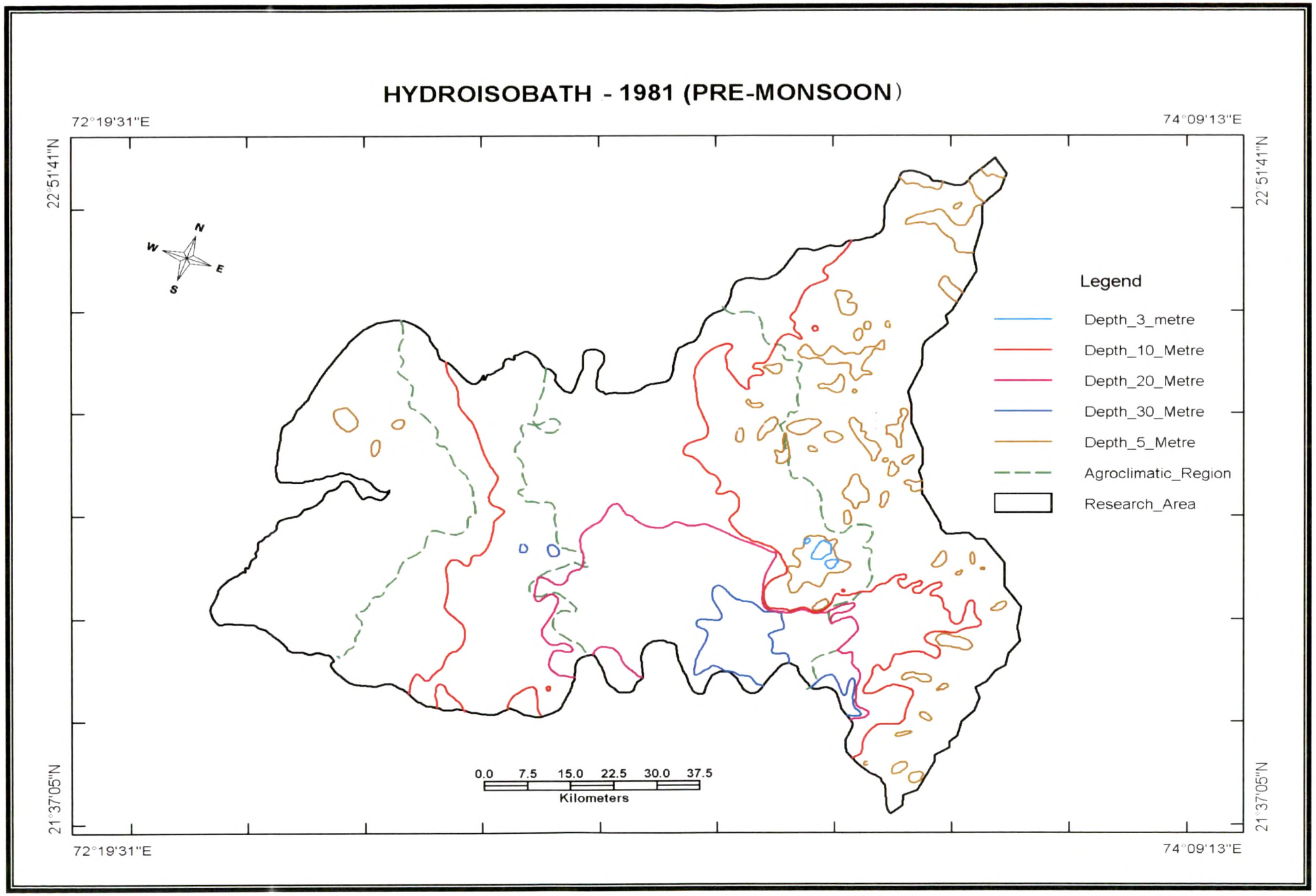

HYDROISOBATH - 1981 (PRE-MONSOON)
72°19'31"E
74°09'13"E
22°51'41"N
21°37'05"N
N
W
E
S
Legend
Depth_3_metre
Depth_10_Metre
Depth_20_Metre
Depth_30_Metre
Depth_5_Metre
Agroclimatic_Region
Research_Area
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers

Figure 6.8

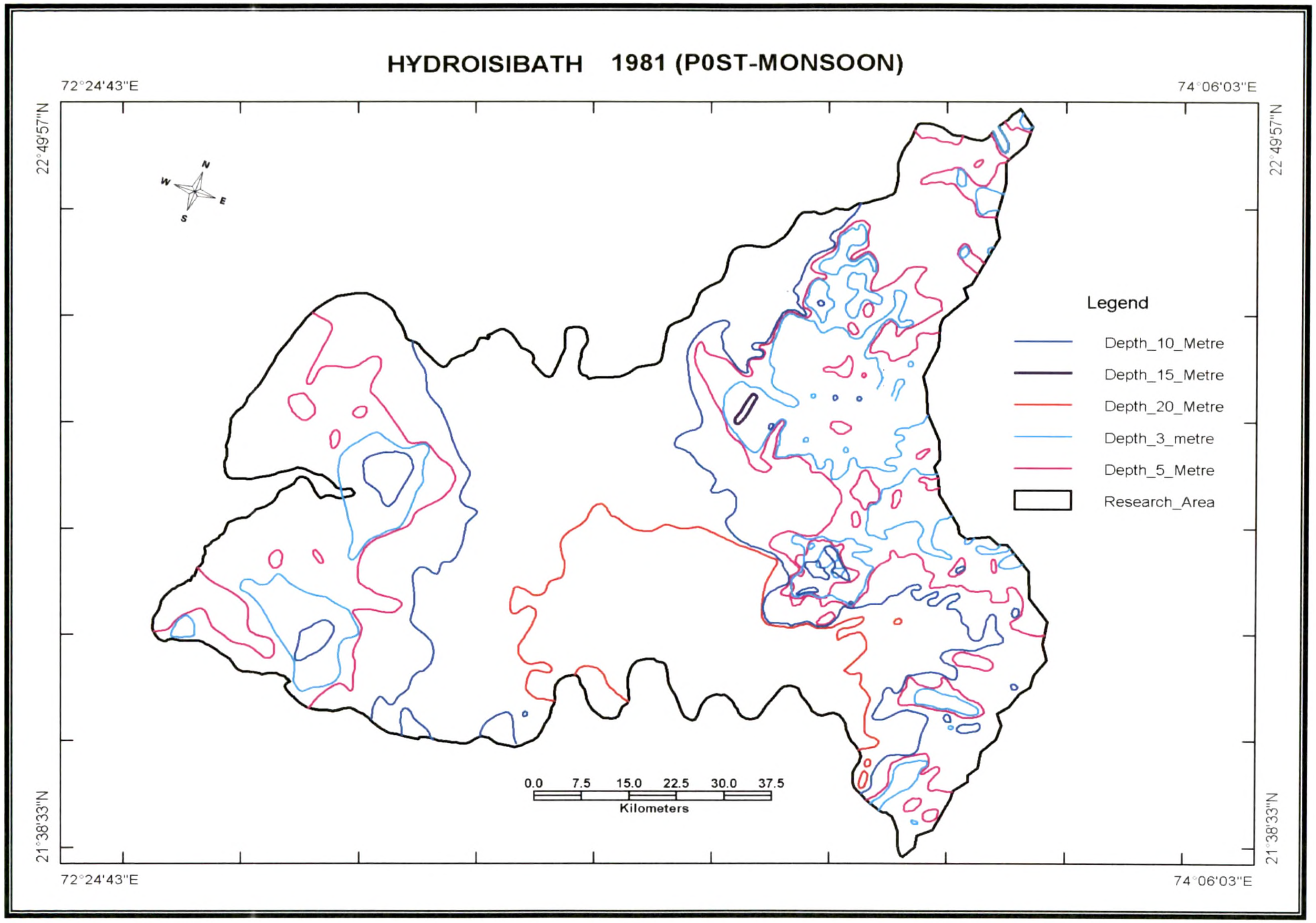

HYDROISIBATH 1981 (P0ST-MONSOON)
72°24'43"E
74°06'03"E
22°49'57"N
21°38'33"N
N
W
E
S
Legend
Depth_10_Metre
Depth_15_Metre
Depth_20_Metre
Depth_3_metre
Depth_5_Metre
Research_Area
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers

Figure 6.9

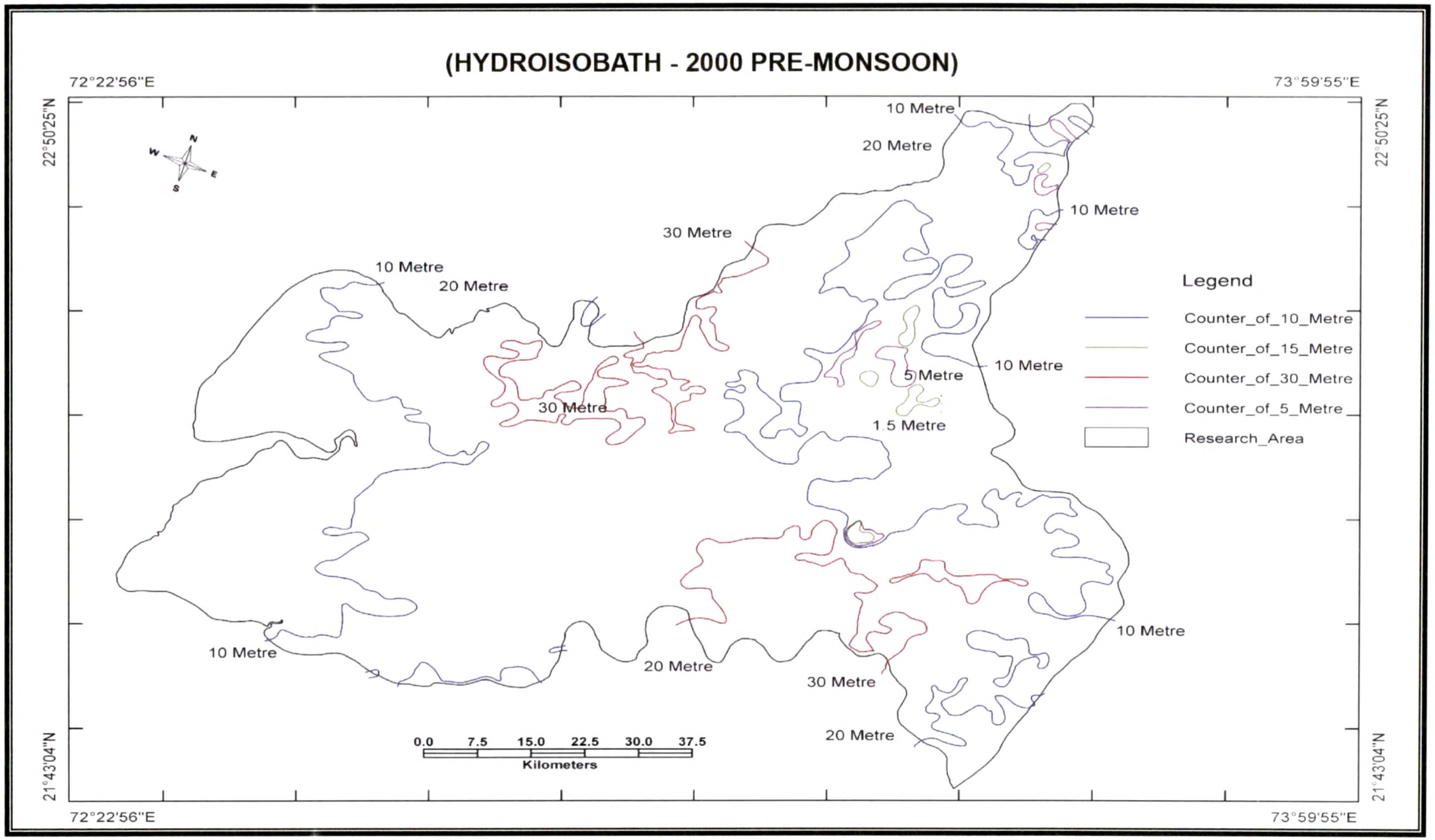

(HYDROISOBATH - 2000 PRE-MONSOON)
72°22'56"E
73°59'55"E
22°50'25"N
21°43'04"N
N
W
E
S
10 Metre
20 Metre
30 Metre
5 Metre
1.5 Metre
30 Metre
Legend
Counter_of_10_Metre
Counter_of_15_Metre
Counter_of_30_Metre
Counter_of_5_Metre
Research_Area
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers

Figure 6.10

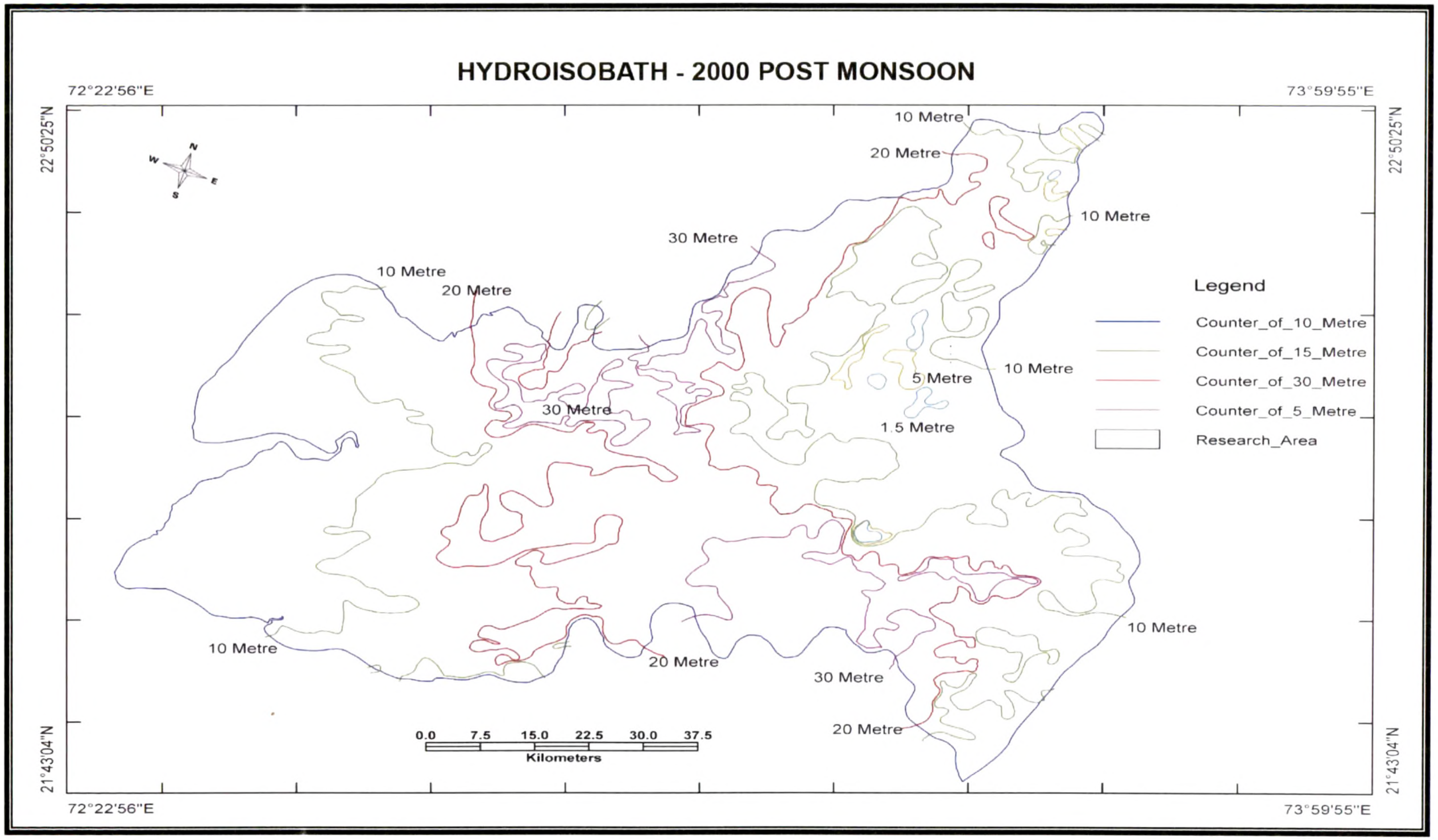
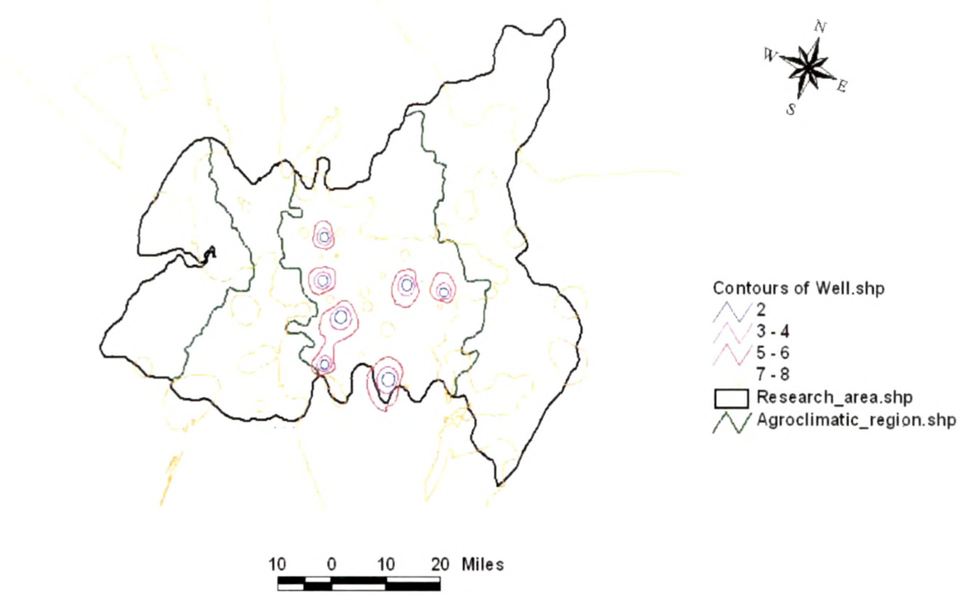

HYDROISOBATH - 2000 POST MONSOON
72°22'56"E
73°59'55"E
22°50'25"N
21°43'04"N
10 Metre
20 Metre
30 Metre
5 Metre
1.5 Metre
Legend
Counter_of_10_Metre
Counter_of_15_Metre
Counter_of_30_Metre
Counter_of_5_Metre
Research_Area
0.0 7.5 15.0 22.5 30.0 37.5
Kilometers
N
S
E
W

Figure 6.11

Ground Water Quality – 1981 (Pre-Monsoon)
(pH)



Ground Water Quality – 1981 (Post-Monsoon)
(pH)

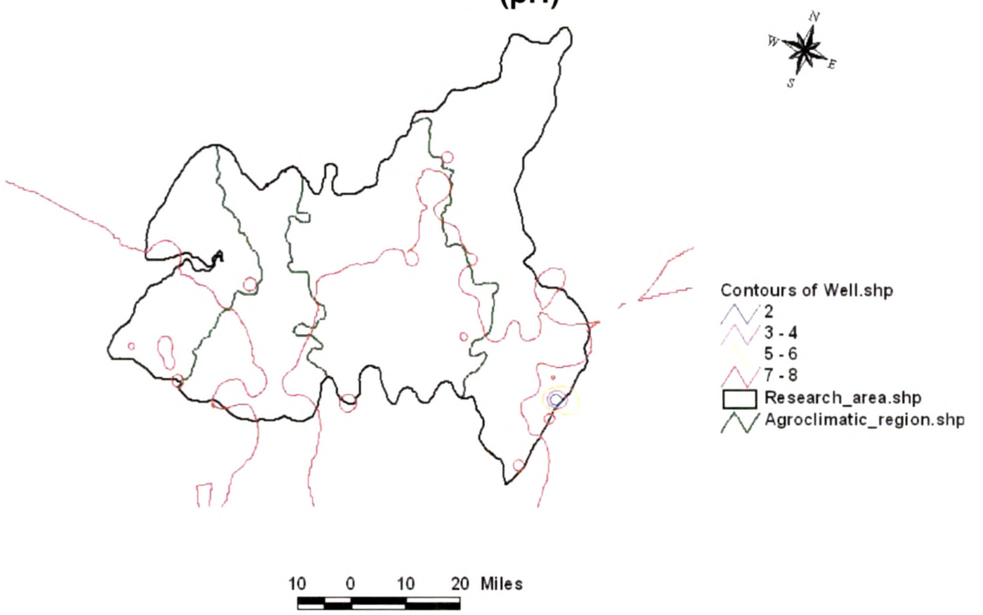
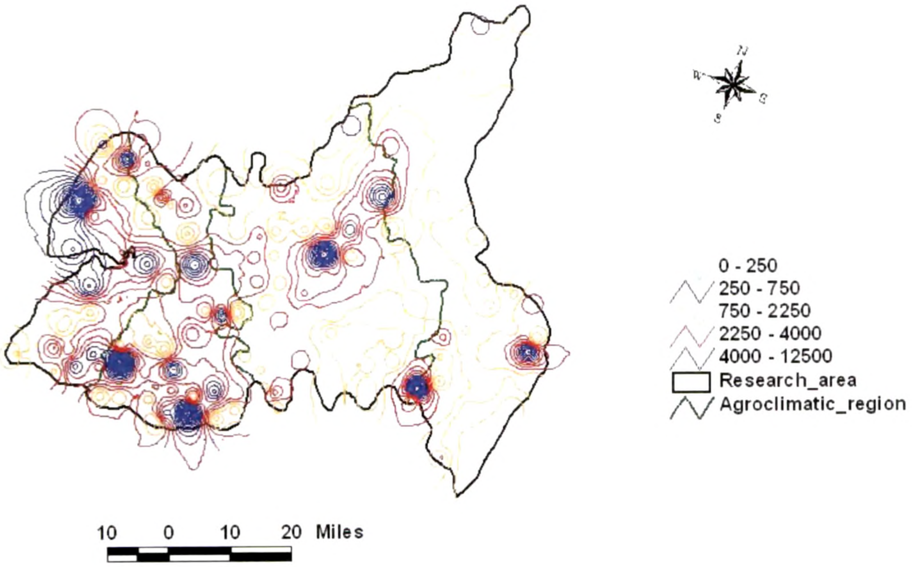


Figure 6.12

Ground Water Quality – 1981 (Pre-Monsoon)
(EC)



Ground Water Quality – 1981 (Post-Monsoon)
(EC)

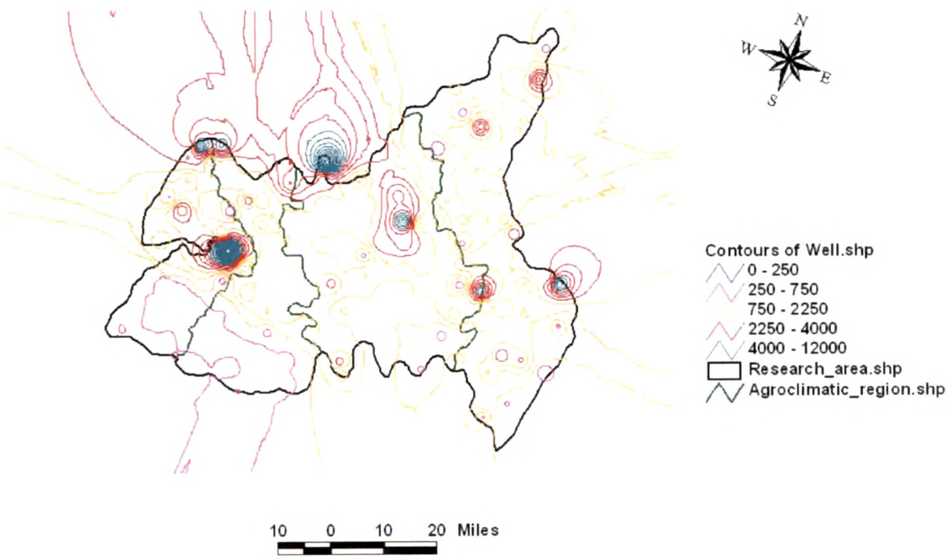
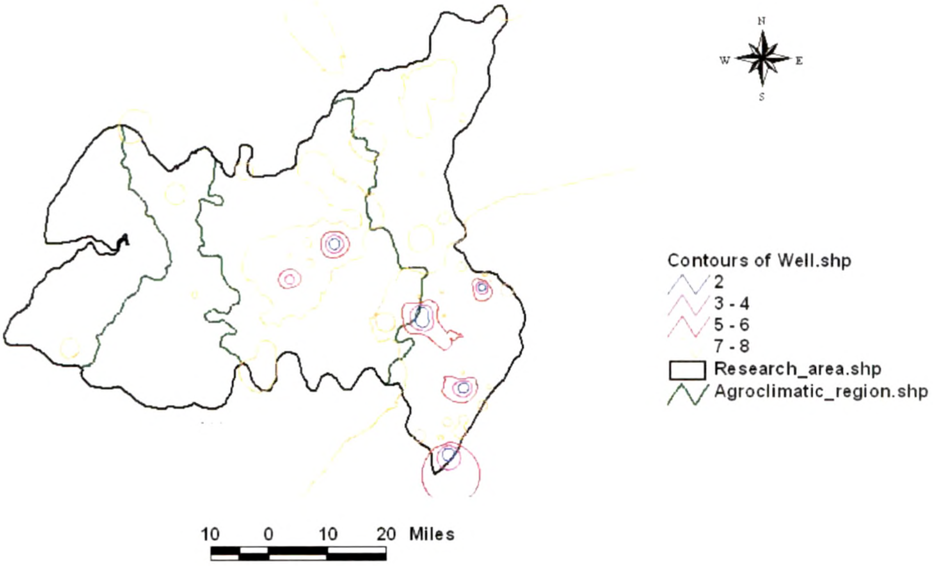


Figure 6.13

Ground Water Quality – 2000 (Pre- Monsoon) (pH)



Ground Water Quality – 2000 (Post- Monsoon) (pH)

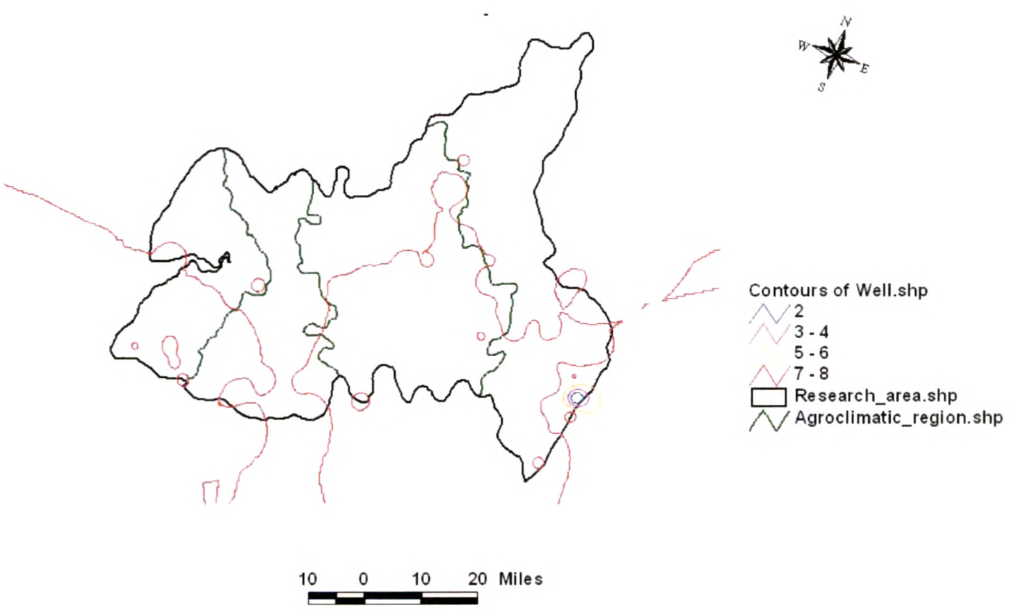
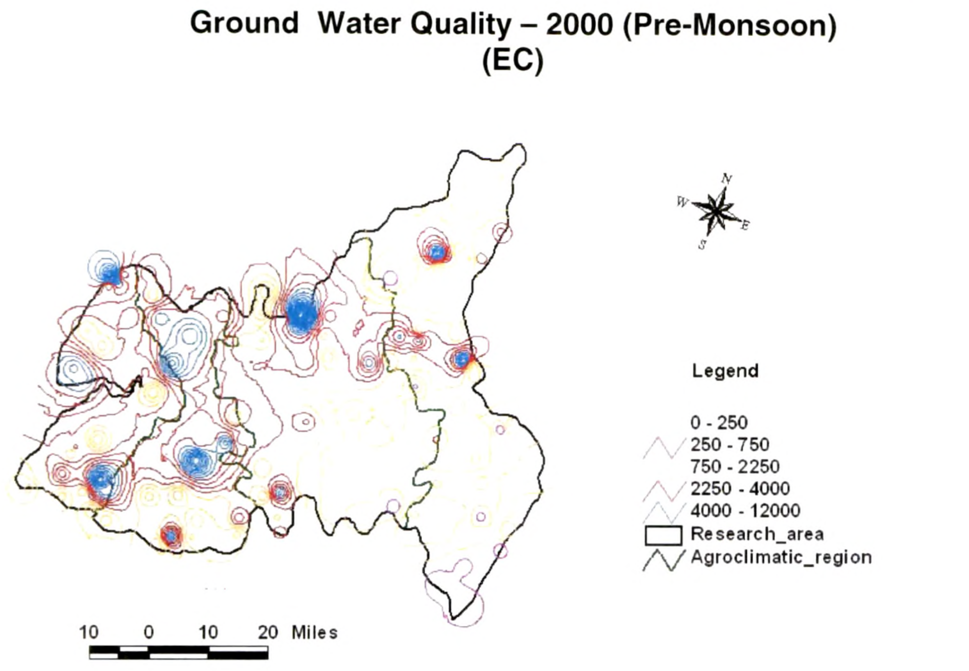


Figure 6.14


Ground Water Quality – 2000 (Pre-Monsoon)
(EC)
N
W
E
S
Legend
0 - 250
250 - 750
750 - 2250
2250 - 4000
4000 - 12000
Research_area
Agroclimatic_region
10 0 10 20 Miles

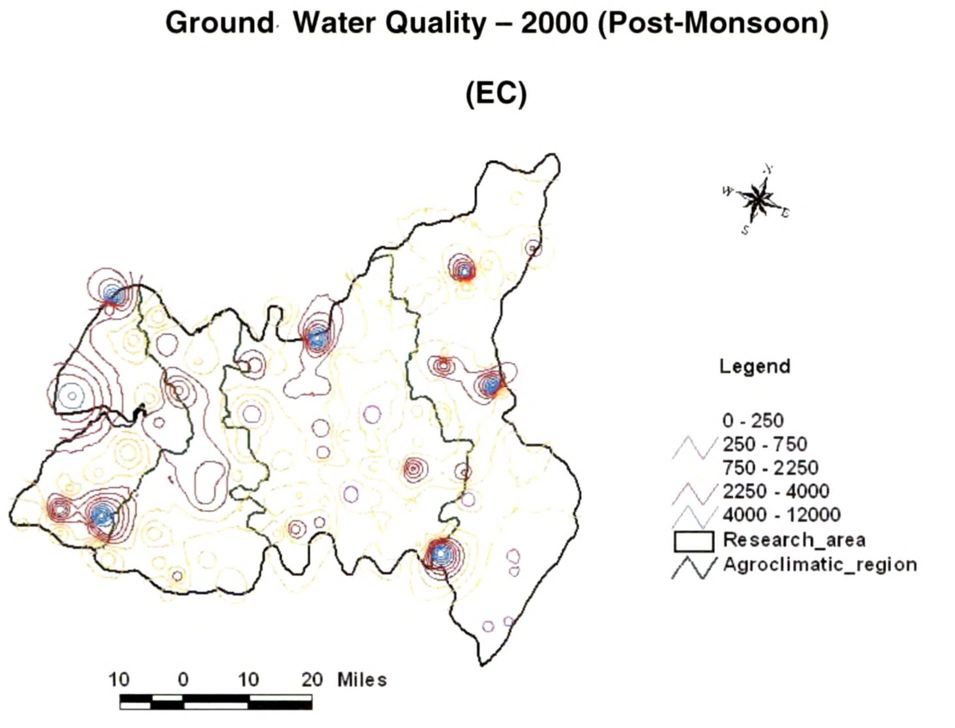

Ground Water Quality – 2000 (Post-Monsoon)
(EC)
N
W
E
S
Legend
0 - 250
250 - 750
750 - 2250
2250 - 4000
4000 - 12000
Research_area
Agroclimatic_region
10 0 10 20 Miles

Figure 6.15

6.4.1 Total Dissolved Salts Plan (Pre-Monsoon)

In the Mahi-Narmada doab area, the T.D.S. content ranges between 205 ppm at Shukalthirth in the southern parts to 13500 ppm at Kododra near sea shore in the south-west.

In eastern part the quality of groundwater is generally good as compared to western parts. In northern and southern parts of the area the quality of ground water is good, whereas in the northern and central parts around villages Hansapura, Kotambee, Harni, Masar and Alamgir the quality of ground water is saline. Higher salinity in ground water is also observed at villages Jojwa, Alindra Gothada, Garadiya, Nava Rampura, Mastpur and Khervadi (Savli and Waghodia Talukas of Region – I) in the North -Eastern part of the study area, which may be a local phenomena (Salinity is inherent in nature). The salinity in groundwater in alluvial formation is high as compared to rocky formation

6.4.2 Total Dissolved Salts Plan (Post-Monsoon)

The TDS plan of post-monsoon period fallows almost the same trend as that of pre-monsoon. In this period the Total Dissolved Salts in groundwater range between 280 ppm at Shukalthirth in the southern part to maximum 12500 ppm at Kododra in the south-western parts. In general quality of groundwater is good in the eastern, northern and southern parts of the area as it is saline in the north-central parts of the study area. The area with higher salinity in groundwater is almost the same as those during the pre-monsoon.

A comparative stuffy of TDS plan of 1981 and 2000 indicates similarity in salinity distribution in region I and II, but this is not true with region III and IV. Since 1981 to 2000, it can be observed that, salinity levels are increasing from region IV to region III and some parts of region – II (e.g. Village Masar of Padra Taluka). Thus the salinity ingress is from west to east of the study area.

In an area covering 3500 sq km. the TDS in ground water are more then 2000 ppm. This area falls in western, central and eastern parts (parts of Savli and Waghodia Taluka) i.e. entire region area IV and III of Narmada Command.

6.5 Classification of Ground Water

In order to study the geochemical type of groundwater, its chemical analysis results of May 2003 (pre and post monsoon) are considered, which show that the groundwater in eastern part i.e. Region – I is generally of Na/Mg-Ca-Hco_3-CL-So_4 type except around Jojwa, Garadia and Kherwadi (Savli & Waghodia Talukas) where the ground water is Na-Mg-Ca-CL-Hco_3 -So_4 type. In central parts covering Region – II, the groundwater is of Na/Mg-Ca-Hco_3-CL-So_4 to Na-Mg-Ca-CL-Hco_3-So_4 type, except Hansapura and Masar where the ground water is Na-Mg-Ca-CL--So_4- Hco_3 type. The groundwater in Region – II, is of Na-Mg-Ca-Hco_3-CL-So_4, Na-Mg-Ca-CL-Hco_3-So_4 and Na-Mg-Ca-CL--So_4-Hco_3 type area. In region IV the ground water is Na-Mg-Ca-CL--So_4-Hco_3 type which indicates deterioration in quality of groundwater from recharged area to discharge area. This characteristic of groundwater may be due to inherent salinity in the aquifers in the coastal areas.

6.5.1 Suitability of Ground Water for Irrigation

Generally suitability of ground water for irrigation is considered with the following norms in table 6.2 & 6.3.

Table 6.2: Irrigation Water Quality

CLASS	EC (Mhos/cm)	USE
C_1 - Low Salinity	< Then 250	Can be used for Irrigation
C_2 – Medium Salinity	250 – 750	Can be used for irrigation. Moderate amount of leaching occurs
C_3 - Medium High salinity	750 – 2250	Can be used, but with certain limitations.
C_4 – High Salinity	2250 – 4000	Cannot be Used for Irrigation
C_5 – Very High Salinity	> Then 4000	Cannot be Used for Irrigation

Table 6.3: Sodium Absorption Ratio (SAR)

Value	Use
Up to 10	Good, Suitable for all soils.
10-18	Moderate, Suitable for loamy to sandy soils.
18-26	High, not suitable.
> 26	Unsuitable

According to U.S Salinity Laboratory suitability of ground water for irrigation is based on electrical conductivity and SAR values. The conductivity is shown as C1, C2, C3, C4 and C5 values (table.) where SAR values are represented as S1, S2, S3 AND S4 on the basis of analytical results of water samples of 258 wells for the month of May 2003, U.S Salinity diagram given in (Figure. 6.16 to 6.21)

It is seen from the study area salinity map, that groundwater in south, north eastern and south-central parts covering Regions – I, II and small area of Region III fall under C2S1 and C3S1 categories, considered to be suitable for irrigation all types of soils. While the groundwater in western part and some part of north-eastern parts, covering Regions I and IV fall in C4S2, C4S3, C4S4, C5S1, C5S2, C5S3 and C5S4 categories which are generally not suitable for irrigation. In north central parts covering Regions II and III, the quality of groundwater falls under C3S2 AND C4S1 categories and normally suitable for irrigation in loamy and sandy soils.

On the basis of analytical result of 258 water samples the irrigation suitability of ground water is classified as below.

(A) CLASS – I WATER (C2S1, C3S1)

Region – I, II, and III in extreme north, south and eastern rocky parts fall in this class. Generally this type of ground water is suitable for irrigation in all type of soils. The ground water is below 2250 Mhos/cm and SAR value less then 10.

(B) CLASS – II WATER (C3S2, C4S1)

The ground water falling in this class is generally not suitable for irrigation in clayey soils. The ground water samples fall under this class representing mainly north-central part covering Region II and III. The area covers some parts of Jambusar, Padra and Vadadora talukas. This type of water has EC ranging between 2250 to 4000 Mhos/cm and SAR value between, 10 to 18. Such waters can be used for irrigation in well drained soils.

(C) CLASS – III WATER (C4S2)

The ground water samples falling under this class are represented in the north-eastern part and western parts of the study area, covering Region I and Region IV. This type of water with EC up to 4000 Mhos/cm and SAR value between, 18 to 26, may create salinity hazard if used in clayey soils. This type of water may be used for irrigation only after applying suitable chemical amendments to the soils.

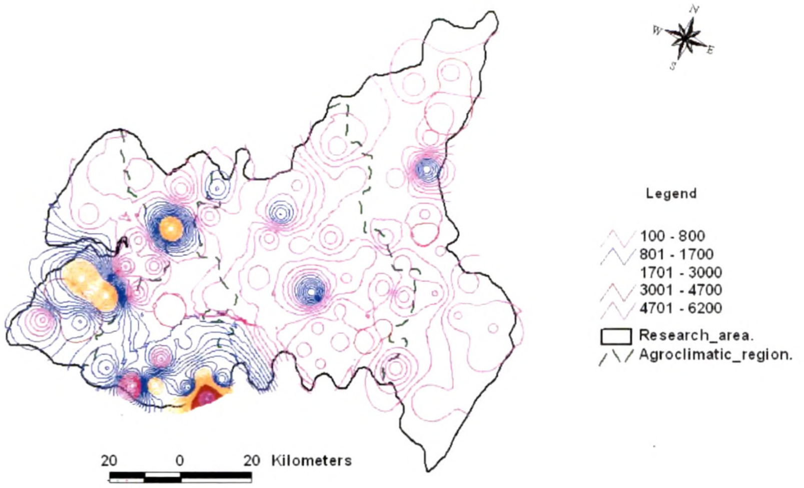
(D) CLASS – IV WATER (C4S3, C4S4, C5S1, C5S2, C5S3, and C5S4)

Water samples in this class are represented mainly in the western parts of the study area. This type of groundwater has EC above 4000 Mhos/cm and SAR valuing greater then 26, is generally not suitable for irrigation in any type of soils. (Table 6.4)

Table 6.4: Regional Distribution of Irrigation water Class

IRRIGATION WATER CLASS	AREA COVERED UNDER DIFFERENT REGION IN sq.km.				
	REGION – I	REGION - II	REGION - III	REGION - IV	TOTAL
CLASS - I	1619.77	1499.43	418.20	-	3537.40
CLASS - II	41.33	1075.37	83.46	-	1200.16
CLASS - III	315.60	32.10	-	-	347.70
CLASS - IV	553.72	123.58	1379.04	771.12	2827.46
TOTAL	2530.42	2730.48	1880.71	771.12	7905.60

Ground Water Quality – 2003 (Pre-Monsoon) (Na)



Ground Water Quality – 2003 (Post-Monsoon) (Na)

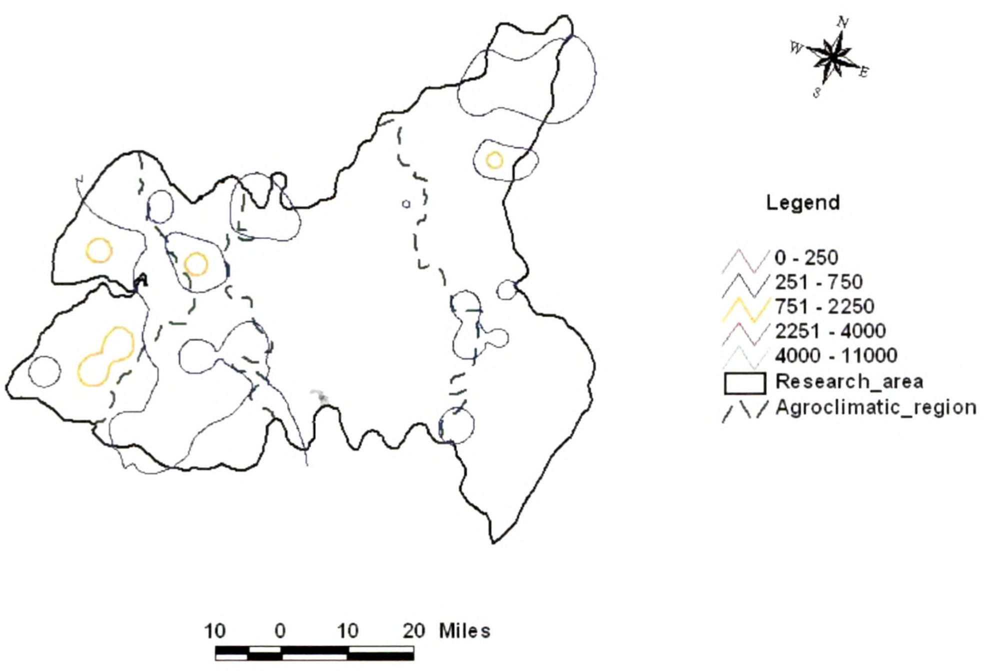
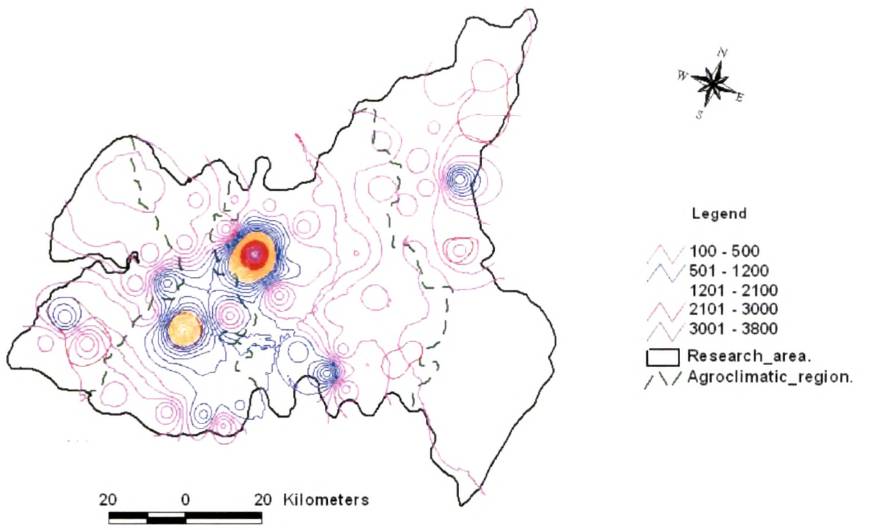


Figure 6.16

Ground Water Quality – 2003 (Pre-Monsoon) (Mg)



Ground Water Quality – 2003 (Post-Monsoon) (Mg)

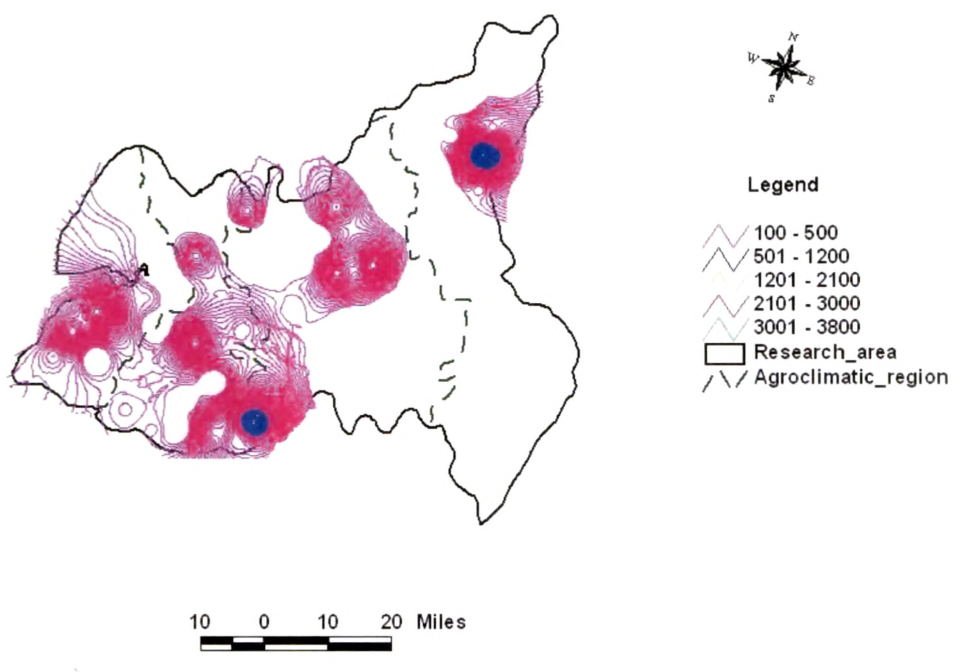
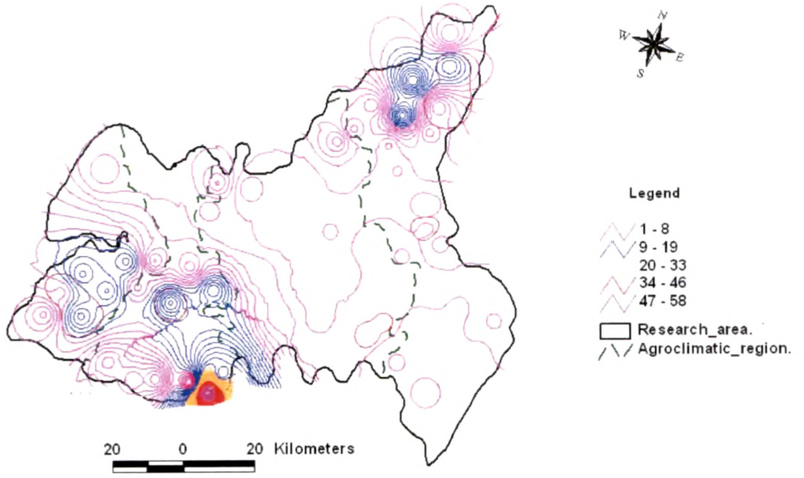


Figure 6.17

Ground Water Quality - 2003 (Pre Monsoon)

K



Ground Water Quality – 2003 (Post-Monsoon)
(K)

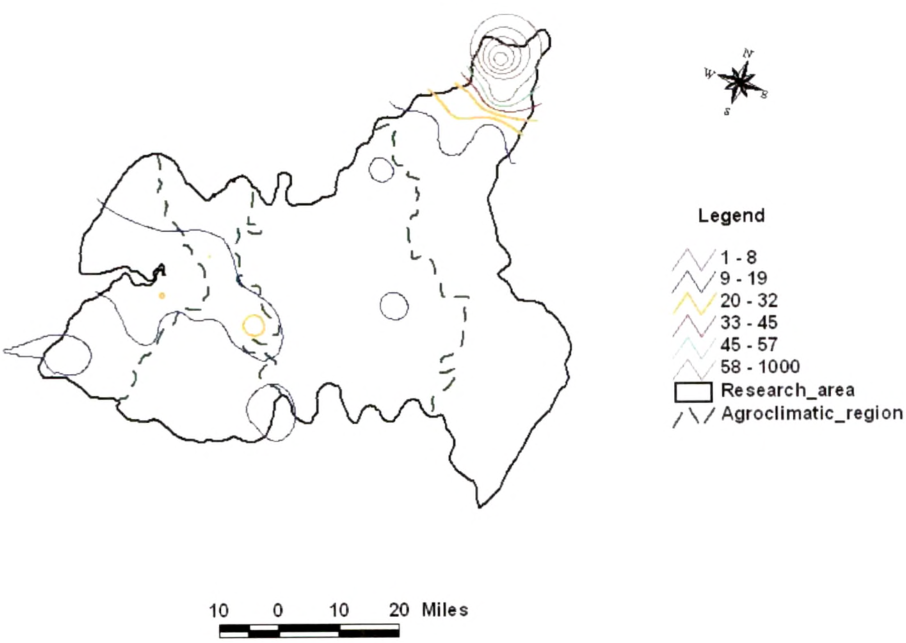
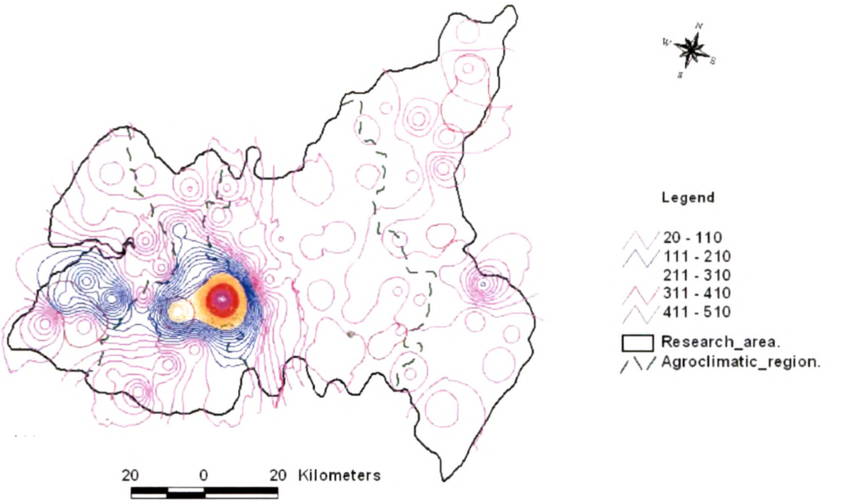


Figure 6.18

Ground Water Quality – 2003 (Pre-Monsoon)
(Ca)



Ground Water Quality – 2003 (Post-Monsoon)
(Ca)

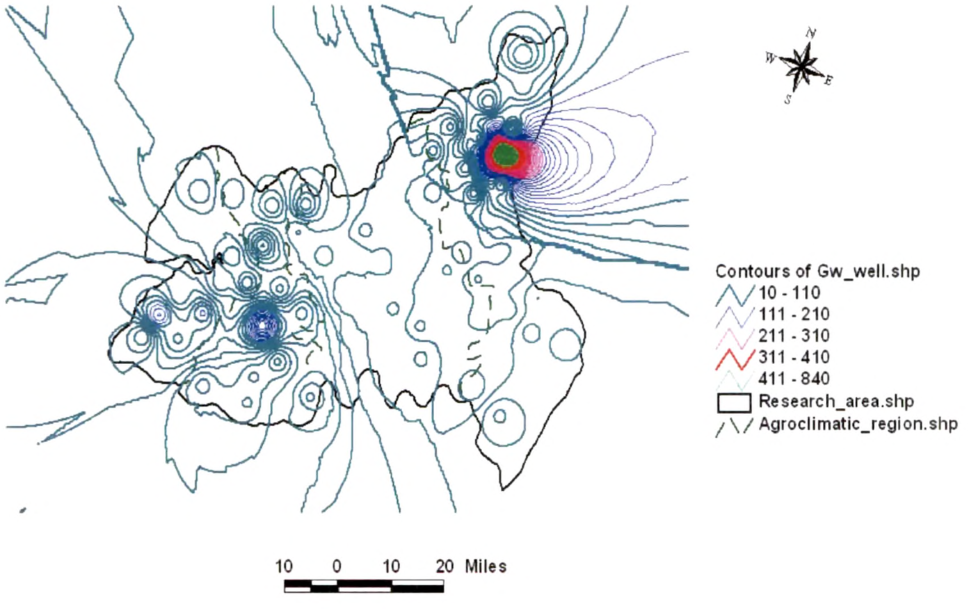
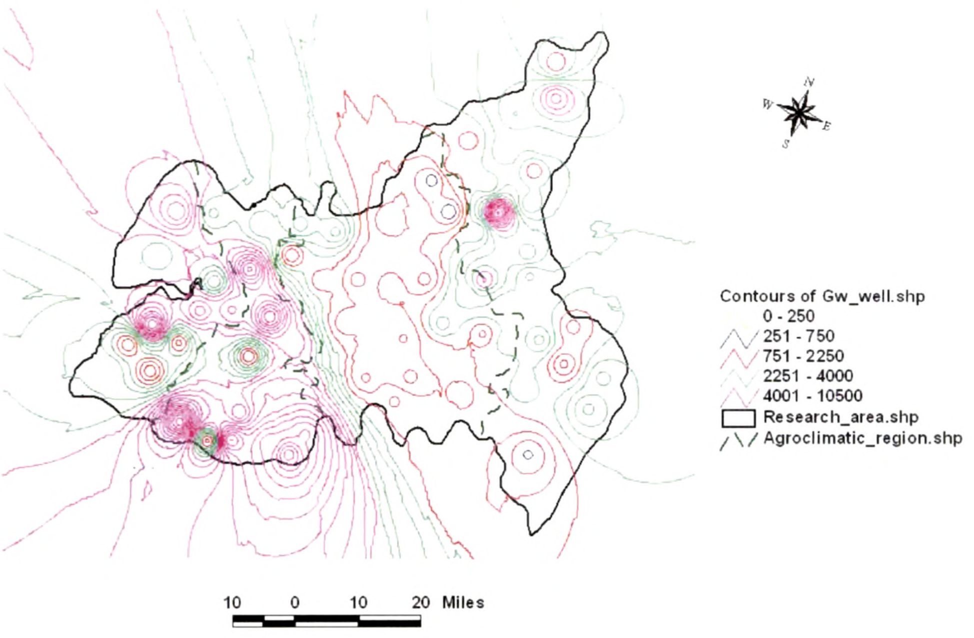


Figure 6.19

Ground Water Quality – 2003 (Pre-Monsoon) (EC)



Ground Water Quality – 2003 (Post-Monsoon) (EC)

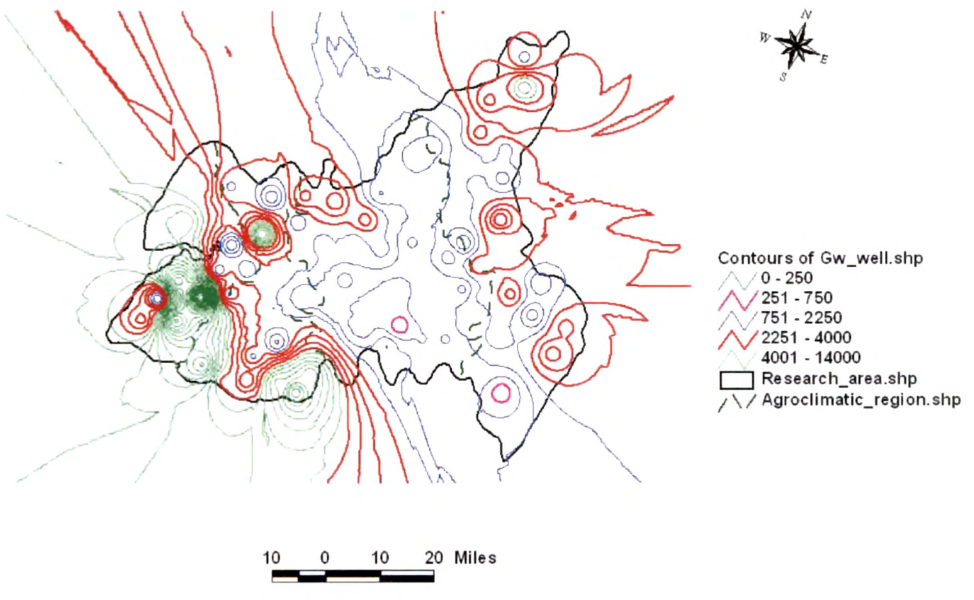
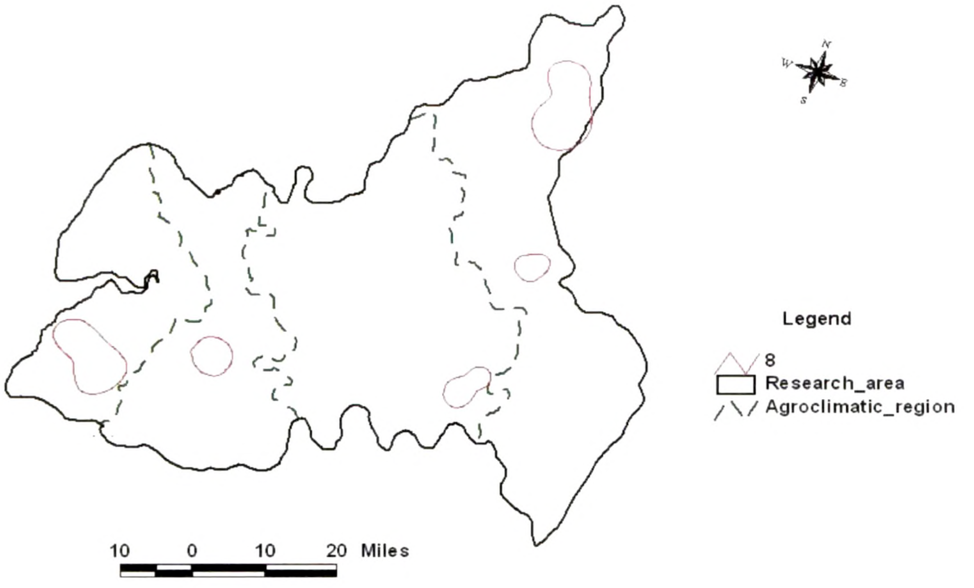


Figure 6.20

Ground Water Quality – 2003 (Pre-Monsoon)
(pH)



Ground Water Quality – 2003 (Post-Monsoon)
(pH)

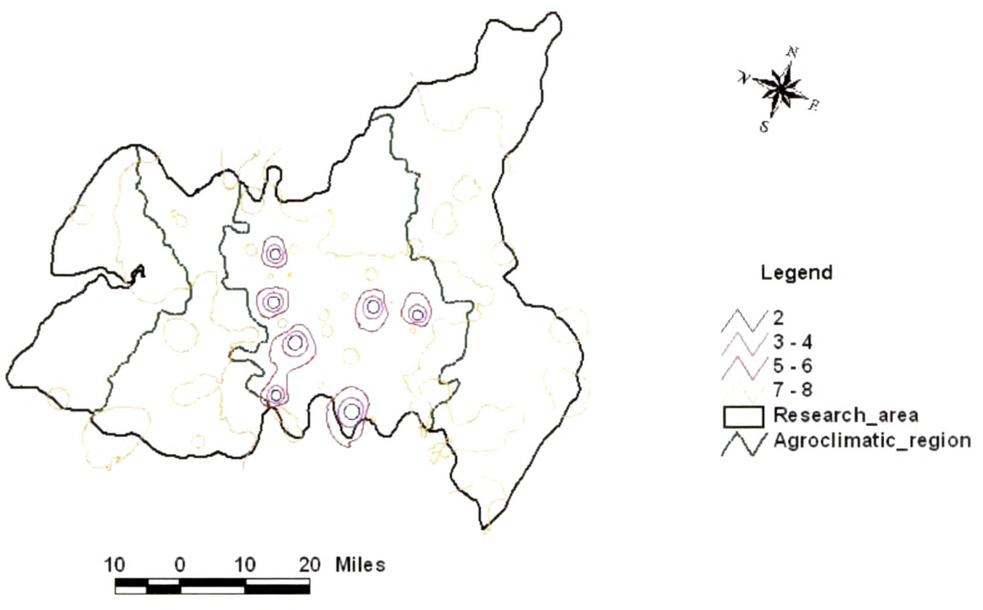


Figure 6.21

6.5 Groundwater Budgeting

The groundwater recharge depends on the various inputs like rainfall, canal seepage, return inflow from irrigation fields, seepage from tanks, inflow from influent rivers etc. the groundwater balance from rainfall can be computed by using precipitation and evaporation data. Since the data generated from the stations installed in the study area are for a short period could not be used for evolving long term balances.

For calculating annual ground recharge, the formula given by groundwater estimation committee, Ministry of Irrigation, Government of India has been used. The total gross recharge is worked out to 978.65 MCM/Yr. The formula used for estimation is as under:

$$\text{Recharging during Monsoon} = \frac{\Delta S + Dw + Rs - Rigw - Ris}{\left\{ \dfrac{\text{Normal Monsoon} = Rf}{\text{Annual Monsoon} = RF} + Rs + Ris \right\}}$$

Where ΔS = Change in groundwater storage volume (water level fluctuation during pre and post monsoon period. (May and October)

Dw = Gross groundwater draft during monsoon.

Rs = Recharge from Canal Seepage during monsoon.

Rigw = Recharge from recycled water from groundwater irrigation during Monsoon.

Ris = Recharge from recyeled water from surface water irrigation monsoon in MCM

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