Study on Groundwater Salinization and Formulation of Management Strategies for the Coastal Aquifers of Mundra Region, Kutch District, Gujarat State

A Thesis Submitted to
The Maharaja Sayajirao University of Baroda
For the Degree of
Doctor of Philosophy in Geology

BY

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CERTIFICATE

This is to certify that **Ms. Sazina A. Bhimani** has carried out her doctoral research work under my supervision. The work embodied in this thesis represents the results of her independent original work and has at no time been submitted for any other degree.

(SAZINA A. BHIMANI)
Candidate

(Dr. K.C. TIWARI)
Supervisor

Dedicated

To

my loving family

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Place: Vadodara
Date: July 04, 2013

(Sazina A. Bhimani**)**

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Chapter - I

INTRODUCTION

CHAPTER – I

INTRODUCTION

PREAMBLE

Water is an essence of life. It is a very vital resource on earth gifted by nature and a very essential resource for any type of development worldwide. Water resource is available as surface water and groundwater resources. Groundwater is most sustainable and reliable resource than surface water. Availability of groundwater depends on local hydro-geological condition. In groundwater potential area, each one can easily access groundwater which makes it more significant resource over surface water. These characteristics of groundwater sometimes become reasons for it's over development. Any type of economic development depends on land and water resource potential of the area. Here groundwater as water resource becomes more priority due to easy accessibility. The problems of arid regions' in terms of water resource availability and its potability need special attention. Scanty rain and paucity of resource, water crisis always remain as main natural hazard for the region. Therefore, in arid areas groundwater potential act as backbone for water supply mainly to subsist demand for drinking water and traditional occupation such as agriculture and animal husbandry.

Kachchh, the western most district of Gujarat is an arid region characterized by water crisis and repetitive drought cycles. It has a very low potential of surface and groundwater resources. Hydro-geologically, Kachchh is bestowed with huge pile of sedimentary sequence. However, most of the geological formations are deposited in marine environment having inherent salinity. Therefore, availability of potable groundwater is highly restricted. Only Bhuj Formation sandstone of Cretaceous period has been deposited in fluvial environment. Along with this, Kankavati Formation sandstone of Tertiary age also provides good quality groundwater in coastal track of the district. These two aquifers are backbone for drinking and irrigation water supply. The overall resource potential of the region, mainly coastal resources become one of the most added attraction and ideal regions for industrial development. Post January 26, 2001 earthquake period, the Kachchh has attracted large number of industries from world wide due to well laid industrial policies and tax holidays, offered by the State Government. The Mundra Taluka (study area) had shared the maximum industrial investment amongst other regions of Kachchh. Along with industrialization, population and basic infrastructure have also grown. Resultantly, manifold increase in industrial and domestic water demands have put groundwater resource of the taluka under tremendous stress and also adversely affected long practiced agricultural industries of the region. Area being coastal region, over exploitation of groundwater has invited the threat of seawater intrusion in the aquifers having considerable environmental implications. Therefore, any development which is beyond the carrying capacity of land, certainly going to cause environmental imbalance in the area. Realizing this very fact, the candidate has opted for Mundra Region to pursue her doctoral research entitled “Study on Groundwater Salinization and Formulation of Management Strategy for the Coastal Aquifer of Mundra Region of Kachchh District, Gujarat”.

As the study pertains to evaluation of water resources of the study area, the candidate has adopted watershed approach.

STUDY AREA

Mundra region, the southern most taluka of Kachchh district is geographically bounded between N 22^0 44' 26" to 23^0 02' 59.3" latitudes and E 69^0 30' 00" to 69^0 58' 54.4" longitudes and cover about 888 km^2 area. (Fig. 1.1)

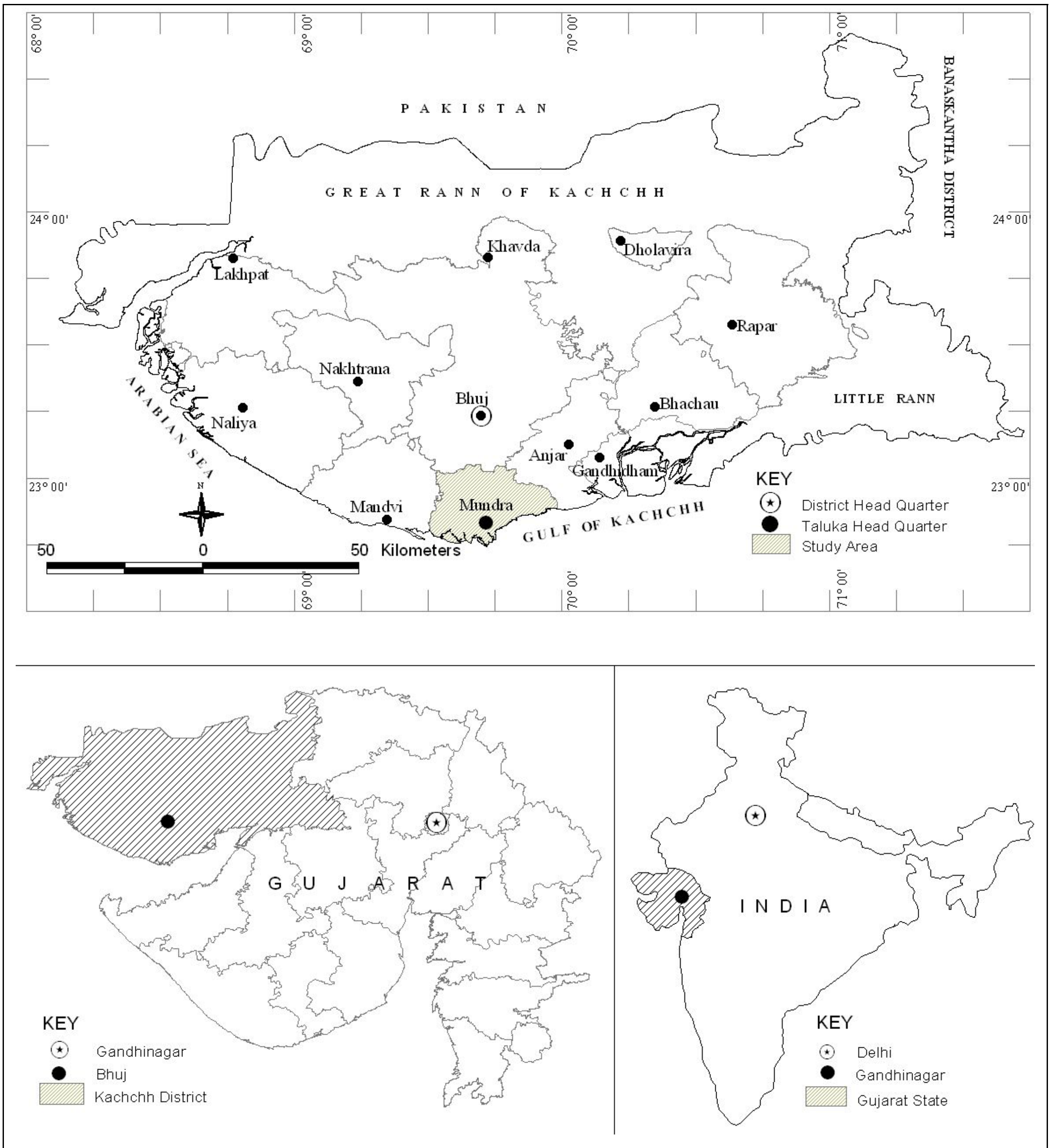


Fig. 1.1 Location Map of the Study Area

AIM AND OBJECTIVES

The research is aimed to carry out an in-depth study on hydro-geological attributes of the study area and make groundwater quality assessment; establish mechanism and causative factors for water quality deterioration; suggest management prescriptions to remediate the problem.

The presented study encompasses following objectives-

1. Geological Studies
    - To establish geological framework of the study area through available secondary data and field study.
    - To work out detailed geomorphic set up of the area and its various attributes.
    - Detailed inventory and analysis of demographic, socio-economic and industrial development of the study area.
2. Hydro-geological Studies with a view-
    - To understand aquifer characteristics, water table fluctuations and implications.
    - Hydro-geological categorization of the catchment area and core area form the point of view identifying groundwater recharge sites.
    - Water balance study.
3. Groundwater Salinization Study of Core Industrial Area through-
    - Seasonal and secular behavior of chemical hydro-geologic parameters and quantity.
    - Temporal and spatial change in TDS, Chloride and Boron.
    - To establish causative factors of groundwater salinity and mechanism there in.
    - Study of impact of Salinity on livelihood and socio-economic profile.
4. Industrial Development and Its Impact (Core Area)
    - Detailed inventory of various industries and their water demand

    - Analysis of landuse system diverted for industrial development and its impact on basic resources.
    - Evaluation of industrial development and the benefits there in
5. To envisage a framework of actions and management plan to address probable threats to groundwater salinization through- "People Centered De-centralized System of Management"

APPROACH AND METHODOLOGY

A multi-disciplinary integrated and participatory approach has been adopted to carry out the presented study. The study has been divided into 03 phases mentioned as below.

PHASE- I (PRE-FIELD STUDIES)

- Critical compilation of secondary data viz, demographic status, socio-economic aspects, landuse pattern, geology, groundwater level fluctuations, water quality, meteorology, industrial development etc. from various government, non-government agencies and individuals.
- Data analysis and identification of gaps for follow up study
- Identification and establishment of network of observations wells on equal area grid basis for catchment and core areas.
- Preparation of various thematic maps based on secondary data using GIS software packages and remote sensing tool.

PHASE- II (FIELD STUDIES)

- Field validation of various thematic maps
- Detailed hydro-geological study through well inventory, seasonal water table monitoring and groundwater sampling for determining important chemical indices through established network of observation wells.
- Field verification of existing rainwater harvesting structures and their effectiveness.

- In field assessment of major industries and their impacts on landuse system, natural resources, traditional livelihood, human resource and socio-economics through field evidences, local people interaction, administrators, NGO's and social workers in individual capacity.

PHASE- III (POST FIELD STUDIES)

- Water balance study and quantification of sectoral demand.
- Field data analysis and interpretation- seasonal & secular behavior of water levels and annual change in groundwater storages through SWL contours, hydro-isobaths and well hydrographs; groundwater movement- gradient, aquifer characterization.
- Chemical Hydrogeology: Chemical analysis of groundwater samples, hydro-chemical data analysis and interpretation on seasonal and secular change in chemical content, spatial and temporal change in groundwater quality indices through contours, isobath maps and variation diagrams.
- Groundwater contamination, causative factors mechanism.
- Envisaging strategies and framework of actions for groundwater resource management on sustainable basis especially groundwater salinizaiton.

OUTCOME

The study provides a comprehensive understanding on various types of ongoing development activities in the region; define methodology, status and mechanism of groundwater salinization; strategies for prevention of groundwater salinity; groundwater management plan for the study area; and participatory management system on sustainable basis.

Chapter - II

MUNDRA REGION
STATE OF ENVIRONMENT

CHAPTER - II

MUNDRA REGION: STATE OF ENVIRONMENT

INTRODUCTION

Mundra is the southern most taluka of Kachchh district bounded by geographical coordinates between N 22^0 44' 26" to N 23^0 02' 59.3" and E 69^0 30' 00" to E 69^0 58' 54.4". The taluka sprawl over an area about 888 sq. km. and inhabiting 59 villages. Administratively, Mundra taluka shares its boundary with Bhuj taluka in North, Anjar taluka in East and North East, Mandvi taluka in West, and the Gulf of Kachchh borders southern most limit of the taluka (Fig 2.1). Mundra town is the head quarter of taluka which is 52 km far from district head quarter. The taluka is very well connected with other parts of the districts through state and national highways. The nearest railway station and airport are located in Gandhidham (35 km East) and Kandla (45 km East) respectively. In addition to road and air communication the taluka has also port facilities for export and import trades. There are two ports located in the taluka operated by Gujarat Maritime Board and Adani Port Trust Limited. Once upon a time the taluka was known as "Paris of Kachchh" due to its world famous date palm orchards. Now a days, the taluka is considered as one of the fastest growing industrial hub of the district. The Special Economic Zone (SEZ), Mega Thermal Power Plants, and other large scale industries are upcoming in the area.

For industrial development of any area, water is considered to be a very basic resource for meeting sectoral demand on day to day basis. The district as well as taluka lack perennial surface water resource. Therefore, the ultimate pressure built on groundwater resource, which is very limited and fragile. Realizing this very fact, the candidate in her presented study has emphasized over this scary but very vital resource input and environmental implications due to its over exploitation with specific reference to core area of industries (Fig 2.1).

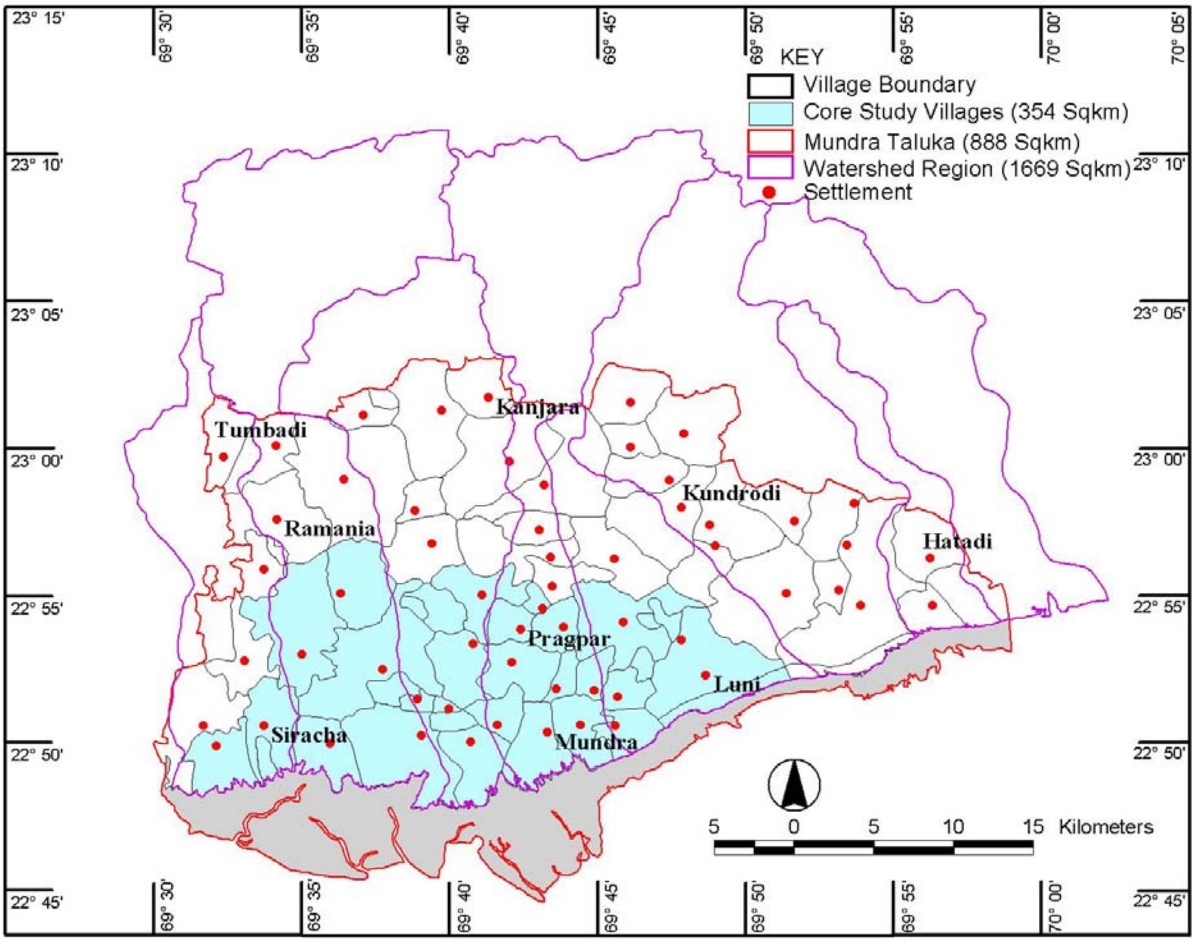


Fig. 2.1 Geographical Status of Study Area

SOCIO - ECONOMIC PROFILE

Socio economic aspects of any region reflect its development status and future trend. As the study area is become a focal point for industrial development it is necessary to study socio economic aspects such as demography, literacy, health and other basic amenities and livelihood having vital bearing over resource utilization. A brief account of socio economic profile of study area is given as under.

DEMOGRAPHY

Demography is one of the important indices of socio economic aspects of any area and invariably linked with the prosperity of the area. Prosperity depends on available static and dynamic natural resources of the area. Any developmental activity in the area makes prompt impact on demography and its changing trends can be easily measured. It is a base line data for any region and considered to be the harbinger of development. The demographic aspects of the study area has been dealt in terms of population, male female ration, population density and decennial growth based on District Census Handbook (2001, 2011).

The demographic status of Mundra taluka point to leap change in population from years 2001 to 2011 and has recorded 54.24 % growth (Table 2.1). Similarly the Mundra Town also shows exceptionally high (57.21 %) decadal growth in population. This sharp growth rate is attributed to on-going in industrialization of the area. Even neighboring villages around Mundra SEZ shows stupendous decadal growth in population viz. Tunda (933 %), Baroi, Moti Bhujpar, Nana Kapaya etc. (Annexure 2.1). This exceptional increase in population is certainly ascribed to industrial development of the area, attracting large number of immigrants from within and outside state for employment.

The decennial growth of the area over last few decades has drastically increased from year 1981 (10.7 %) and became doubled in year 2001 (20.9 %). It has increased more than four times (84 %) in year 2011. Similarly, population density has increased from

93.48 persons/sqkm (2001) to 172.01 persons/sqkm in year 2011. Population density of the Mundra taluka (172.01) is very high in compare to districts' density (46) (Table 2.1).

Looking to M/F ratio, it was almost to equal (1:1) till the year 1991 and then progressively reduced to 1:0.70 in year 2011. This observed M/F ratio imbalance is due to immigration of male population to the area for employment in industrial sector. The changing trends in study area demography over last six decades have been plotted by adopting an average decennial growth @ 25.83 % to determine projected population in year 2051 (Fig 2.2). The projected population of Mundra taluka stands at 3.84 lakh.

Table 2.1 Demographic Status of Study Area

Census Year	House Holds	Population (Lakh)			M/F Ratio	Density per sq. km.	Decennial Growth Rate (%)
		Total	Male	Female			
1961	12830	54425	24868	29557	1: 1.18	61.29	-----
1971	12567	57079	26916	30163	1: 1.12	64.28	4.88
1981	13308	63224	30733	32491	1: 1.05	71.20	10.77
1991	13945	68652	34041	34611	1: 1.01	77.31	8.59
2001	16973	83010	42311	40699	1: 0.96	93.48	20.91
2011		152747	89609	63138	1: 0.70	172.01	84.01

Source: District Census Handbook, Year: 1961, 1971, 1981, 1991, 2001, 2011

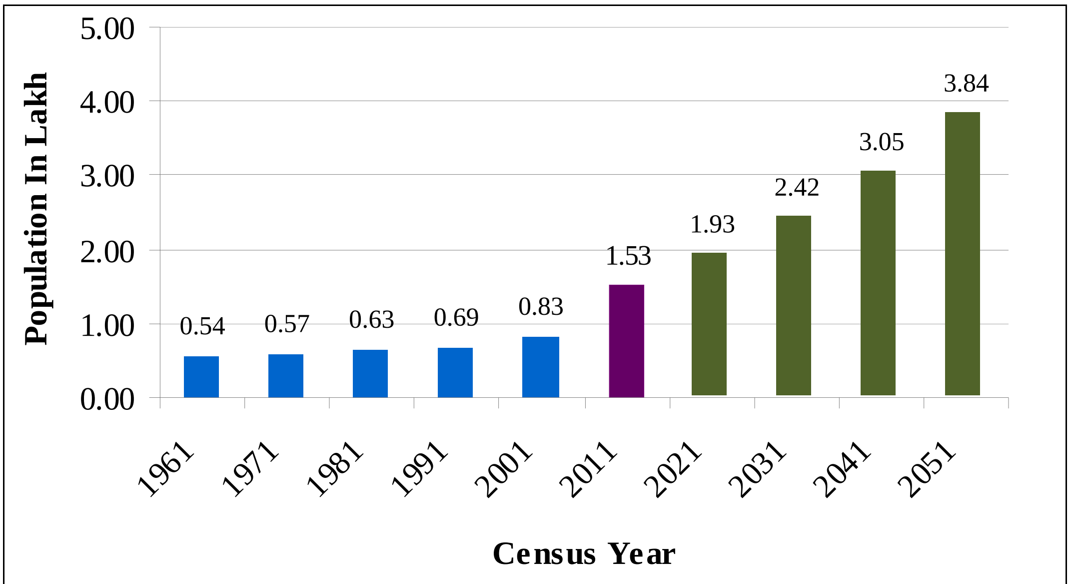


Fig. 2.2 Decennial Demographic Trends of Mundra Taluka

Source: District Census Handbook, Year 1961, 1971, 1981, 1991, 2001, 2011

On the socio-economic status front, Mundra taluka is dominated by general caste population which constitutes almost 77.97 % of total population. The schedule caste and schedule tribe population is 16.67 % and 5.36 % of total population respectively. M/F ratio more or less remained constant although, female population is marginally less. Schedule caste includes Muslims, Harijan while schedule tribe includes Koli, Vagher communities (Table 2.2).

Table 2.2 Socio- Demographic Status of Mundra Taluka

Category	Total Population	Total Male	Total Female	M/F Ratio	% of Total Population
SC*	13,839	7,169	6,670	1: 0.93	16.67
ST*	4,449	2,275	2,174	1: 0.95	5.36
Open	64,722	32,867	31,855	1: 0.96	77.97
Total	83,010	42,311	40,699	1: 0.96	100

Source: Census Handbook, Year 2001

***SC- Schedule Caste, ST- Schedule Tribe**

LITERACY AND EDUCATION

Literacy is an important indicator of development of the region. Literacy plays a vital role in development of society and the region. Literacy rate depends on educational development of the region. Literacy and educational details have been derived from Census Record of year 1991, 2001, 2001 and Kachchh Jilla Panchayat Statistical division.

As per Census Handbook (2011), total literate population in the Mundra taluka is 1.03 lakh which is 67 % of total population. Taluka literacy rate is lower than literate population of the district (71.58 %). Out of this, male literate population is 0.68 lakh (66 % of total literate) and female literate population is 0.35 lakh (36 % of total literate). However, population of literate females has increased in last decade (Annexure 2.1).

According to Jilla Panchayat Statistical division, the taluka has enough facility for primary education (103) whereas total nos of secondary education schools (15) are less (Table 2.3). Each village has been facilitated with primary education facility. There are total 03 colleges for higher education and 03 training institutions i.e PTC, B.Ed. colleges for Primary Training Center (PTC) and for B.Ed. degree.

Table 2.3 Education Facilities in Mundra Taluka

Type	Total Nos	Boys	Girls	Teachers
Primary	103	8986	8045	550
Secondary	15	2069	1026	66
Higher Secondary	4	239	149	61
Graduation	3	---	---	---
Training School	2	21	248	9
Adult Lireacty Class	116	---	---	---
Other Education institute	11	48	123	

Source: District Stastical Division 2010-11, Census Handbook, 2001

HEALTH

Health facility is a basic amenity for healthy society. Scenario of health facility reveals type and state of development. Sufficient health facility plays a key role in development of society. The post earthquake Census Handbook (2001) does not contain any information on health amenities. Therefore, the candidate has relied upon the primary data base that has been compiled by Arid Communities and Technologies (ACT) in year 2006 and 2009 (Table 2.4). The Mundra taluka health profile shows total 10 villages have facility of primary health center while for remaining villages health facility is available with in the distance of minimum 1 km to maximum 30 km. However, there exist private health centers in 20 villages. There are also ayurvedic practitioners in three villages. Maternity home facility is available in 03 villages only while, remaining villages depend upon facilities located within 0.5 to 30 km radius. Besides this, there is only 01 childcare center in entire taluka. The state government provides prompt emergency service named 108 ambulance. There exists mobile health facility in terms of Health Workers (40 nos.), Malaria Workers (40 nos.) and PHC Nurses (24 nos.) in the taluka. About 20 villages avail health services from private visiting doctors. Beside these, there are sufficient number of hospitals operated by Government, private and voluntary trusts. However, civil hospital with multi-specialty facilities is available at the district head quarter Bhuj only.

Table 2.4 Available Health Facilities in Mundra Taluka

Sr. No.	Type of Facility	Total	No of Village	Distance in Km	
				Minimum	Maximum
1	Primary Health Center	10	10	1	30
2	Private Health Center	20	20	0.5	36
3	Ayurveic Practitioner	3	3	-----	----
4	Maternity Home	3	3	0.5	35
5	Child Care Center	1	1	0.5	30
6	Medical Store	3	3	0.5	30
7	Ambulance	4	-----	-----	-----

Source: ACT, 2006

Table 2.5 Details on Water Born Disease in Taluka

Disease	Percentage	Since Years
Malariya	14.38	8
Diariya	4.50	4
Kidney Stone	0.88	5
Joints Pain	10.25	6
Skin disease	3.25	3
Flourosis	2.50	2
Other	7.13	2
Total	42.89	-----

Source: ACT, Bhuj, 2009

Looking to health problems, most of the disease caused by drinking water called water borne disease. According to survey carried out by ACT, about 43 % population is affected by water borne diseases (Table 2.5). Major water borne disease observed in the taluka is Malaria, which is seasonal. Second major disease is joint pain, which has appeared since last six years only. There is a problem of marginal high fluoride content in groundwater in some parts coastal area. Groundwater as a source for drinking water influences health by fluorosis disease.

TRANSPORT AND COMMUNICATION

Type and status of transport and communication facility helps to understand development of the region. Transport facility can be divided as road ways, railways, water ways and airways whereas communication facility can be divided as post office, telephone, courier, internet, mobiles et. In case of transport facility, the Mundra taluka is bestowed with roadways and waterways. The taluka is connected by national coastal highway with Mandvi and Gandhidham whereas it is connected with Bhuj and Anjar towns through state highways. Most of the villages are inter connected by *pakka* road with near by village and taluka. The taluka has no railway for public transport. There is a private railway track for industrial goods transport between Gandhidham and Mundra

Port. The taluka has long coastline along the Gulf of Kachchh where number of ports and jetties have been developed for import and export of goods. Major public transport is based on roadways through GSRTC (51 villages), private taxis (32 villages) and small vehicles (53 villages).

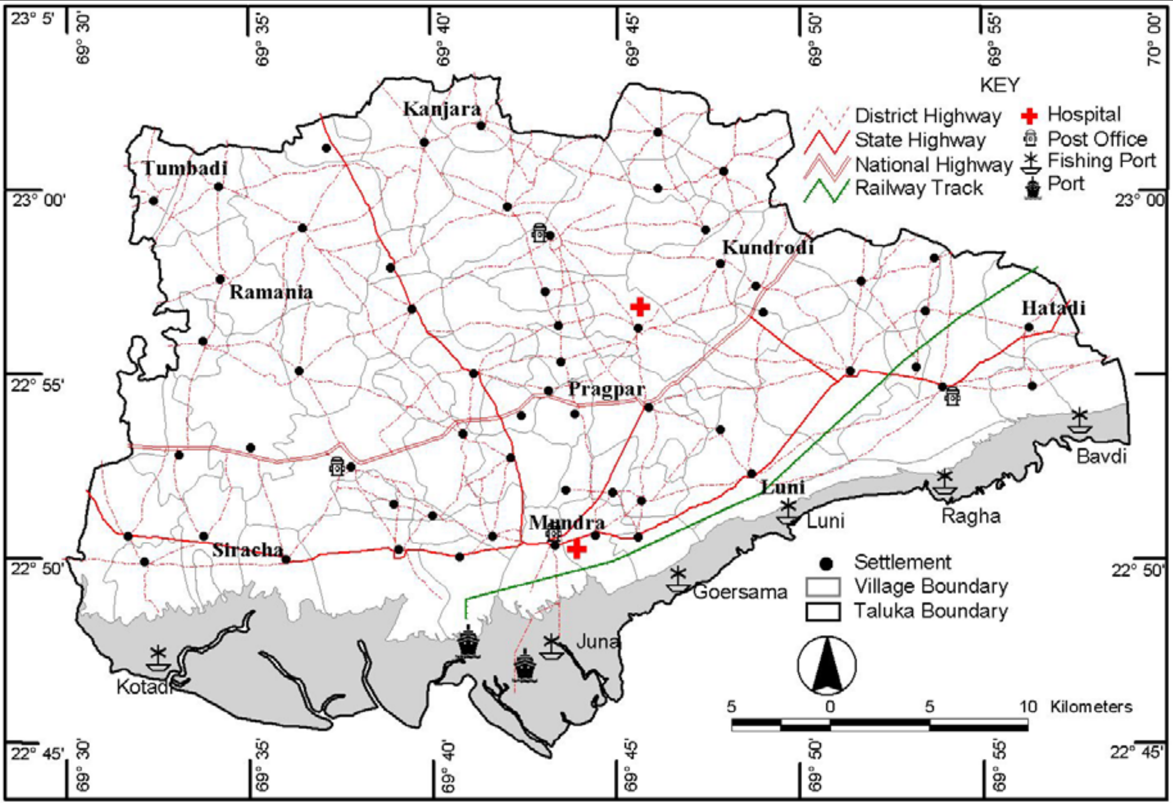


Fig. 2.3 Transport and Communication Network of the Taluka

The taluka has communication facility in terms of post office, telephone network, and courier network. In all 06 sub-post offices and 19 branches exists in the taluka. There are about 80 post boxes spread in entire taluka. There is telephone network by Bharat Sanchar Nigam Limited (BSNL) available in most of the villages. All the villages have mobile network facility with the help of BSNL and other mobile service providers.

Beside these, there is domestic electricity facility for 24 hours in all villages as all the villages covered under *Jyoti Gram Yojana*. However, electricity for agriculture is restricted to eight hours per day. There also exists common library and reading center facility in the taluka.

OCCUPATION

Socio-economic development depends on occupation and natural resources of the region. The taluka is rich in coastal resources as well as land and groundwater. There are three main natural resource based occupations viz; agriculture, animal husbandry and fisheries. Beside these, there is a large sector of industries for livelihood especially for service sector.

As per Census Handbook (2001), total working population of the taluka is 38.4 % of total population which is little higher than that of the district. Looking to past four decades census data, there is very high growth in working population from 1991 to 2001 which may be due to increased employment opportunities in industrial sector (Table 2.6).

Table 2.6 Comparative Analysis of Taluka Population Growth and Changes in Working Population with District (Year 1971 to 2001)

Particulars	Year 1971		Year 1981		Year 1991		Year 2001	
	MDR*	KCH*	MDR*	KCH*	MDR*	KCH*	MDR*	KCH*
Population (in lakh)	0.57	8.5	0.63	10.5	0.69	12.6	0.83	15.8
Decennial Growth (%)	4.88	22.0	10.77	23.6	8.59	20.2	20.91	25.6
Total Workers (% of Population)	31.7	33.0	33.9	36.0	34.8	36.4	38.4	38.3
Total Non Workers (% of Population)	68.3	67	66.1	64	65.2	63.6	61.6	61.7

Source: District Census Handbook, Kachchh, 1971, 1981, 1991, 2001 and 2011

***MDR: Mundra, KCH: Kachchh**

Working population can be bifurcated as main and marginal worker categories and it can be further classified as cultivators, agriculture labors, house hold industries and other works. Over the period of last four decades, population of main workers in taluka has decreased from 95.7 % (2001) to 80.4 % (1991). There has been a perceptible increase in total working population whereas main population has decreased, which indicates that part of people demoted from main working category to marginal workers. The increase in marginal working population from 4.3 % (1991) to 19.6 % (2001) ascribes this fact. The period between 1991 and 2001, population of cultivators and agriculture labors has decreased whereas there has been an increase in house hold industry and other work population. This indicates that people have migrated from traditional occupation to advance occupation (Table 2.7).

Table 2.7 Demographic Status of Worker's Class in Mundra Taluka

Particulars	Census 1971	Census 1981	Census 1991	Census 2001
Total Main Working Population	18,112	19,399 (90.6%)	22,837 (95.7%)	25,591 (80.4%)
Main Cultivator Population	7,259	6,600	6,678	5,461
Main Agriculture Labor Population	5,845	6,017	8,294	5,684
Main Household Working Population	312	819	325	543
Main Other Work Population	4,696	5,963	7,540	13,903
Total Marginal Working Population	----	2,017 (9.4%)	1,024 (4.3%)	6,244 (19.6%)
Marginal Cultivator Population	----	----	----	684
Marginal Agriculture Labor Population	----	----	----	3,121
Marginal Household Working Population	----	----	----	361
Marginal Other Work Population	----	----	----	2,078

Source: District Census Handbook, Kachchh, 1971, 1981, 1991, 2001 and 2011

Traditional occupations are main occupation of the taluka where major communities are engaged with these. A brief account on traditional occupation of the taluka along with industrial development is described as under.

Agriculture

Agriculture is dominant occupation in the taluka especially in coastal area. Agricultural occupation can be divided into three parts viz. irrigated agriculture, rain fed agriculture and horticulture (Table 2.8). According to District Census Handbook of year 1991, Rain fed agriculture covers major part of cultivable land area (about 83 % of total agriculture land). Major crop type in rain fed agriculture are Pearl Millet, Sorghum, Groundnut, Seasemum, Guar, Green gram, Senna where mix cropping practice is most common. Mix cropping pattern adopted to cope up from threat of insufficient rainfall or drought. Rain fed agriculture practice is most vulnerable to drought. There exists practice of combining animal husbandry with rain fed agriculture. In low rainfall year, crop may get failed in terms of grain production however, it can provide good quantity of fodder, which enables people to sustain livelihood through animal husbandry.

Table 2.8 Status of Irrigated Land Area in Mundra Taluka

Agriculture Type	Area Sq. Km.	
	Year 1991	Year 2001
Irrigated Area by government canal	45.9	16.4
Irrigated Area by Groundwater	44.3	114.0
Irrigated Area by tank	0.8	----
Total Irrigated Area	**91.0**	**130.4**
Total Rain fed Area	**445.9**	**406.6**
Total Agriculture Area	**537.0**	**537.0**

Source: District Census Handbook 1991, District Statistical Division, 2001

Irrigated agriculture covers about 17 % of total agriculture land of the taluka which has increased (24 %) in year 2001. The increased irrigated area is in fact of rainfed agriculture area, converted into irrigated area and is facilitated by groundwater. Based on source of irrigation it can be further divided into three types viz. deep bore well irrigation, well irrigation, and canal irrigation. Groundwater has remained as a main and potential source for irrigation. The taluka has good potential of groundwater based on shallow and deep aquifers. There are also medium and minor irrigation schemes, which support agriculture. Irrigated agriculture is considered to be more secured than rain fed and facilitate the farmers to take two to three crops. Main crop type is cash crops, while others are grain based crops, fodder crops, vegetables etc. (Table 2.9).

Table 2.9 Cropping Pattern in Various Types of Irrigated Agriculture

Season	Bore Well Irrigation	Well Irrigation	Canal Irrigation
Monsoon	Cotton, Castor, Pear Millete, Sorghum, Ground nut, Seasemum, Sugarcane	Seasemum, Sorghum, Pearl Millet, Green gram, Castor, Groundnut, Cotton	Seasemum, Pearl Millet, Sorghum, Green gram, Guar, Cotton, Groundnut
Winter	Wheat, Isabgul, Lucern, Carrot	Wheat, Cumin, Lucern, Carrot, Isabgul, Sorghum	Wheat, Cumin, Isabgul
Summer	Pearl millet, Sorghum, Vegetable	Sorghum, Guar, Pearl Millet	--------
Horticulture	Sapota, Date Palm, Coconut, Mango	--------	--------

Source: ACT, 2006

The taluka is internationally known for its horticulture products viz date palm. Horticulture is dominant practice in coastal area. Date palm and sapota orchard are famous practices and plays important role in taluka as well district’s economy. Date palm has established an international market, which gave a identity to Mundra as *'Paris'* of Kachchh.

Animal Husbandry

Animal husbandry is second main occupation of the taluka after agriculture. It is an individual occupation as well as in combination with rain fed agriculture. Cow and buffalo are common livestocks with agriculture. Looking to the data of last four livestock census period, there is an overall increase in population of cow and buffalo category (Table 2.10). There is also drastic increase in population of camel category in year 2007. In case of small animal, sheep population has decreased over the period while goat population has increased. Low rainfall and drought disaster also affect animal husbandry as there is shortfall in fodder during drought years. In very severe drought, the community has to migrate with livestock to Saurashtra and further to Maharashtra. Migration phenomenon affects the socio-economic status of the family. Further, degradation of grassland area has created perennial crisis for fodder. This phenomenon is more commonly seen in upcoming new industrial areas where traditional pasture land is allotted to industries. However, there are some initiations to support this occupation through grass bank, dairy development. There are about six milk cooperatives in the taluka.

Table 2.10 Livestock Population of Mundra taluka

Census Year	Cattle	Buffalo	Sheep	Goat	Camel	Horses & Ponies	Total Livestock
1992	23659	5798	20015	9569	431	195	59667
1997	23663	5758	9569	20015	431	195	59671
2003	24805	7749	13326	23859	510	81	70330
2007	36803	15890	14916	22894	1191	86	91780

Source: Livestock Census 1992, 1997, 2003, 2007

Fisheries

The taluka has a very significant and diverse coastal resource which plays an important role in area's socio-economic system. This resource provides a very important livelihood of fisheries to the taluka. The taluka earns crores of rupees from this occupation. The coastal resource is characterized by mud flat, rich mangrove belt, creek, bio-mass, which support and facilitate fish diversity and production. In all 930 families (4725 population) are engaged with fisheries occupation. Traditionally there are total seven fishing ports in the taluka (Fig 2.3).

Fish production depends on state of coastal environment and supporting ecosystem. For the past thirteen years fish production data suggests (Table 2.11) that over the years, fish production has increased from 1998 to 2006 except in years 2000-01 and 2002-03. Then during post 2006 phase, there has been a continual decline in fish production (Fig 2.4). This may be attributed to intense anthropogenic interference; as thick mangrove forest belt along the coast has been destroyed for number of upcoming industrial units especially, jetty and ports. This led to imbalance in marine ecosystem like salinity, lack of breeding ground etc. This has affected not only fish production but also types and quality of fish catch.

Table 2.11 Status of Fish Production - Mundra Taluka

Sr. No.	Year	Center Wise Fish Production in Metric Tons						Total Production MT
		Navinal	Jharpara	Mundra	Shekhadiya	Luni	Bhadreshwar	
1	1998-99	1113.7	301.3	1660.1	308.5	1693.6	1324.8	6402.0
2	1999-00	1138.8	180.7	1731.0	175.0	1964.2	1680.3	6870.0
3	2000-01	710.4	76.0	335.8	88.0	1050.5	1902.3	4163.0
4	2001-02	549.0	365.1	1381.6	192.1	2031.8	2642.8	7162.5
5	2002-03	843.9	531.9	1645.3	239.5	1489.4	1618.7	6368.7
6	2003-04	508.9	771.4	1633.5	177.0	1953.7	3008.1	8052.5
7	2004-05	608.2	995.0	1871.9	175.5	1315.5	2064.5	7030.7
8	2005-06	1070.5	332.7	1030.8	214.8	3159.7	2159.5	7967.9
9	2006-07	641.8	1044.3	1330.3	315.1	1843.5	2262.7	7437.7
10	2007-08	259.1	448.3	618.8	170.6	2274.0	3259.5	7030.3
11	2008-09	594.8	451.2	1912.8	137.3	1520.8	1835.8	6452.6
12	2009-10	1.5	0.0	1014.0	27.9	1062.9	2580.7	4686.8
13	2010-11	0.0	101.5	989.1	65.5	1020.0	2055.0	4231.1

Source: Fisheries Department, Bhuj

Fig 2.4 Fish Production Trend of Mundra Taluka

Industrialization

Owing to rich natural resources and unique coastal characteristics, the Mundra region has attracted many industries that in turn became major source of livelihood to the people. During last one decade Mundra taluka has witnessed rapid industrialization. There are about 31 large to small scale industries (Table 2.12) in the taluka viz; Port, Power plant, steel plant, oil refinery, coal refinery, mineral and mining industry etc. Export and import oriented industries are centered at Adani Port. Main import materials are edible oil, coal, steel, container, machinery, wood, phosphoric acid while export materials are wheat, bentonite, bauxite, salt, lignite, and steel pipes. Major industrial pockets in taluka are developed around Mundra, Jharpara, Navinal, Kapaya, Siracha, Tunda, Samaghgha, Vadala, Luni and Bhadreshvar villages (Fig 2.5). This industrialization has also strengthen the residential and other infrastructures of the town like schools, garden, hospital etc. Special Economic Zone (SEZ) promoted by Adani Group is most supportive and paved way for further industrial development. The impact of industrialization is witnessed in sudden out burst of decadal population growth of Mundra town, which has touched 63.5 % mark i.e. from 12,900 (2001) to 20,300 (2011).

Table 2.12 Details on Established Industries in Mundra Taluka

Sr. No.	Name	Location	Type
1	Mundra Port and SEZ Ltd.	Coastal Track	Port, Industrial Park, Infrastructure Project
2	Gujarat Adani Port Ltd.	Mundra, Goersama	Petrochem and Refinery
3	Adani Wilmar Ltd.	Baroi, Pragpar	Fortune Oil
4	Adani Chemicals Ltd	Dhrab	Chemical
5	Adani Power Ltd.	Siracha, Viraniya	Power Industry
6	Indian Oil Corporation	Patri, Bhadreshwar	Oil Factory
7	Coastal Gujarat Power Ltd.(TATA Power)	Tunda, Kandagara Mota	Thermal Power Plant
8	OPG Power Gujarat Ltd	Bhadreshwar	Thermal Power Plant
9	Gujarat Energy Transmission Corporation Ltd	Siracha, Moti Bhujpar, Mokha	Energy Transmission
10	Welspan Power and Steel Ltd	Navinal	Power Industry
11	Jindal Saw Pipe Ltd	Samagogha, Pragpar, Moti Bhujpar	Metallurgical Industry, Steel Pipes
12	Jindal Coke Ltd	Toda	Coke Processing
13	Saw Pipe Ltd.	Nana Kapaya, Samagogha	Metallurgical Industry, Steel Pipes
14	Lakshmiwadi Mines & Minerals Pvt.Ltd.	Bhorara, Gundala	Mines and Minerals
15	Phillips Carbon Black Ltd.	Wadala, Mokha	Coke Processing
16	Mahashakti Coke Ltd.	Lakhapar	Metallurgical Industry
17	Shree Ashapura Minechem Ltd	Baraya	Bentonite Processing
18	BLA Coke Pvt ltd.(Metcoke plant)	Baraya	Coke Processing
19	Nilkanth Concast Private Ltd.	Vadala	Boilor and Steel Manufacturing Plant
20	Saurashtra Ferrous Pvt. Ltd	Baroi	Manufacturing of Steel and Iron
21	Maruti Suzuki India Ltd.	Mundra	Metallurgical Industry
22	Aadinath Polyfils Private Ltd.	Dhrab	Chemical
23	Agro Crops Exime Ltd	Nana Kapaya	Agriculture Sector
24	Ms. Kotak Agro Processing Pvt. Ltd	Baraya	Agriculture Sector
25	L T C Agro Sales Ltd	Ratadiya	Agriculture Sector
26	Ashok Alcho Chem Ltd.	Baraya	Chemical
27	Deast Industries Private Ltd.	Vovar	Chemical
28	Gujarat State Petronet Ltd.	Gundala	Oil Factory
29	HPCL Mittal Pipeline Ltd.	Gundala	Infrastructure
30	Rishi Container Fait Station Private Ltd.	Mota Kapaya	Infrastructure
31	Shree Amit Marketing Private Ltd	Patri	Infrastructure

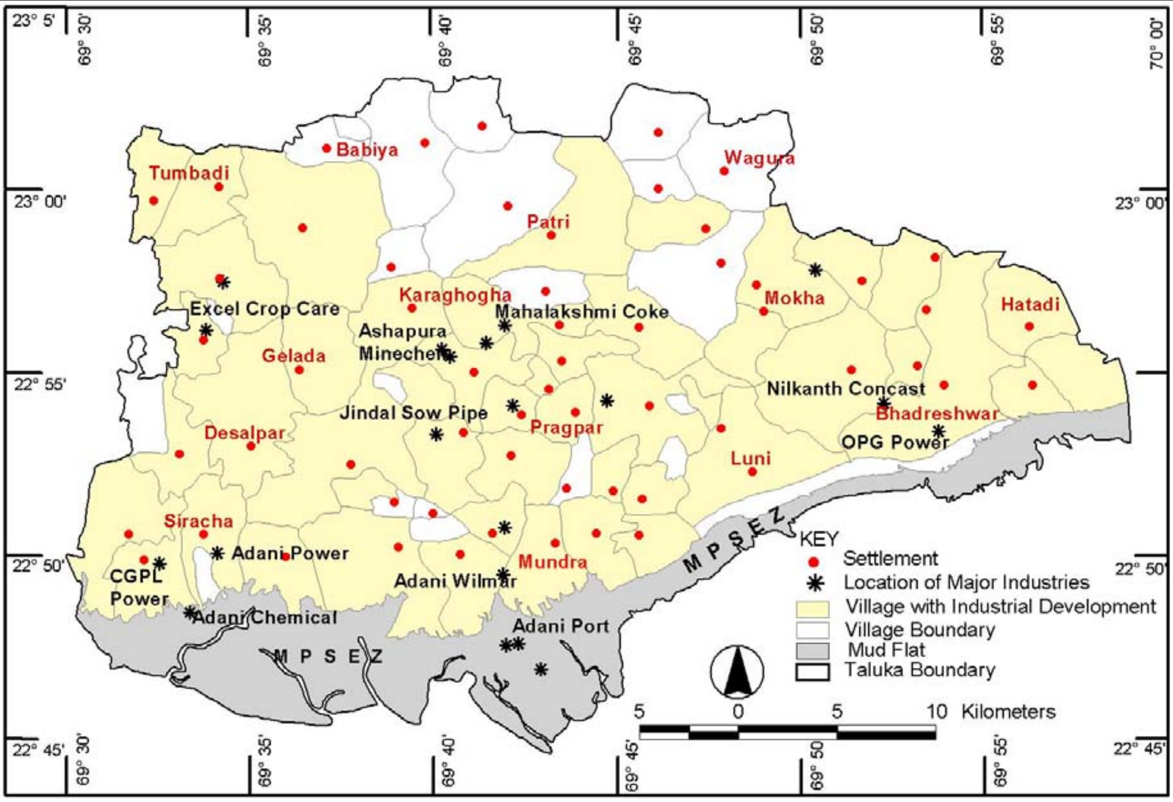


Fig. 2.5 Location of Major Industrial Pockets in Mundra Taluka

METEOROLOGICAL PARAMETERS

It is important to take an overview of various meteorological parameters where livelihood strength depends on climate. It is also an important input in land and water resources development. The information on meteorological parameters has been gathered from Indian Meteorological Department (IMD), Bhuj. Overall climate of the taluka fall in arid to semi arid climatic zone. In coastal regions climate is bit humid – sub humid. The Mundra taluka receives maximum rainfall as compared with other talukas of the district. The rainfall pattern is erratic and deficient hence, drought is a regular phenomenon.

RAINFALL

Rainfall is considered to be very important factor for richness of natural resources as well as overall development of any region. Average annual rainfall of the taluka stand at 440 mm/year (Annexure 2.2). Looking to the last 112 years of rainfall data (Annexure

2.2 & Fig 2.6), there has been a perceptible increase in rainfall during the last decade. The average annual rainfall is more than 500 mm/year in last five years whereas it is 464 mm in last ten years. The taluka has received lowest rainfall (30.8 mm) in the year 1987 while highest rainfall about 1079.6 mm was received in the year 1961.

The rainfall distribution pattern of taluka is depicted as isohytel map (Fig 2.7) suggests increasing trend from hinterland (360 mm) to coastal tracks (400 mm). This suggests that orography has no role in governing the rainfall distribution over the study area.

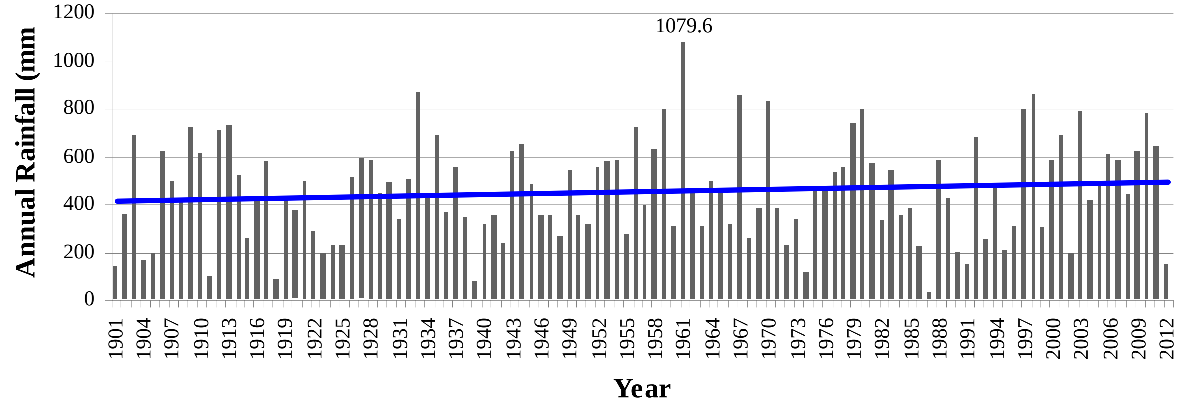


Fig. 2.6 Average Annual Distributions of Rainfall Over Last 112 years

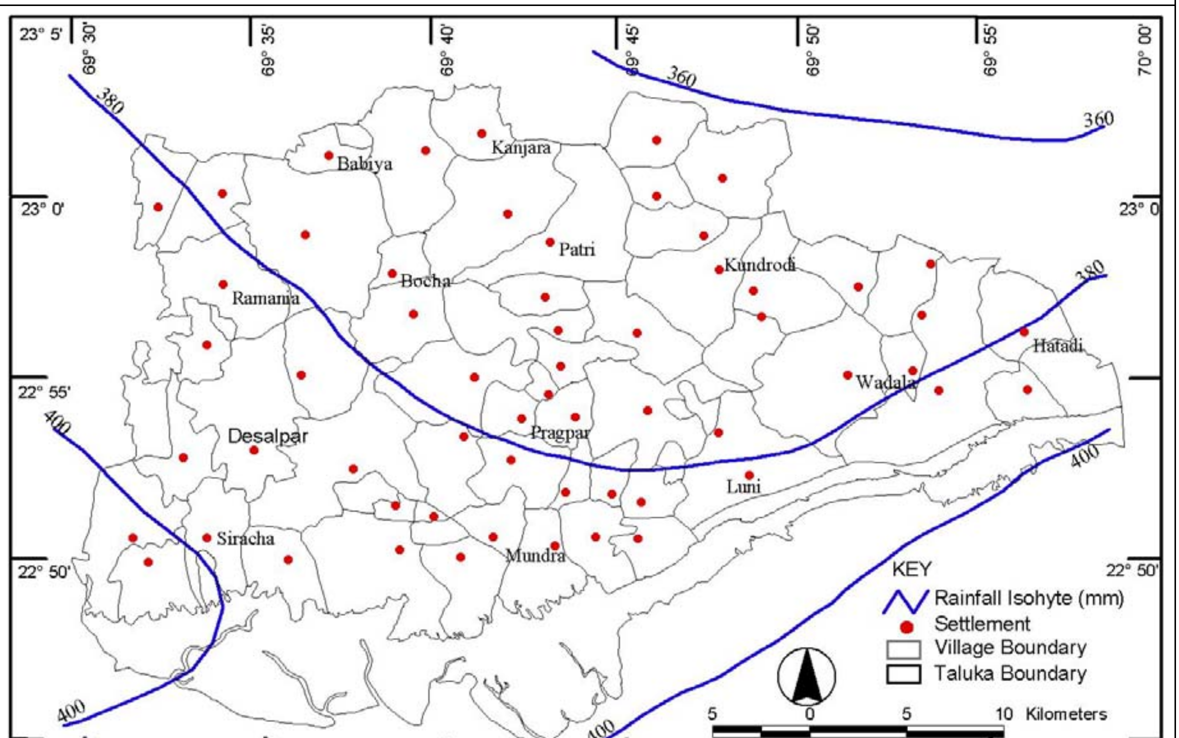


Fig. 2.7 Isohyets Pattern of the Mundra Taluka

TEMPERATURE

Being a coastal region, average temperature is lower than the interior region. In an annual seasonal cycle of three months, January is the coolest month during winter season while May represents the hottest in summer season. During winter daily mean minimum temperature stand around 10.1 ^{0}C and daily mean maximum temperature is around 26.1^{0}C. During summer May is the hottest month with daily mean maximum temperature stands at 38.7 ^{0}C and daily mean minimum temperature is about at 25.6 ^{0}C. In the remaining months, temperature remains pleasant with the daily mean maximum and minimum temperatures around 30 ^{0}C and 25 ^{0}C respectively. (Fig 2.8)

HUMIDITY

Being arid climatic conditions, air is generally dry except during the monsoon season. However, the relative humidity in the coastal parts of the taluka is high throughout the year exceeding 60 % on the average. During monsoon months the relative humidity exceeds 80 % in the coastal region and over 65 % in the interiors of the taluka. The rest of the year the air is dry with relative humidity to the order of 25 % or less. March and April months are the driest months. (Fig 2.8)

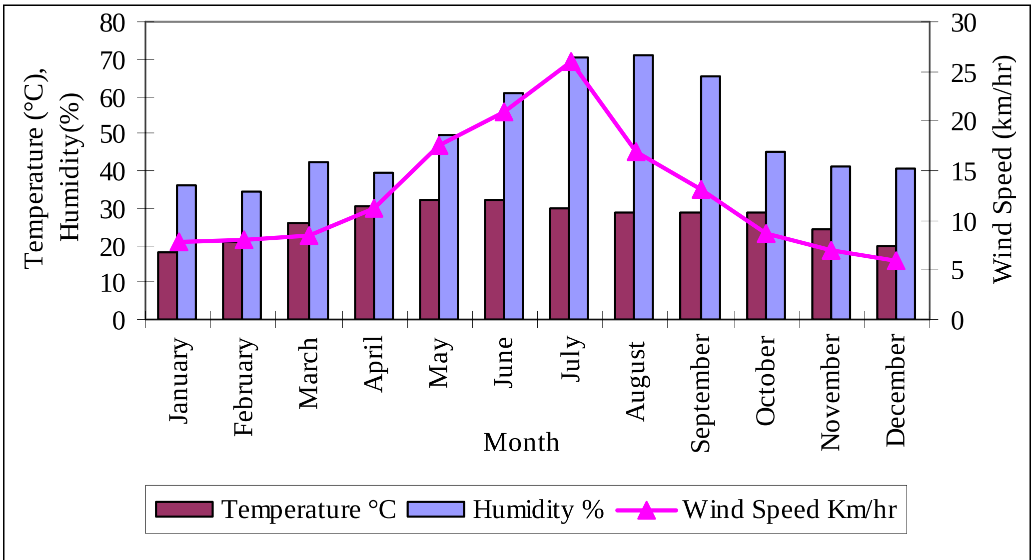


Fig. 2.8 Relationship between Temperature, Humidity and Wind Speed

WIND

The prevailing wind directions in the study area are southwesterly during summer and monsoon seasons and northeasterly during winter season. The mean wind speed ranges from 5.9 to 7.9 kmph during winter months and 21 to 26 kmph during monsoon months. During the month of April-May, the mean wind speed is around 11.2 to 17.6 kmph.

Monthly patterns of various meteorological parameters of Mundra Taluka are given in Table 2.13.

Table 2.13 Meteorological Parameters of Mundra Taluka

Month	Temperature ^{0}C (Max-Min)	Humidity % (Max-Min)	Rainfall (mm)	Wind Speed (Km/hr)
January	26.1 - 10.1	48 – 24	1.88	7.9
February	29.1 - 12.9	52 – 17	3.06	8.1
March	34.0 - 18.3	59 – 26	0.99	8.5
April	37.6 - 22.7	57 – 22	0.06	11.2
May	38.7 - 25.6	66 – 33	0.71	17.6
June	36.7 - 27.4	72 – 50	66.67	21.0
July	33.0 - 26.3	77 – 64	214.13	26.0
August	31.7 - 25.3	80 – 62	95.31	17.0
September	33.2 - 24.1	77 – 54	41.61	13.0
October	35.6 - 21.5	64 – 26	9.68	8.6
November	32.3 - 15.6	55 – 27	9.16	7.0
December	28.0 - 11.2	56 – 25	1.72	5.9
Annual Mean	**33.0 - 20.1**	**63 – 36**	**445**	**12.1**

Source: IMD, Bhuj

NATURAL RESOURCES

Land, water, livestock, and human beings are considered to be the major resources of any region and have been accepted as vital indices in the socio-economic assessment of the region.

LAND

The taluka has plenty of land resources. The taluka spreads over 888 sq km and by and large used for residential, agriculture, grassland and forestry, water reservoirs and industries. As per District Census Handbook (1991), almost 50 % of the total area accounts for rain fed agriculture while irrigated agriculture covers only 10 % of total land. Cultivable and non-cultivable lands are about 13 % and 22 % of total land respectively. There is only 2.7 % of total land area is under forest use (Table 2.14). Land use pattern of the taluka has been analyzed based on satellite data (Fig 2.10).

Owing to on-going industrialization in the taluka, the last decade has witnessed drastic change in land use pattern. The change in land use systems has been assessed through secondary data collected from Taluka Panchayat, which is maintaining the revenue records on diversion of land for various industries (Table 2.14). The distribution of land use pattern (Fig. 2.9) based on 2012 Taluka Panchayat records has been compared with land use pattern of the year, 1991 (Table 2.3). The assessment of change in land use suggests that-

a. There has been no significant change in agricultural land. Only 2.8 sq.km. agriculture land has been acquired by industries. However, some agriculture land has been converted to non-agriculture purpose i.e. residential purpose by land developers, which has not been recorded.
b. However, there has been a marked reduction in cultivable waste land (29.3 sq.km.) and non cultivable waste land (34.5 sq.km.), which is attributed to diversion of land for industries in the region. The cultivable waste land diverted to industry also includes grazing land of the area for livestock use.

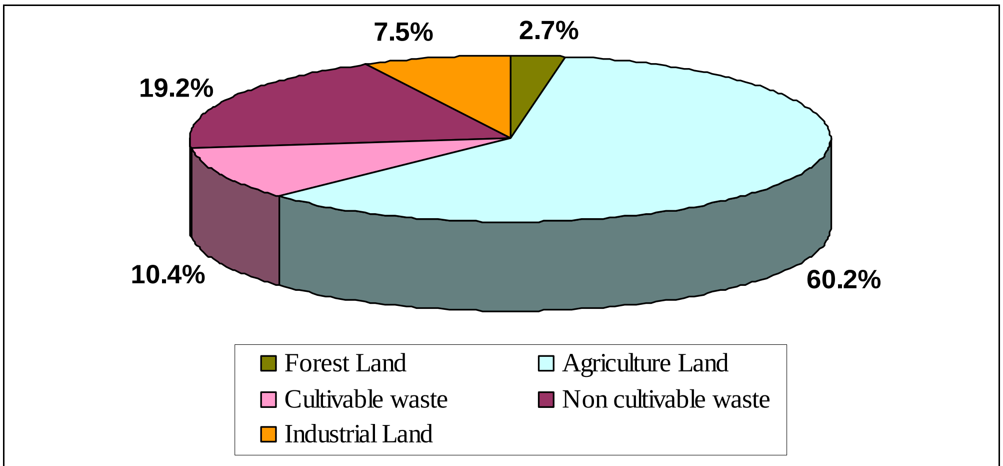


Fig. 2.9 Distribution of Land use pattern of Mundra Taluka of Year 2012
Source: District Census Handbook 1991, Taluka Panchayat, 2012

Table 2.14 A Comparative Status of Land Use in Mudnra Taluka

Land Use Category	Area Sq.Km. (Census 1991)	Land Acquired by Industries (Sq.Km.)	Area Sq.km. (Year 2012)
Forest Land	23.9	0.0	23.9
Irrigated Agriculture Land	91.1	2.8	
Rain fed Agriculture Land	445.9		534.3
Cultivable waste (including Gauchar and Groves)	121.9	29.3	92.7
Non cultivable waste	205.2	34.5	170.7
Total Land	**888.0**	**66.49**	821.5

Source: District Census Handbook 1991, Taluka Panchayat, 2012

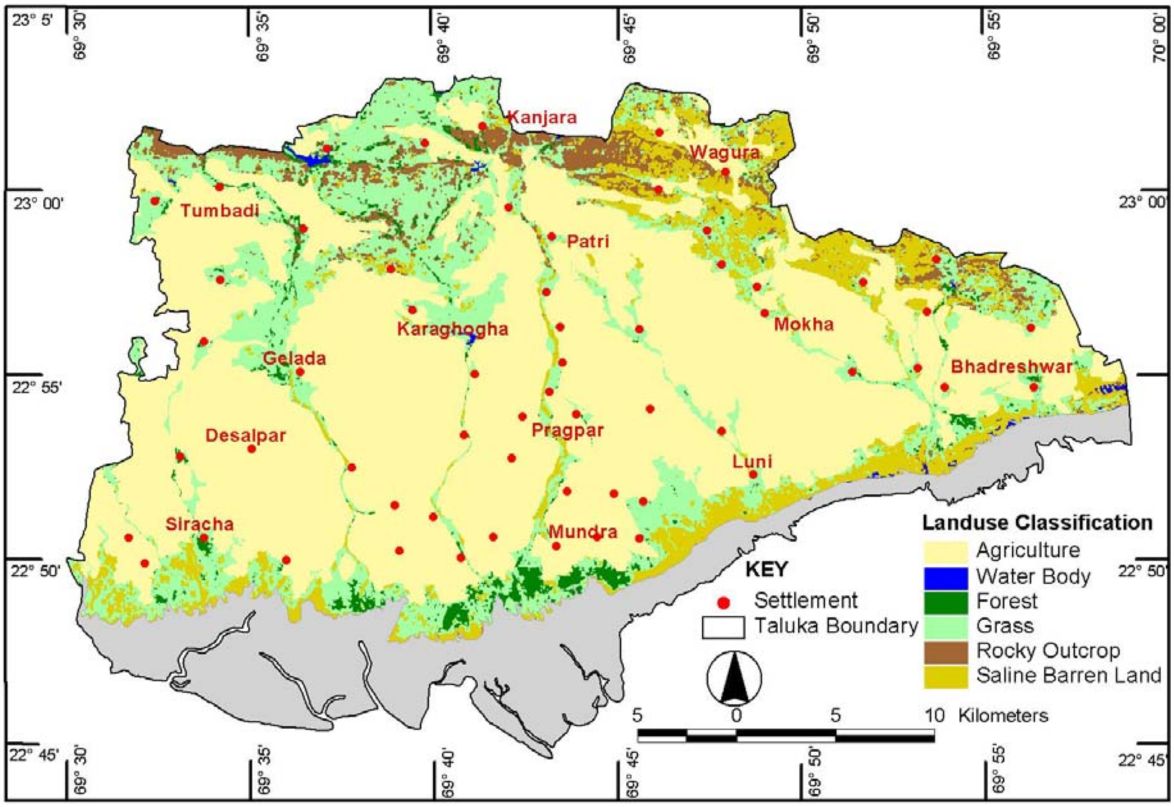


Fig. 2.10 Land Use Systems of Mundra Taluka (Based on Remote Sensing Study)
Source: ACT, 2006

WATER

Water is the most important natural resource for the sustenance of life and livelihood. Rainfall is the only source of water and can be divided as surface and groundwater resource.

Surface Water

Precipitation is received through rivers as surface runoff. The region is drained by two major rivers named Nagmati and Bhukhi Rivers having 46 km and 40 km lengths respectively. There are other minor streams namely Khari, Phot, Mitti and Lerakh meeting directly to the sea. Water as stream runoff is checked by dams, check dams, and ponds for various purposes. Surface water structures are constructed by the State Irrigation Department and Village Panchayats, NGO's and Trusts, under various government funded schemes.

At the taluka level, there are 07 dams constructed under state funded minor irrigation scheme with a gross storage capacity of 24.33 MCM and having potential to irrigate about 53.80 sq.km. of land. There exists large number of water storage tanks; villagers use this resource for domestic and partly for irrigation purposes. Taluka is also having innumerable check dams constructed for groundwater recharge. As per survey carried out by ACT (2006), there are about 500 structures in use for drinking, domestic, irrigation, and groundwater recharge purposes (Table 2.15). Overall distribution pattern of existing surface water bodies in terms of number of structures in unit area is shown in Fig. 2.11.

Table 2.15 Categorization of Surface Water Structures in Mundra Taluka

Sr. No.	Type of Structure	Total Nos
1	Village tank for drinking for people	6
2	Village tank for drinking for cattle	30
3	Village tank for Domestic use	2
4	Village tank for drinking and domestic use	27
5	Tank for cattle in pasture land	182
6	Government Irrigation Dam	7
7	Other irrigation structure	7
8	Percolation Tank	85
9	Check Dam	154
Total Structures		**499**

Source: Irrigation Department, Bhuj, A.C.T., 2006

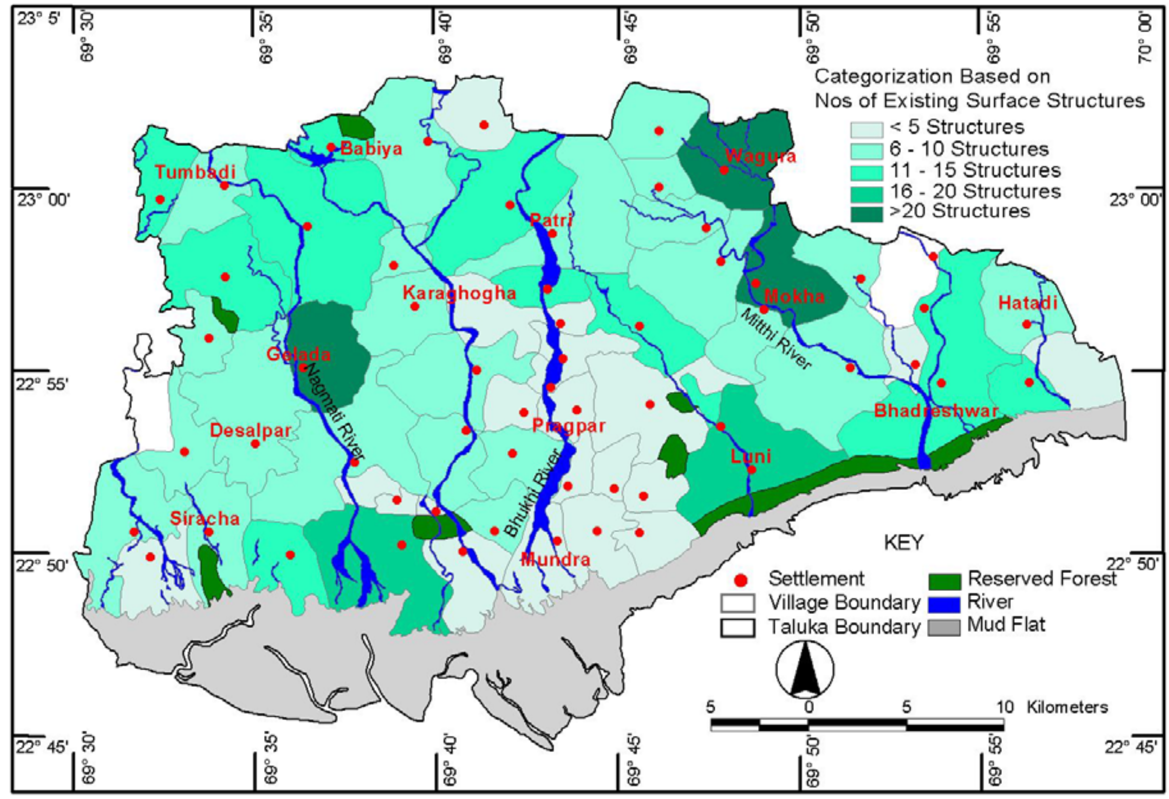


Fig. 2.11 Unit Area Distribution of Existing Surface Water Resources in Mundra Taluka
Source: A.C.T., 2006

Groundwater

Groundwater is the most dependable resource for any region. Taluka being an arid and drought prone region, it has more significance over surface water resource. Evaporation loss and contamination can be avoided by storing water subsurface. The taluka is bestowed with potential aquifers mainly *Kanakavati* Sandstone, which used to provide good quality and quantity of groundwater. This very crucial resource is now threatened due to over exploitation mainly to subsist industrial and agriculture demands. Further, the coastal region of the taluka is threatened by seawater intrusion and associated problems. In absence of any regulation on groundwater exploitation, the groundwater scenario may reach from bad to worst. GWRDC has groundwater monitoring network in entire Kachchh. Looking to groundwater resource utilization pattern, GWRDC has placed the Mundra taluka from dark category to semi critical category in year 2002.

Water resource potential studies conducted by ACT (2006, 2009) has estimated that in all there are about 7092 sources including open wells, dug cum bore wells and bore wells (Fig.2.12). These sources are in use for drinking, irrigation and industrial needs. There are about 1773 open wells, out of them 797 wells are disused. The reason of abandoning such wells is depletion of groundwater levels, which has led to development of deep bore wells. There are about 5319 deep bore wells; out of them about 1576 bores are now abandoned. This is attributed to further deepening of water levels or water quality degradation. In the coastal region, the groundwater levels show fast depletion and inflicted with the seawater intrusion and quality deterioration problems.

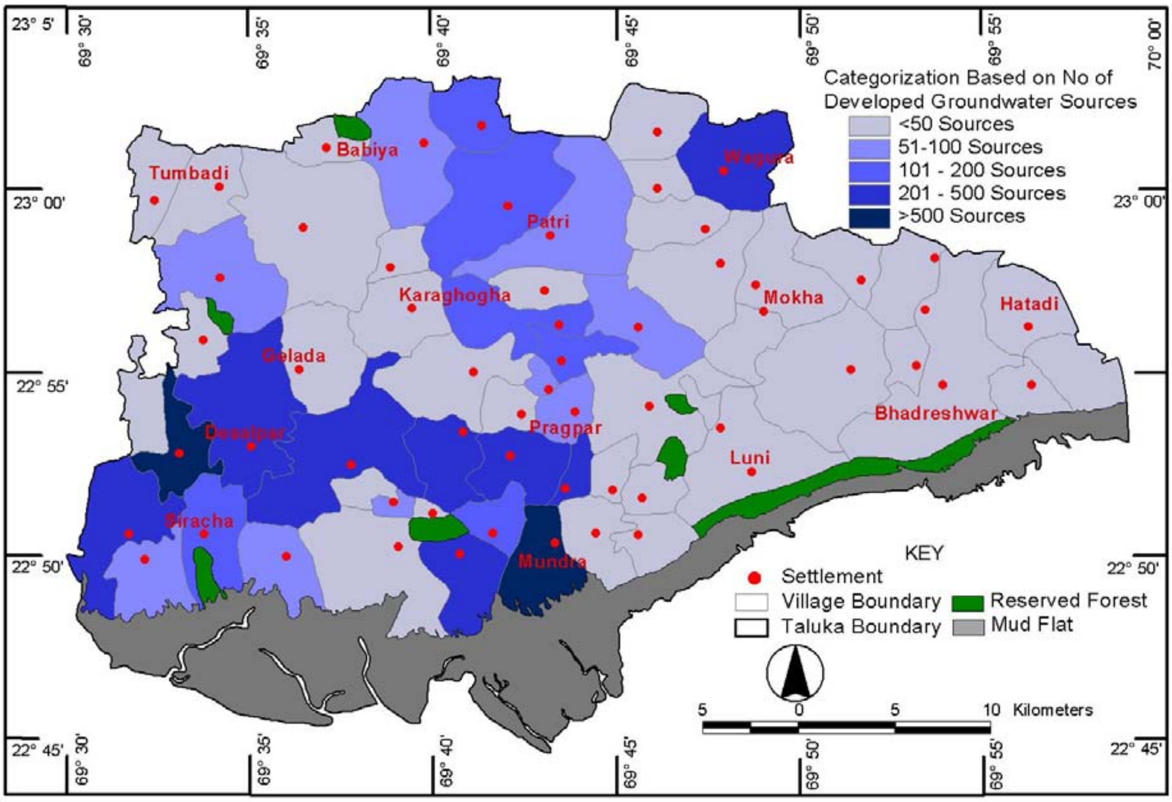


Fig. 2.12 Village Based Classification of Available Ground Water Resources, Mundra Taluka (Source: A.C.T., 2006, 2009)

Table 2.16 Estimated Groundwater Based Sources in Mundra Taluka

Use of Well	Open Well Nos.	Bore Well Nos.	DCB Well Nos.
In Use for Drinking	36	43	6
Abandoned Drinking wells	35	1	2
Total wells for Drinking Water	**71**	**44**	**8**
In Use for Irrigation	940	3330	364
Abandoned Irrigation Wells	762	100	1473
Total wells for Irrigation	**1702**	**3430**	**1837**
Total Well	**1773**	**3474**	**1845**

Source: A.C.T., 2006, 2009

LIVESTOCK

Livestock is another natural resource supporting main livelihood of animal husbandry. Animal husbandry is main occupation of the taluka. It is the only livelihood source in many villages. Cow is a dominant animal for livelihood. There is a prevailing system to keep cow at family level rather than using them for business. Cow is believed to be as holistic animal. It is observed that there has been a considerable increase in buffalo population during last decade. Small animal like goat and sheep are also major group for animal husbandry. Camel and horse are mainly used for carrying goods. Due to industrialization, there is rapid change in land use pattern and due to that open pasture land is decreasing. Grassland (8.4 sqkm) is allotted to Mundra Port Special Economic Zone and other industries in Siracha, Kandagara Mota, Tunda, Navinal, Jharapara, Mundra, Luni, Gundala, Wadala, Mokha villages. Cultivable waste land is also in use for grazing from which 20.9 sq.km. area has been allotted for industrial development. On other hand the farmers have switched over to more cash crops than fodder based crops. This paradigm shift in cropping pattern has created scarcity of fodder on regular basis.

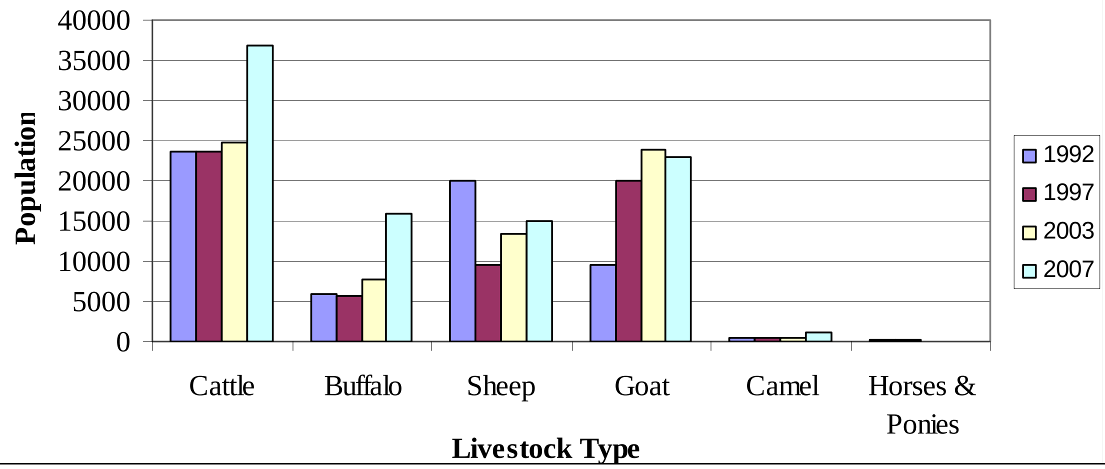


Fig. 2.13 Livestock Population of Mundra Taluka Over Last Four Census Period

Source: Livestock Census (1992, 1997, 2003, 2007)

COASTAL RESOURCE

Coastal track is one of the important natural resource in terms of mangroves, salt brine and wind energy supporting many livelihoods of the taluka. The taluka has very rich 53 kilometer long coastline. Mud flats (153.56 sqkm) adjoining to coast are wide i.e. minimum 0.68 km at Luni to 07 kilometer at Mundra and Navinal village. Now, the mud flat area is covered under Mundra Port SEZ.

The study area was bestowed with dense mangrove belt forming important part of marine ecosystem. Mangrove is a supporting system for fishing ground and its diversity. Mangrove is also useful as a fodder for cattle and providing big support in scarce year. It is also a natural obstacle against high waves and surface seawater ingress. The last 10 years of rapid industrialization and port development activities, mangrove belt has been destroyed which has impacted adversely on fisheries occupation and marine biodiversity. Wind is also an important natural resource. It is a source for pollution free electricity generation. There are many wind farms along the coast generating electricity.

DEVELOPMENT ASPECTS (CHANGING TREND)

Development scenario of the taluka is different from the other parts of district in terms of diversity in industries, pace of industrialization and economy. Industrialization is a major and core development of the taluka. The pace of industrial development in taluka is very high. Industrial development has upgraded the taluka in many ways especially, infrastructural development and urbanization. Infrastructure development lead to new roads, hotels, residential buildings, hospitals, schools, markets and transport. Mundra is fast developing city, same way the satellite villages like Kapaya Mota, Gundala, Vadala, Bhujpur are the growing towns. This has considerably impacted the service sector viz; transport, construction, communication which has become one of the important livelihood. The on-going industrial development has collectively strengthened the economy of district with ample employment opportunity. Socially there has been changing trend in composition of caste, culture and population. There are many families immigrated from other districts of Gujarat and other states of the country, which may impact traditional culture of the taluka in coming years.

A schematic diagram (Fig 2.14) explain prospects and consequences of industrial development in the taluka.

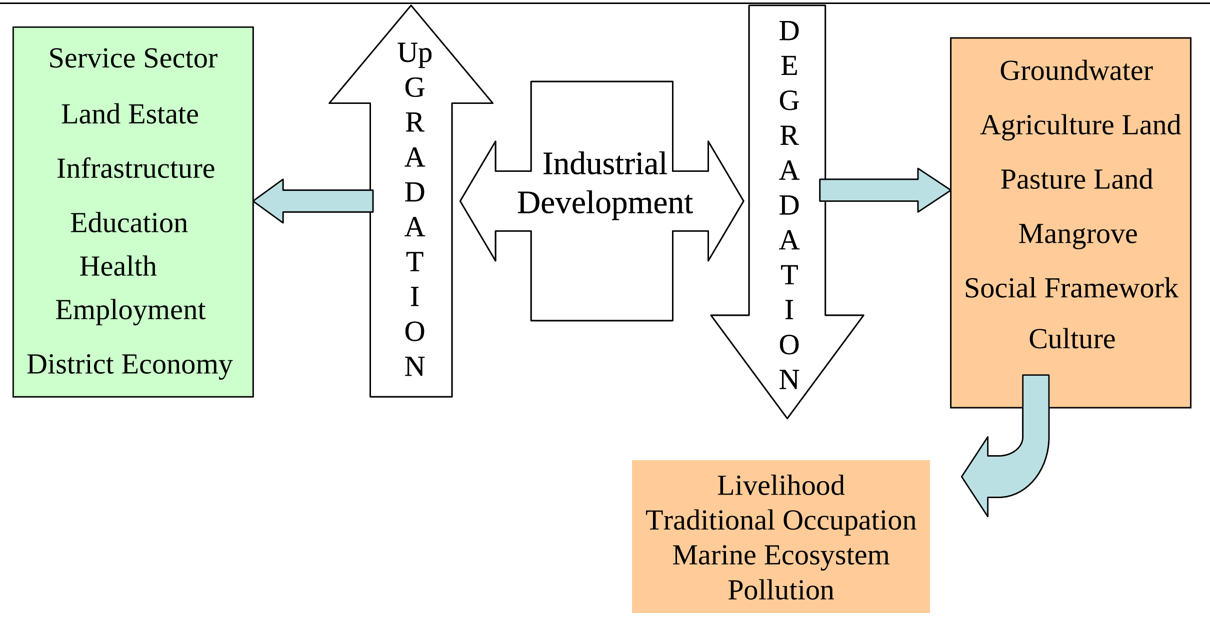


Fig. 2.14 Development Chart of the Mundra Taluka

Chapter - III

GEOLOGICAL SET UP

CHAPTER – III

GEOLOGICAL SET UP

REGIONAL GEOLOGICAL SETUP

PREVIOUS WORK

Kachchh region represents some of the classic strato-type sequences of the Indian Mesozoic and Tertiary Eras. Vast exposed sediment pile with enriched faunal and floral assemblages, intense magmatism, and rich mineral resources have remained all time attraction to the earth scientists to explore the geological diversities of Kachchh. Perhaps due to these very characteristics geological variations the Kachchh has produced voluminous geological information since the early nineteenth century.

Grant (1837) was the first person to provide geological account of Kachchh. His base work has inspired the subsequent investigators to work out the geological details.

Blanford (1869) has presented ideas about the geological architecture and also indicated the presence of E-W trending regional faults.

Wynne (1869, 1872) has described the geology of Kachchh in detail along with thematic maps and some important litho-stratigraphic sections. Based on depositional environment, he has divided the Jurassic Formation in to two broad divisions viz., as marine (Lower Jurassic) and non-marine (Upper Jurassic). Stolickza (1871 - 1873) based on paleontology and physical aspects, has proposed four stratigraphic groups namely; Pachchham, Chari, Katrol and Umia series in ascending order.

Waagen (1875), Oldham (1893) and Vredenburg (1907) have studied the Kachchh geology and suggested further modifications.

Rajnath (1932, 1942) has contributed largely on Jurassic rocks of Kachchh based on fossils assemblages such as ammonites, lamellibranches and plant fossils. Based on bio-stratigraphic diversity, he has further sub divided Umia Series as Umia and Bhuj Series. In depth study of Jumara dome in western Kachchh, he classified the entire sequence into 26 beds belonging to Chari and Pachchham Series. Similarly, he also re-classified Katrol Series in to three parts as lower, middle and upper. Structural aspect of Kachchh was studied by Auden (1949); he also worked on economic minerals and hydro-geological aspects.

Agrawal (1957) has studied Jhura Dome area and given bio-stratigraphic nomenclature as “Habo Series” (Chari Series) and Mebha Oolites (Dhosa Oolite). Latter all available paleontological and stratigraphic data have been complied in book form “A Manual of Geology of Kachchh” by Pascoe (1959).

Poddar (1964) has modified the status of Jurassic stratigraphic unit ‘Series’ as ‘Formation’ during his work, which was carried out as a part of hydro carbon exploration activity by Oil and Natural Gas Commission.

An exemplary and descriptive Paleontological and Bio-stratigraphic studies on geology of the Kachchh is carried out by group of workers of ONGC over a considerable period of time viz., Ghosh and Ghosh (1959), Sengupta (1959), Guha (1961), Poddar (1963), Biswas (1965, 1971), Biswas and Raju (1971), Biswas and Deshpande (1968, 1970). Their significant contribution lead to complete revision of the Mesozoic stratigraphy of Kachchh.

Biswas and Deshpande (1968) have revealed the presence of Precambrian basement rock (Syenite) at Meruda Takkar Island (Bet) situated north of Khadir Island in Great Rann of Kachchh. Mesozoic formation has been deposited over this Precambrian basement. Biswas (1980, 1982, 1987) has provided conceptualized picture of domes formed along all the major faults of the region i.e. Nagar Parkar Fault (NPF), Island Belt Fault (IBF), Kachchh Mainland Fault (KMF) and Katrol Hill Fault (KHF).

The Study of Tertiary rocks of Kachchh on the Nummulitic limestone with an assigned age of Oligocene was first initiated by Nuttle et al (1925). After a long gap, Mathur (1963, 1966), Venkatachala (1968a) and Prasad (1984) made significant contributions on Tertiary bio-stratigraphy of Kachchh. Biswas (1965) had recommended bio-stratigraphic classification of the Tertiary rocks and published a detailed geological map of the Tertiary rocks. Prasad (1998) has contributed bio-zonation of Middle-Late Jurassic sediments of Keera and Jura dome area based on ammonite faunal occurrence.

Along with stratigraphic and paleontological characteristics of Kachchh, the Seismo tectonic activity has attracted many workers, viz., Baker (1846), Frere (1870), Oldham, 1926), Quittmayer and Jacob (1979) Wynne (1872), Oldham, (1893); and Davison, (1936). They investigated 4.20 m subsidence of the southern side of the present day linear trench zone and complete submergence of Sindree Fort (located about 10-15 km south of Allah Bund Fault) due to 1819 Allah Bund Earthquake. Recently, Johnson and Kanter, (1990); Bilham, (1998); Rajendran et.al, (1998) have worked out earthquake models on probable fault plane mechanism of 1819 Allah Bund Earthquake. They believed that fault busted in 1819 was of reverse nature.

Quaternary geology of Kachchh was first investigated by Hardas and Merh (1968). They have discovered Miliolite rocks exposed along the coastal parts and in some inland areas. These Foraminiferal sandstone believed to be similar to Miliolite Limestone of Kathiawar deposited in marine environment during Pleistocene period (Fedden 1884, Auden 1952). Platt (1962) has given outline of the Rann sediments which was mainly based on the published accounts by Lyell, (1853) Wynne, (1872) Oldham, (1917) and Roy (1974) etc.

Thakkar,et.al. (1999) has carried out study on geo-morphology of Kachchh, quaternary tectonic history and terrain evaluation of the central Kachchh Mainland area. Subsequently, Karanth (2000), Sohoni (2001 and 2002) have studied tectono-structural attributes of central Kachchh Mainland with special emphasis on active tectonics and paleo-seismicity. They have recorded eight active faults in the Kachchh region such as Nagar Parkar Fault, Allahbund Fault, Kachchh Mainland Fault, Katrol Hill Fault, Naira River Fault, Bhujpur Fault and Wagad Fault. They opined that present day seismic activity in Kachchh is a sign of continued tectonism along these faults. The N-S trending Bhujpur fault fall in the candidate's study area, although no surface signatures are visible; its presence has been conjectured through topographic and sub-surface profiles and drainage deflection.

Recent earthquake event of 26th January 2001 in Kachchh has opened the flood gate for seismo-tectonic studies encompassing varied aspects viz. earthquake nature, fault mechanism, GPS derived crustal deformation (pre, co and post seismic), epicentral location, focal depth etc. Major contribution on these aspects has come from Gupta et al (2001), Bendick et al (2001), Rajendran et al (2001), Karanth et al (2001), Kayal et al (2002) Hough et al (2003), Sridevi Jede et al (2003), Schmidt et al (2006), Reddy and Sunil (2008), Shanker and Pande (2001), Gaur (2001), Singh et.al. (2001), Biswas and Khatri (2002).

LITHO-STRATIGRAPHY OF KACHCHH

The Kachchh stratigraphy represents a complete sediment sequence from middle Jurassic (Bathonian) period to Holocene, which is very uncommon and unique character. Geologically the region is very rich and diverse in fossil assemblage. Stratigraphy of Kachchh has been studied by many workers. Geology of Kachchh presented by Biswas (1993) incorporates most descriptive and an indepth account among all and is considered as basic reference in this presented study. Lithologically, geology of Kachchh is dominated by sedimentary sequences which filled the Kachchh basin having Precambrian basement (Fig. 3.1). The sedimentary formations have been deposited under fluvial and marine environment. The Mesozoic sediments have been invaded by large scale magmatic activity coeval to the Deccan Trap activity of Cretaceous to Paleocene age. The basaltic extrusive lava flows form base for the younger Tertiary sedimentary sequence in large part of Kachchh area. Following is a description of litho stratigraphy of Kachchh Region.

PRE CAMBRIAN BASEMENT

The basement for the Kachchh Basin sediments assumed to be Syenite rocks and considered to be equivalent to the Erinpura Granite of Pre Cambrian age. These magmatic rocks are exposed as solitary outcrop at Maruda Takkar Bet in the midst of Great Rann of Kachchh and considered to be the basement for younger group of rocks. The basal conglomerate of Mesozoic rocks exposed at Cheria Bet comprises graintic boulders (Biswas, 1993) explicitly indicate that beginning of the Mesozoic sedimentation in Kachchh took place on a Precambrian basement.

MESOZOIC ROCKS

Mesozoic rocks are characterized by various litho facies in different area. Biswas (1993) has classified Mesozoic stratigraphy in accordance with their area wise occurrence such as Kachchh Mainland, Pachchham Island and Wagad Highland. The area wise classification further divided into various rock units and has been correlated with each other according to litho stratigraphic marker horizons. The derived litho-facies are in tune with basin geography such as maximum marine characteristic in west and finer to coarser clastic fluviatile facies towards north and east, while there is no bed in east having rich fossil assemblage. Mesozoic rocks represent a complete cycle of sedimentation where oldest rock formation is exposed in Kala dongar (Pachchham Island) while Bhuj formation (Kachchh Mainland) represents the youngest one.

Mesozoic stratigraphy is ranging in age from Bathonian (Middle Jurassic) to Santonian (Lower Cretaceous). Lower Cretaceous rocks are invaded by basaltic lava flows, the Deccan Trap of Upper Cretaceous to Lower Paleocene age. Sedimentary formations of Mesozoic Era are exposed in six uplifted areas such as Kachchh Mainland (Bathonian to Santonian), Pachchham (Bathonian to Callovian), Khadir, Bela, Chorar Islands (Bathonian to Oxfordian) and Wagad Highland (Oxfordian to Portlandian).

Mesozoic rocks represent depositional environment from marine to fluviatile and end with volcanism. Rocks of Jhurio, Jumara, Kala Dongar, Gora Dongar and Khadir Formations are marine deposited, while rocks of Juran and Lower Wagad Sandstone represents paralic environment. Bhuj and upper Wagad Sandstone Formations are deltaic to fluviatile (Biswas, 1993). Mesozoic litho-stratigraphy as worked out by Biswas (1993) has been outlined in Table 3.1. Area wise each formation has been described briefly in ensuing paragraphs.

Pachchham Island

Litho-stratigrphy of Pachchham Island represents lower part of Mesozoics in Kachchh. Rocks are characterized as arenaceous in lower and upper parts, while middle part is dominated by arenite and rudite. The Pachchham rocks have been regrouped in two formations based on lithologic characteristics (Table 3.1). Here lower Kala Dongar Formation is overlained by Gora Dongar Formation.

Kala Dongar Formation: Basal unit of the Kala Dongar Formation is exposed at Kunwer Bet characterized by basal conglomerate, sandstone and fossiliferous limestone. The formation is poorly fossiliferous. It forms bulk of Kala Dongar hill. Complete section of

Kaladonger Formation is exposed on the scrap below the Babia peak. The rocks have been backed due to basaltic intrusion. The formation is dominated by Conglomerate, Sandstone, Aranaceous Limestone. Shale, Siltstone with Claystone as sub ordinate rocks.

<u>Gora Dongar Formation:</u> The formation is overlying Kala Dongar Formation and is exposed on the southern flanks of Gora Dongar hill range. Based on lithologic characteristics it is further divided into four members. The oldest member is Gora Dongar Flagstone consists of thinly bedded grey, yellow, pale brown colored fossiliferous pelsparite. It forms a hard cap over Kala Dongar Formation. The member is overlained by Gadputa Member consists of pale brown to pinkish colored, soft and massive, medium to coarse grained felspathic sandstone; Raimarlo Member comprises buff colored Limestone which are folded. The youngest Morad hill Member consists of Lower shale unit and Upper sandstone unit.

Table 3.1 Mesozoic Litho-Stratigraphy of Pachchham Island (After Biswas, 1993)

Period	Unit	Lithology	Depositional Environment
Callovian	Gora Dongar Formation 150 (+) m	Shale, siltstone, coarse grained sandstone, limestone, felspathic sandstone, and flagstone	Sub Littoral
Bathonian	Kala Dongar Formation 450 (+) m	Conglomerate, sandstone, arenaceous limestone, shale, siltstone, and claystone	Littoral

Kachchh Mainland

Mesozoic rocks exposed in central hilly terrain of Mainland area are bordered by narrow strip of Tertiary formations. Mesozoic rocks of mainland have been divided in four formations, viz., Jhurio, Jumara, Jhuran and Bhuj (Biswas, 1993). Overall litho-stratigraphy of Mesozoic rocks of Kachchh Mainland is given in Table 3.2

<u>Jhurio Formation:</u> It is the oldest formation of Mesozoic stratigraphy of the Mainland Kachchh which is either directly overlies the basement or on equivalent lower part of Kala Dongar Formation. Jhurio Formation is well exposed in deep valley of Jhurio hills with an aggregate thickness of 330 m. Upper part of the Jhurio Fm. is also exposed as

core of Jumara dome and deep ravines of Habo dome. Chief rock types of the Jhurio formation are medium grained white and grey crystalline limestone; pinkish coarse crystalline limestone with lenses of golden oolites, golden yellow calcareous 'Golden Oolite' and grey quartzose shale. Jhurio Fm. is further divided into seven members according to their litho faceis variations. Jhurio is the only formation in the Mainland where pure crystalline limestone occurs. The thickness of the formation varies in different regions such as 290 m thick in Jhurio dome, 75 m in Jumara dome and 15 m in Habo dome (Table 3.2). Depositional environment of the Jhurio Fm. has been ascribed to stable shelf to sub littoral. (Biswas, 1993)

Table 3.2 Mesozoic Litho-Stratigraphy of Kachchh Mainland (After Biswas, 1993)

Period	Unit	Lithology	Depositional Environment
Upper Cretaceous - Paleocene	Deccan Trap Formation 60-400 (+) m	Dark green and greenish black fine grained Basalt, amygdaloidal and vesicular basalt	Terrestrial Lava Flow
Cretaceous (Neocomian - Santonian)	Bhuj Formation Thickening towards west 400-900(+) m	*Upper:* Coarse grained felspathic sandstone, pale brown to dirty white, friable, current bedded. *Lower:* Brown, reddish felspathic sandstone with grey kaolinitic shale, sandy shale with thin hard iron stone bands. Carbonaceous shale with floral remains.	Deltaic to Fluvial
Disconformity			
Argovian - Neocomian	Jhuran Formation Thickening towards west 375-850 m	*Kateswar Member:* Greenish sandstone with Trigonia bands (exposed only in Ghuneri Mundhan area, W. Kachchh) *Upper Member:*Pink and yellow sandstone with minor shale intercalations. *Middle Member:* Grey shale with thin sandstone bands. *Lower Member:* Shale and sandstone with thick calcareous sandstone bands.	Paralic
Callovian - Oxfordian	Jumara Formation (300 m)	Khaki, grey gypseous shale with marl bands. Highly fossiliferous formation. Upper part is characterized by shale with fossiliferous oolitic marl bands (Dhosa Oolite)	Marine
Upper Bathonian - Callovian	Jhurio Formation 325m(+)	*Upper:* Bedded white limestone, Golden Oolitic bands occur in lower half, *Middle:* Golden Oolitic limestone and shale. *Lower:* Thinly bedded limestone, shale, Golden Oolitic limestone	Marine

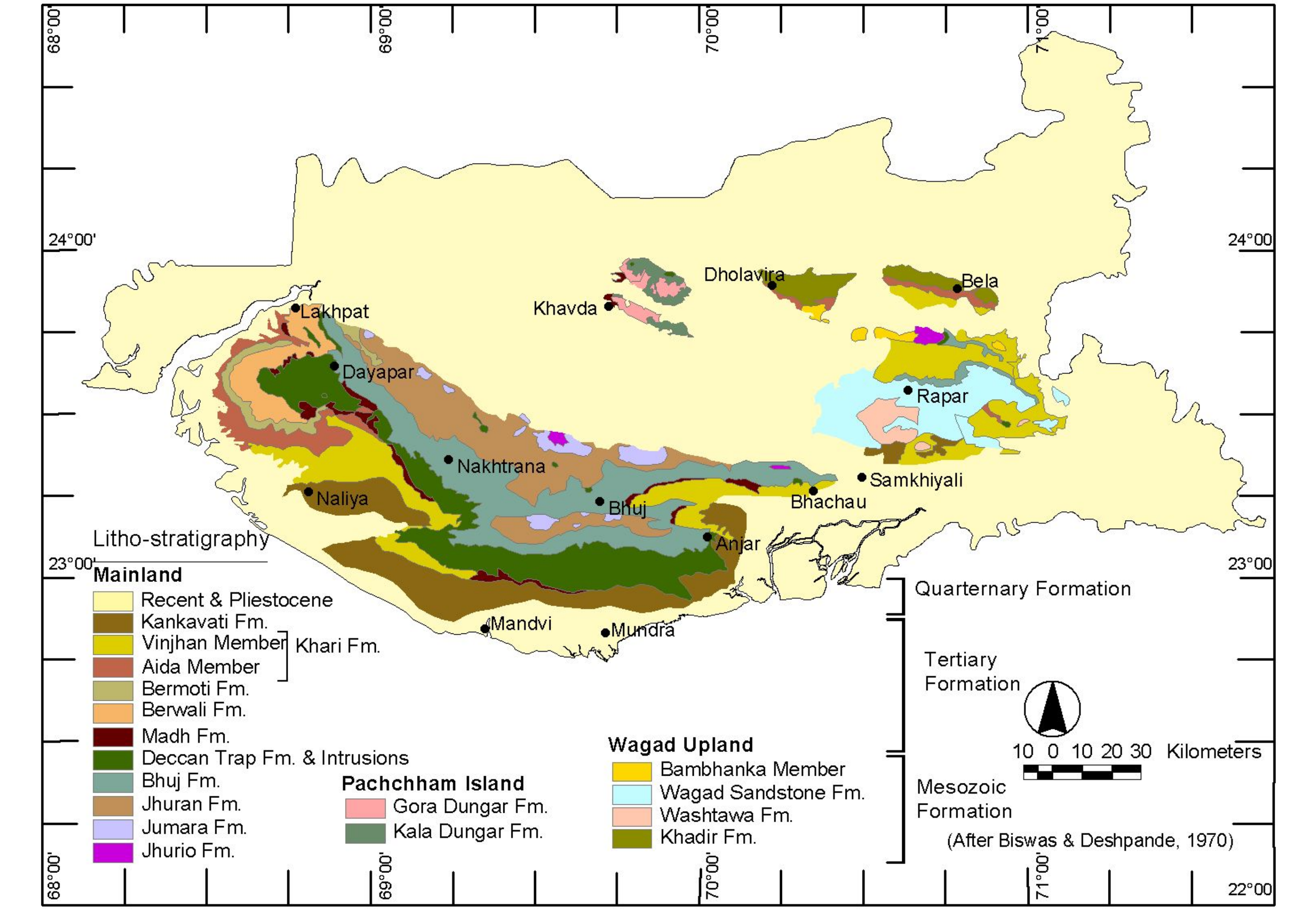


Fig. 3.1 Geology of Kachchh Region

Jumara Formation: This formation is characterized by thick argillaceous sequence overlying Jhurio Fm. The Jumara Fm is further divided in four members. It is very well exposed in central part of Jumara Dome. The Jumara Fm is richly fossiliferous and fossil content tend to gradually decrease eastward. Basal member of the Jumara Fm can also be seen at Jhurio and Habo domes. Well exposed sequences are also reported from Manjal, Keera and Dhar Dongar. Main rock types are Quartzose Shale and Gypseous Clayey Shale with hard beds of Marlite and Calcareous Quartzose Sandstone. The Marlite and quartzose sandstones are highly fossiliferous. Shale is greenish grey to olive green in color. The bands of golden oolite are also associated particularly at Keera dome. The rocks of Jumara Fm have been deposited in sub littoral environment (Biswas, 1993). Thickness of Jumara Formation varies from section to section such as 275 m measured at type section, 285 m in Jhurio section and 290 m in Habo hill section.

Jhuran Formation: The rocks of Jhuran Fm. are widely exposed and occupies about half of the Mesozoic area of Mainland. The Jhuran is overlying Jumara Fm. Jhuran sequence is exposed in northern hill range of Mainland as well as Juran river section. Jhuran Fm is known for a variety of Sandstones such as red to yellow, fine to medium grained micaceous felspathic Sandstone; coarse to medium grained calcareous Sandstone; fossiliferous Sandstone. Along with this, grey colored very well laminated shale is also found. Also, variety of sedimentary structures have been noticed in this formation such as current bedding, ripple marks, load and grooves cut and fill and slump etc. The western part of Jhuran Fm. is more rich in fossil content than its eastern part. Jhuran Fm is further divided into four members. (Table 3.2) Thickness of Jhuran rocks gradually decreases from west (790 m at Jara-Mundhan area) to central parts of Mainland area (345 m at Jhurio section). The Jhuran Fm exhibits various depositional environments viz. high energy wave zone, sub littoral, littoral and tidal flat. Jhuran Fm mark the combination of Mainland Mesozoic marine sedimentation as the sediments deposition marks final withdrawal of sea (Biswas, 1993)

Bhuj Formation: Sedimentary sequence of Bhuj Fm represents typical non-marine and youngest Mesozoic formation of Mainland Kachchh. Its good exposures are observed around Bhuj city such as Pur River section, Bhuj-Mundra road, Bhuj-Mandvi road, Rukmavati River, Ler-Chakar road section etc. The formation comprises from top thick bed of brown, buff to orange, red, current bedded felspathic sandstone with thin bed of Kaolinitic shale; hard band of purple colored ferrugenus sandstone. Shale (3-6 m) is associated as an intercalated bed with sandstone having thickness 15 – 30 m. Current bedding is very commonly seen in this sandstone. Beside this, ripple marks, load-casts, sole marks, hollow iron oxide concentration have also been noticed. This sandstone bed is rich in micro flora. The sandstone is soft, friable, massive, well sorted, and medium to fine grained. Snadstone of Bhuj Fm. attain maximum thickness of about 800 m measured in western parts of Mainland at Ghuneri where as, it attain least thickness (<265 m) in west central part at Jara-Hajipir. Bhuj Fm. is predominantly of fluviatile in nature however, thin marine sediments (Trigonia Bed) are present near Guneri village (Biswas, 1993), indicating presence of sea. Bhuj Fm. has been further divided in to 02 viz., the Upper and Lower Bhuj Formation (Table 3.2)

Deccan Trap Formation (DTF): This constitutes a part of terrestrial basic lava flow of late Cretaceous to early Paleocene time. These basalts act as boundary between Mesozoic and Cenozoic sedimentary sequences. The Mesozoic sediments were uplifted, folded, intruded and covered by Deccan Trap basalt. In all five to six lava flows have been identified and mapped where in two flows have been separated by occasional inter trappean beds. The DTF is exposed only in southern parts of Mainland. The DTF outcrops are E-W trending having 6 to 10 miles width and about 65 miles length sprawling between Anjar in east to Miani in west.

Wagad Highland

Stratigraphy of eastern Kachchh is represented by independent blocks (land masses) of Wagad, Khadir, Bela and Chorar. The Wagad region is separated from Mainland by a strip of flat alluvium covered area bounded by faults i.e. the Wagad Depression. The litho-stratigraphy of the region represents shallow marginal facies (Biswas, 1993). Rock of Wagad Highland area has been divided into three units viz. Khadir Formation, Washtawa Formation and Wagad Sandstone Fm. (Table 3.3).

Table 3.3 Mesozoic Litho-Stratigraphy of Wagad Highland **(After Biswas, 1993)**

Period	Unit	Lithology	Depositional Environment
Argovian – Neocomian	Wagad Sandstone 410 m	Grey, gypseous, quartzose, laminated sandy shales, massive, buff, grey, red, yellow, pinkish white colored, fine to medium grained, felspathic sandstone	Littoral to Deltaic
Upper Oxfordian	Washtava Formation 340 m	Alternate beds of shale and sandstone, Buff colored, massive felspathic sandstone, flaggy sandstone, gypseous shale	Sub littoral to Littoral
Bathonian - Upper Oxfordian	Khadir Formation 525 m	Grey, khakhi, gypseous, ferrugenus laminated shales, buff, pale brown, grey to reddish colored, massive, felspathic sandstone and conglomerate	Littoral to Sub littoral

Khadir Formation: Khadir Formation represents one of the oldest formations of the Mesozoic geology of Kachchh. The strato type section is exposed in Khadir Island. The Khadir Formation is sub divided into five members viz., from oldest to youngest (a) Cheriya Bet Conglomerate Member; (b) Hadibhadang Shale Member; (c) Hadibhadang Sandstone Member; (d) Gadhada Sandstone Member and (e) Bhambhanaka / Gangta Member. Cheriya Bet Member consists of conglomerate comprising granite pebbles and is exposed in small Island i.e. Cheriya Bet in Rann. The member is overlained by Hadibhadang Shale Member consists of alternate bands of shale and sandstone. However, it is predominated by shale unit, which is compositionally siliceous, gypseous and ferrugenous and laminated in nature. The younger Hadibhadang sandstone member consists of buff colored, medium to coarse grained, massive, friable, felspathic, quartzose sandstone. The Gadhada sandstone Member is well exposed in south Khadir around Gadhada village and comprised of alternating beds of lamellar and massive sandstone with flaggy calcareous bands. Sandstone is mostly pale brown, grey to reddish brown in color. The sandstone unit exhibit current beddings. The Hadibhadang sandstone Member is overlained by Bambhanka Shale Member consists of three distinct lithologic beds viz., thick basal grey- khakhi colored laminated shale; middle sandstone bed and the upper shale with sandstone bands. Similar lithologic sequences i.e. Bembhanka Member have been observed by Biswas (1993) in the neighboring Gangta Bet situated south of Khadir Island. Here the lower part of the Member is predominated by sandstone with thin intercalations of shale and comprises contrasting conglomerate unit. The presence of basal conglomerate and arkose sandstone as a base of Khadir Fm tend to ascribe its deposition over the Precambriam basement (Biswas & Deshpande, 1968). Although direct contact is no where exposed except a solitary occurrence of Synite outcrops at Maruda Takker, a small bet in GRK north of Khadir Island (Biswas, 1993).

The 550 m thick Khadir Fm has been bestowed with large scale occurrence of faunal and floral assemblages. Based on sediment characteristics, lateral facies variation and fossil content, the Khadir Fm is represented by a mixed type of depositional environment from beach to littoral-sub-littoral, near shore deposition in a transgressive sea during Bathonian to upper Oxfordian time (Biswas, 1993).

The Washtawa Formation: The rocks of Wasthawa Formation are exposed in central parts of Wagad highland. Maximum thickness of the formation has been observed in Washtawa dome. Lithologically this formation consists of three units viz. lower most unit comprises an alternate sequence of thickly bedded sandstone and shale; middle unit represents buff colored, current bedded, massive felspathic sandstone; and upper unit is characterized by flaggy and fissile sandstone and laminated gypseous shale. Most of the sandstone beds represent current bedding and ripple marks thereby indicate it's of fluvial origin. Total thickness of the formation stand at 340 m and the base is not exposed. The entire sequence is ferruginous with is very low carbonate content. Dominant fossils are ammonite, belemnite, gastropod, lamellibranchs. The depositional environment is sub littoral to littoral (Biswas, 1993).

The Wagad Sandstone Formation: The Washtawa and Khadir Formations are overlain by a thick and younger litho-stratigraphic sequence of Wagad Sandstone. This formation is extensively and exclusively developed in Wagad highland region except its central part represented by older Washtawa Formation as an inlier and surrounding area is covered by a narrow strip of Tertiary rocks. The Wagad Formation can be divided into two distinct parts viz., the western and eastern Wagad. The wastern Wagad region has been classified into two members viz., lower marine unit known as Kanthkot Member and Upper non marine unit as Gamdau Member. As one move towards east, the marine sandstone laterally grade into non marine sandstone and merge into single formation as Wagad Formation. Kanthkot Member is well exposed in scarp of Kanthkot hill, while Gamdau Member is well exposed in the hills around Gamdau and south of Wamka village. Dominant rock type is sandstone which is soft, friable, massive and susceptible to weathering. Sandstone is having hard calcareous and ferruginous cap (Biswas, 1993).

The lower part of Kanthkot Member is characterized by sandy shale which is grey in color, gypseous, quartzose, interlaminated with sandy and ferruginous layers with intercalations of felspathic and ferruginous sandstone. The basal shale is overlained by a thick bed of massive, current bedded, buff – grey – red colored, fine to medium grained, felspathic sandstone, with a deceptive shale bed as top. The basal unit is overlained by yellow, pink to while, massive, soft, friable, medium to coarse grain, felspathic- quartzose sandstone. Fossils found in Kanthkot member are mainly *Trigonia*, *Belemnites* and *Ammonites.*

Gamdau Member consists of yellow, pinkish white, medium to coarse grained, felspathic sandstone with lenticular conglomerate and shale. The sandstone is friable, massive and current bedded. Eastern Wagad part consists of yellowish white to brown, occasionally calcareous, medium to coarse grained, felspathic sandstone with intercalations of grey, gypseous sandy shales. The formation is influenced by basaltic, intrusives and faults (Biswas, 1993).

CENOZOIC ROCKS

Cenozoic rocks ranging in age from Paleocene to Holocene. Cenozoic era is characterized by repetitive phenomena of marine transgression and regression. The Kachchh basin is considered to be the strato-type area for Tertiary rocks in India. The Cenozoic rocks have been divided into two broad divisions such as Tertiary and Quaternary.

In Kachchh basin the Tertiary rocks are deposited over the eroded surface of Mesozoic and Deccan trap rocks. The rocks are distributed as narrow strip, fringing the Mesozoic rocks in Mainland, Islands and Wagad Highland regions. The Tertiaries are well exposed in coastal parts of the Mainland region.

Tertiary Rocks

The Tertiary rocks in Kachchh basin are ranging in age from Paleocene to Pliocene. The Tertiary type sections are well exposed as narrow coastal strip in southern and western parts of Kachchh Mainland where in, Deccan Trap forms as basement to these rocks. Rocks are generally dipping seaward which indicate further extension of Tertiary sediments in offshore regions of the Gulf of Kachchh and Arabian Sea. The Tertiary rocks have been divided into five formations described as under-

Table 3.4 Tertiary Litho-Stratigraphy of Kachchh Mainland Region (After Biswas, 1993)

Period	Unit	Sediment Characteristics	Depositional Environment
Pliocene	Kankavati Fm. 325 (+) m	Grey quartzose sandstone with thin shale bed, claystone, silt stone, conglomerate	Littoral to Tidal flat
Miocene	<u>Khari Fm.</u> Vinjhan Mem. 110-140 m Aida Mem. 85 (+) m	*Vinjhan Member:* Grey silty shale, micaceous sandstone, gypseous khakhi, bluish grey and brown claystone, yellow limestone, marlites, *Aida Member:* Red and yellow variegated siltstone, grey and brown claystone	Epineritic to Neritic, Transgressive overlap
Oligocene	<u>Ber Moti Fm.</u> Waior Mem. 09 – 12 m Ramaniya Mem. 13-32 m	*Waior Member:* Gluconitic sandstone, fossiliferous calcareous siltstone, silty clay, foraminiferal limestone, calcareous sandstone, sandy limestone *Ramaniya Member:* Calcareous argillites with biogenic limestone, calcareous calystone, brown calcareous siltstone, grey marlite	Epineritic
Eocene	<u>Berwali Fm.</u> Babiya Mem. 45- 60 m	*Babiya Member:* Foraminiferal limestone, clay, green, greenish grey fossiliferous shale, claystone, gypsum as vein and concretion, calcareous claystone	Neritic
	Kakdi Mem. 36- 65 m	*Kakdi Member:* Laminated grey, brown, olive green, glauconitic shale	Littoral to Lagoonal
Paleocene	Madh Fm. 10- 55 m; 20- 30 m in Lakhpat	Laterite, pisolitic bauxite, Trap pebble conglomerate, bentonitic clay, red yellow ferruginous clay, grey and white tuffaceous clay	Continental to Supra Littoral

Madh Formation: Stratigraphically, this formation is resting over the Deccan Trap Formation and marked as the base for Tertiary rocks. The rocks of Madh Fm. span between middle to late Paleocene and are characteristically bounded by two planes of disconformities at lower Paleocene and lower Eocene times. Overall sediments have been deposited in continental to supra littoral environment. A strato type section of Madh Fm is exposed around Mata no Madh village in western Kachchh, representing as a narrow belt bordering the Deccan Trap (Biswas, 1993).

Madh Fm. is represented by a variety of rock types viz., red and brown altered trap rocks, laterite, pisolitic bauxite, lateritic trap pebble conglomerate, yellow bentonitic clay, red and yellow ferruginous clays, grey and white tuffaceous shale and red sandstone. The lithological variation is very frequent. Madh Fm. show marked changes in lithology in its lower part. It consists of laterite with lateritic clay, pink lithomarge clay, trappean rock fragments and blue green trappean clay. Middle part comprises grey to brown thinly bedded shale, carbonaceous shale and tuffaceous sandstone whereas, upper part is characterized by irregularly bedded, coarse grained, tuffaceous felspathic sandstone. It attains almost 55 m thickness in its type section (Biswas, 1993).

Berwali Formation: Lying above the Madh Fm. the litho-sequence of Berwali Fm belongs to Eocene age, representing the earliest marine sediments of the Cenozoic era. Berwali Fm. comprised of is gypsiferous clay, limestone and marlite beds and is exposed only in western Kachchh. The type section is exposed in Berwali River north of Vayor. Berwali Fm. is further divided in two Beds viz; (01) Kakdi Bed: Lower Eocene sediments exposed in Kakdi River; (02) Babia Bed: Middle Eocene sediments exposed in Babia hills (Biswas, 1993).

Kakdi Bed occurs as a narrow belt and the type section is exposed as 7-23 m high cliffs along Kakdi River. The sediments are mostly shale, clay with abundant fossils of Pelecypods and Gastropods. In its type section, lower part is represented by laminated grey, brown, olive green, variegated glauconitic shale with grey to greenish grey, hard marlite and limestone bands. Gypsum is present as thick bands and veins along joints. Upper part contains grayish brown to grey unfossiliferous claystone and shale with lateritic intercalations. Shale due to its susceptibility to erosion are subdued; where as resistant marlite and materite bands form roof cap of the cliff. Lower unit indicates quiet shallow water lagoonal and the upper unit represents tidal flat environments indicating regressive phase of the sea (Biswas, 1993).

Babiya Bed represents younger sequence of Berwali Fm. which is ideally exposed in Berwali River section and Babia hill. The unit constitute of 9 km wide arcuate belt. The lower part is highly fossiliferous, representing calcareous yellow, limonitic, gypseous claystone and grey shale with fossiliferous marlite beds (Biswas, 1993). Upper part is thickly bedded comprising cream buff colored foraminiferal limestone where fossils are cemented by micro crystalline calcite. Lamellibranches and Gastropods are associated with marlite bed whereas corals and echinoids occur with shale. Maximum thickness of this bed stand at 62 m in Berwali section and tend to decreases to 45 m northward at Narayan Sarovar. Presence of rich benthonic and planktonic fauna signify stable shelf sub littoral environment (Biswas, 1993).

<u>*Ber Moti Fm:*</u> The litho-stratigraphic sequence of Ber Moti Fm. has been ascribed Fm. to Oligocene age and overlies the Berwali Fm (Biswas, 1993). This formation represents sequence of banded, impure limestone, marlites and clay rocks of Berwali Fm. Well developed litho-sequence is occurring as narrow strip along southwestern coastal tract. Ber Moti Fm. is sub-divided into two beds viz., lower Ramania Bed and upper Waior Bed. Ramania Bed is dominant one and occupies most of the area of this formation. Waior Bed outcrops occur as thin bend bordering Ramania Bed.

Ramania Bed overlies Babia Bed of Eocene age. The rocks of Ramania Bed is well exposed in stream situated west of Ramania village and has been named after it. It is also well developed in Berwali, Bermoti Nadi, Walsara and Lakhpat areas. Thickness of the unit in type section is 32 m while 13 m in Madh basin. Main rock types are cement colored calcareous claystone, brown calcareous siltstone, white, cream colored limestone, grey marlite and grey, yellow sandstone. However, in Madh basin black shale and claystone are exposed. Limestone, shale and clay invariably appear as oolitic with the marked presence of dark green glauconite. The unit is highly fossiliferous comprising echinoids, pelecypods, gastropods and foraminifera fossils (Biswas, 1993).

Waior Bed is well exposed on the right bank of Waior stream with an overall thickness of about 8 m. The unit is also exposed as an articulate belt rimming the Ramania outcrops around Narayan Sarovar Nose. The rocks form featureless plain with occasional presence of hill made up of hard bands in upper part. Lower part of the bed is argillaceous where as upper part comprises calcareous sediments. Lower most bed is characterized by the presence of thick rusty brown glauconitic argillaceous sandstone with green pellets of glauconite, overlained by a thin fossiliferous calcareous siltstone band, which in turn is followed by greenish grey to yellow, fossiliferous, silty claystone with inter bed of fossilifeous calcareous sandstone and sandy limestone. Thickness of the type section is around 12 m. Depositional environment of the bed is ranging from supra littoral- lagoonal to littoral with increase in depth of sea representing transgressive phase of the sea (Biswas, 1993).

Khari Fm.: The rocks of Khari Fm. belongs to Miocene age and overlies Ber Moti Fm. The Khari Fm. is very well developed and sprawl in wide area covering Mainland and Wagad Highland regions. The strato-type section occurs in Khari River where as, its upper part is exposed in Kankavati River. In the western parts of Kachchh extensive outcrops of Khari Fm. occurs as continuous belt from Lakhpat to Mandvi. Its eastward continuity is further seen from Anjar to Mainland area. Overall litho-stratigraphy of Khari Fm. has been divided into two beds viz., Aida and Vinjhan Members. Both litho units are lithologically and palaeontologically are diverse and distinctive (Biswas, 1993).

Aida Member is well exposed in area east of Waior. Good exposures of this unit can be seen in high cliffs of Waior and Khari streams. However, this unit gradually pinched out between Vinjhan Member and Madh Fm. west of Netra on account of a fault passing between Aida and Vinjhan Members. In islands and Wagad highland, Aida rocks directly overlie the Mesozoic rocks forming a peripheral rim around Mesozoic sediments. Aida Members are comprised of red yellow, mottled to variegated friable siltstone and occasional grey, brown claystone. Calystone and siltstone are laminated. Lower part of the Aida Member is less fossiliferous comprising mainly lamellibranches and plant fossils whereas upper part shows predominance of Grastropods and Pelecypods. Aida Member attains its maximum thickness of about 80 m in its type section. In other area, its thickness varies from 15 m to 55 m. In its mud sequence, presence of worm burrows and ferruginous bands indicate tidal flat environment whereas, sand sequence indicate tidal channel type of deposition (Biswas, 1993).

Vinjhan Member represents an upper most division of Khari Fm. which is well exposed in Vinjhan section of Kankavati river. Along the KMF the outcrops are overlying the Madh Fm. rocks. Lithologically Vinjhan Member consist of khakhi, bluish grey, brown claystone, yellow limestone and hard, yellow fossiliferous marlite bands. In its upper part, claystone is silty and well laminated with ferruginous and micaceous partings. Siltstone is also laminated, having micaceous composition with lenses of clay. Top of the unit consists of grey silty shale and micaceous sandstone. Rocks of Vinjhan Member exhibits rich assemblage of mega and micro fossils representing gastropods, corals, echinoids, lamellibranches and foraminifera. Vinjhan Member attains its maximum thickness of 145 m in its type section. Uniform distribution of lithology indicates that the rocks have been deposited in quiet waters of sub littoral zone (Biswas, 1993).

Kankavati Fm: The rocks of Kankavati Fm. belong to Pliocene age. In its type area rocks of this formation are overlying Khari Fm. of Miocene age. The litho- sequence represents a youngest Tertiary unit and overlain by coastal alluvium throughout its extension. Kankavati Fm. is exposed as a wide continuous belt of outcrops along the coastal plains of southwest, south and southeast of Kachchh Mainland region from Naliya in west to Anjar in east. A complete sequence is exposed in Kankavati River cliffs between the villages of Vinjhan and Sandhan. However, in the Mainland region i.e. south and south eastern parts, only upper most unit of the Kankavati is exposed, which is having Deccan Trap as base (Biswas, 1993). Same way patchy outcrops are seen occurring in Wagad highland area. Kankavati sandstones are highly porous and permeable in nature therefore hydro-geologically constitutes ideal aquifers.

The Kankavati Fm. is dominantly arenaceous in composition with intercalations of clay stone, shale, siltstone, marlites and calcareous sandstone as sub-ordinate constituents. The Kankavati Fm. attains its maximum thickness of 320 m in its type section that gradually decrease towards east. The complete sequence indicates its deposition in a regressive sea phase and under littoral to flood plain environment (Biswas, 1993).

Quaternary Rocks

The study of Quaternary landscape, sedimentation, distribution pattern, and the quaternary stratigraphy in the present context attain very much significance due to its been ideal repository for groundwater resource. Major contribution on Quaternary aspects of the Kachchh region have come from the workers of Department of Geology, the Maharaja Sayajirao University of Baroda viz., Roy, (1997), Roy and Merh (1981), Patel and Merh (1988) Chamyal et al. (1995); Merh (1995); Merh and Chamyal (1993, 1997).

Quaternary sediments belong to Pleistocene to Holocene age having Tertiary rocks as their base. The rocks are divided into two parts viz., Miliolite Formation and Recent deposits. Recent alluvium is overlain by Aeolian and marine sands. The depression of Banni and Rann has been filled by the sediments carried by the Indus, Nara, and other rivers on western part of Indo-gengatic plains as well as by seasonal drainage of Kachchh.

Table 3.5 Quaternary Litho-Stratigraphy of Kachchh Mainland (After Merh, 1995)

Period	**Formation/ Series**	**Lithology**	**Depositional Environment**
Holocene to Pleistocene	Recent	Alluvium, Rann silts and blown sands, Mud flats, Salt deposits and dark bluish grey silt of Rann	Marine, Fluvial and Aeolian
	Miliolite Formation (15 - 30 m)	White and pale brown miliolitic limestone	Aeolian

__Miliolite Formation:__ According to litho-stratigraphy proposed by GSI (1988), age of miliolite is middle to late Pleistocene. The formation is of Aeolian origin and has similar characters to that of Miliolite Formation of Saurashtra region. Miliolites are mostly obstacle deposits partly modified by the fluvial processes as evident by the presence of pebble and gravels of substrate rock (Bhatt, 2003). Its patchy outcrops occur at the foot of steep edge hills, hollows and depression of hilly track, and shoulder surrounding to high hills. Occurrence of miliolite rock ranges from 45 to 180 m above mean sea level (Baskaran, 1989). Its patchy occurrence in Mainland area has been observed at Charwar range, Dhola range, Roha hill, Dhinodhar hill, Dhrubiya dongar etc. In Wagad highland region, the miliolites occur as small outcrop at Adhoi hill and along Kanthkot fault scarp. In Island belt, deep valley of Gora and Kala dongar of Pachchham, north escarpment of Khadir and Bela hills are the ideal locations. The miliolitic rocks are white to pale brown in color and composed of sand and calcareous pellets. Sand grains are clear quartz, very well rounded and highly sorted. Calcareous pellets might have formed by rolling of taste of miliolite foraminifera (Biswas, 1993). The rock is poorly cemented. The outcrops of miliolitic limestone are extensively quarried as building stone material. The rocks are paper thin laminated with coarse and fine grain arranged as alternate bands. It's wedge type cross bedding show aeolian characters (Biswas, 1993). Thickness of the Miliolite formation varies from outcrop to outcrop viz;, Charwar hill (15 m), Dhinodhar hill (35 m) Washtawa area of Wagad highland (> 35 m). Miliolitic rocks are characterized by heterogeneity in grain size, high order of sorting, presence of ample foraminiferal tests, deposition against natural barrier and dunal appearance. These all characters point to their wind borne nature (Bhatt, 2003).

Recent Deposits: These are non indurated loose sediments belong to Holocene – recent age. It consists of variety of sediments deposited by the mechanical, aeoline, fluvial and marine environments. The fluvial deposits are alluvium and bouldery terrace deposits. Aeolian deposits are blown sand and dunes found in peripheries of highlands. In coastal parts, recent deposits are mainly associated with sandy beaches and consists of quartz; carbonaceous material available in beach sands comprise forminifera and skeletal debris. In western Kachchh, tidal flat and flood plain deposits are full of fossils transported from mainland area. Bordering Island belt, conglomerate and oyster shell beds are found which represent raised beaches attributed to past high strandline (Biswas, 1993).

The Rann region represents recent deposits comprising fine laminated, dark bluish to grey colored clayey silt with intermittent gypsum laminae. Rann area is having a cap of 5 to 8 cm thick crystalline salt, deposited by evaporation. The salt layer dissolved seasonally in monsoon and reprecipitate. At the boarder of Rann towards mainland, large alluvial fans have been formed under the fluvial and gravity induced mechanical actions. Banni grassland area comprises fine grained clayey sand, deposited by rivers flowing from mainland region.

STRUCTURAL AND TECTONIC SETUP

The tectonic and structural style of Kachchh region represents an ideal case of rift tectonism. Although earlier workers viz., Wynne (1872) was first to map three parallel ridges in Kachchh. Krishnan (1968) studied it in further detail and classified these parallel ridges as three anticline structures exposed in northern, middle and southern parts of the Kachchh. The credit for conceptualizing regional tectonic and structural framework of Kachchh goes to Biswas (1971). Biswas based on detailed tectono-morphological description of the various structures developed an overall tectonic framework of the Kachchh and ascribed it as pericontinental rift basin developed on the western passive margin of the continent (Biswas, 1980,1982 and 1993).

The basin was formed during the late Triassic break up of Gondwana land into two small continents viz., east and west Gondwana (Biswas 1982). India was a part of east Gondwana, which drifted anticlockwise from middle Jurassic time onwards. Later on during early Cretaceous, other part of east Gondwana (Antarctica and Australia) drifted away from India. During late cretaceous time, Indian plate continued to drift with increasing speed of 15 to 20 cm/year northward along with completion of 50^0 rotation (Biswas 1982). When Western margin of India crossed the equator, Deccan (Re-union) hot spot was erupted spreading basaltic lava flows over million sq km area. Commencement of collision of India with the southern boundary of Eurasia occurred during Late Paleocene- Eocene time. The joining of India and Eurasia occurred during

Eocene- Oligocene time when motion nearly halted and anticlockwise rotation was 9^0 while northward movement continued during Miocene Pliocene time (Biswas 1982). During post collision, Kachchh rift basin became a shear zone with convergent strike slip movement along sub parallel rift faults. This resulted in present uplifts with respect to Kachchh mainland. The Kachchh Mainland Fault along the rift axis becomes the active principle fault. This strike slip fault is overstepped by South Wagad Fault (SWF) in the eastern part of the basin (Biswas, 2002, 2005). The overstep zone between the two fault system is the most rupture nucleation site, concluded based on closed epicentred locations of two major earthquakes (Anjar 1956 and Bhuj 2001) followed by concentrated aftershocks.

Landscape of Kachchh is an excellent example representing active role of tectonism in its development. Physiography of the region gives an expression of tectonic movement along lineament of the Pre-Mesozoic basin configuration resulted due to original fault pattern present in Precambrian basement (Biswas 1971, 1974 and Deshpande & Biswas, 1976). The Kachchh basin has a unique history of continued tectonism along all major faults which reactivated time by time and resulted in to as series of earthquake incidents. Physiography of Kachchh is clear manifestation of such active tectonism since Mesozoic time. Neotectonic activity has influenced terrain in terms of evolution of landforms and fluvial regime.

Structurally, Kachchh is situated at the contact boundary of northwest of India with geosynclinal belt of the Sindh-Baluchistan. This marginal portion is characterized by block faulting and folding. The Kachchh is regionally characterized by series of upliftments along major faults. These upliftments along faulted margin is marked by narrow linear zone, a series of asymmetric domes and brachy anticlines (Biswas, 1993). This uplifted area is bounded by a fault or sharp flexure on one side and gently dipping peripheral plain and strata of Tertiary age on other side. Mesozoic strata of Kachchh basin are tectonically disturbed through fault, fold and intrusion due to igneous rock. Later on Tertiary formation wrapped the Mesozoic formation around highland and lie over it on gentle dipping plain (Biswas, 1993 and 2005).

Thus, Kachchh basin represents a complex framework of faults and other lineaments. Major bounding faults are (1) Nagar Parkar Fault (NPF) that mark northern most boundary of the basin; (02) Allah Bund Fault in North in Great Rann of Kachchh; (03) Island Belt Fault distinguished islands in Great Rann of Kachchh; (04) Kachchh Mainland Fault separating Kachchh Mainland from Banni Grassland; (05) Offshore West Coast Fault marking western limits of the Kachchh basin; (06) Gulf of Kachchh and Little Rann Fault in south and eastern margin respectively; (07) Wagad Fault that separate Kachchh Mainland from Wagad Upland and (08) The Northern Kathiawar Fault delineating southern side of Kachchh basin (Biswas 1980). There exists many subsidiary faults sympathetic to these major faults that have developed during various stages of the repeated reactivation of the major bounding faults (Srivastava *et al.*, 1964; Biswas, 1980 & 1982; Biswas and Deshpande, 1970; Sharma, 1990; Sychanthavong, 1984). Among these viz., Katrol Hill Fault, Vigodi Fault, Fault system of Little Rann of Kachchh, Naira River Fault, Bhujpur Fault, Vinjhan Fault, Vinjhan Anticlinal Nose and Kothara Embayment, Gulf of Kachchh Embayment, Narayan Sarovar Anticlinal Nose, and Bhachau Anticlinal Nose are significant (Biswas, 1993).

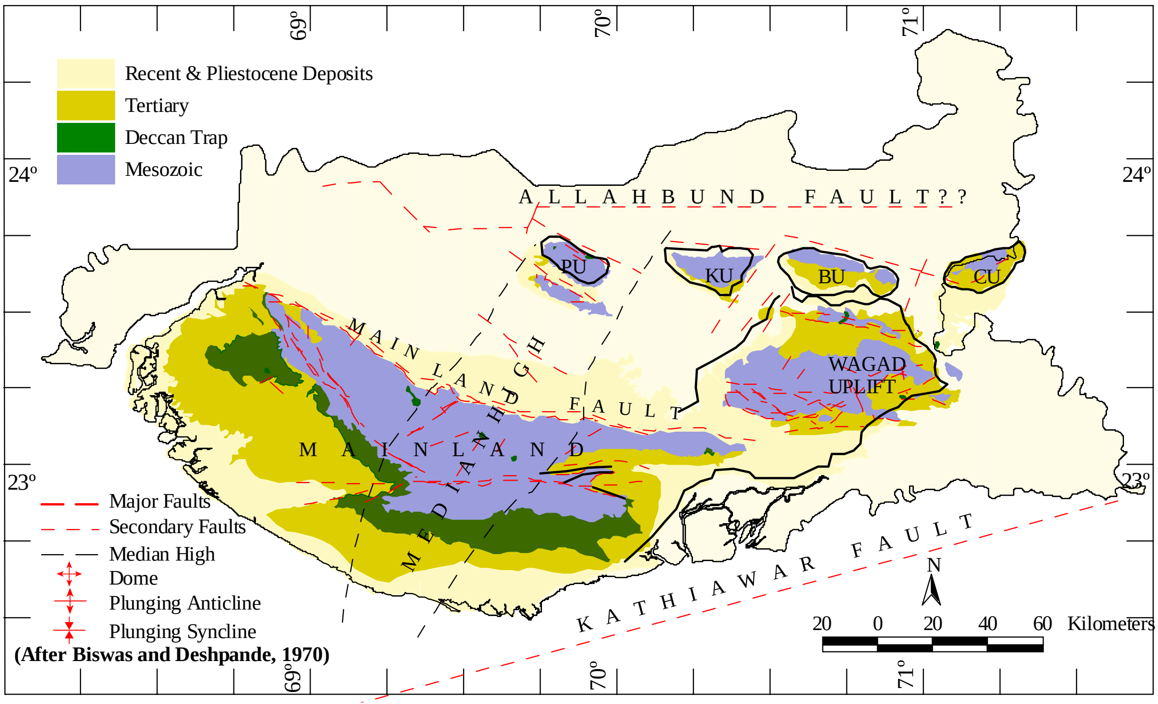


Fig. 3.2 Tectonic Set up of Kachchh Region

Tertiary rocks of Kachchh are the repositories of past tectonism. Therefore, reactivation of the major faults has considerably influenced the geomorphic processes of the region. Sengupta (1967) has given a detailed account of the off-shore faults of the Kathiawar and Kachchh regions where in he specified strong possibilities of the presence of sets of faults within the Gulf. Ghosh (1981) has carried out study on Quaternary morpho-stratigraphy and neotectonic aspects in Little Rann of Kachchh. He has identified many evidences of neo-tectonic movements from post Tertiary to Recent times.

LITHO-STRATIGRAPHY OF THE STUDY AREA

Geology plays an imperative role in hydro-geological environment of the region. Considering this, geology of the study area has been detailed out by compiling available information followed by ground checks.

Litho-stratigraphically, the study area is divisible into 07 Formations belonging to Mesozoic, Cenozoic and Quaternary Eras. These formations include Jumara Fm, Jhuran Fm, Bhuj Fm, Deccan Trap Fm, Madh Series, Kankavati Fm, and Quaternary Sediments (Fig. 3.3 & Table 3.6).

MESOZOIC

Mesozoic litho-stratigraphy of the study area is characterized by marine fluviatile deposits of Jumara Fm, Juran Fm, Bhuj Fm (Biswas, 1993). During late Cretaceous time, volcanic eruption has given rise to Deccan Trap Fm (Table 3.6).

Jumara Formation

Jumara Fm. is an oldest formation deposited in sub littoral environment during Callovion and Oxfordian period (Biswas, 1993). It comprises of mainly grey gypseous shale with fossiliferous oolitic marl bands (Dhosa Oolite). Very few isolated outcrops are found in upper part of the study area. The Jumara rocks are overlained by Jhuran Formation.

Table 3.6 Litho-Stratigraphy of the Study Area

ERA	Period	Age	Formation & Thickness	Lithology	Depositional Environment	Locality
CENOZOIC	Quaternary	Holocene to Pleistocene	Recent (12-15 m)	Alluivum, River Sand, Clay, Pebble, Dunal Sand	Marine, Fluvial and Aeolian	Siracha, Jharapara, Mundra, Luni
			Miliolite Formation	White to pale brown miliolitic limestone	Aeolian	Wadzar, Kanjara, Kera
	Tertiary	Pliocene	Kankavati Fm. (40 to 120 m)	Pink, Pale brown, friable sandstone with shale bed, conglomerate	Littoral to Tidal flat	Gelada, Bhujpur, Gundala, Hatadi
		Paleocene	Madh Fm. (10-12 m)	Laterite, Trap Pebble variegated clays	Continental to Supra Littoral	Ramaniya, Bocha
MESOZOIC	Cretaceous	Upper Cretaceous to Paleocene	Deccan Trap Fm. (70- 80 m)	Dark green and greenish black massive basalt, amygdaloidal and vesicular basalt	Terrestrial Lava Flow	Babia, Wanki, Lifra, Vaghura, Bhalot, Khedoi
		Neocomian to Santonian	Bhuj Formation (110-120 m)	Coarse grained, pale brown to dirty while, friable, current bedded felspathic sandstone, with grey shale, sandy shale	Deltaic To Fluvial	Meghpar, Reha, Kotada, Warli, Wada
	Jurassic	Argovian to Neocomian	Jhuran Formation	yellow sandstone, grey shale and thick calcareous sandstone	Paralic	Jadura village, Katrol Hill range
		Callovian to Oxfordian	Jumara Formation	Grey gypseous shale with fossiliferous oolitic marl bands (Dhosa Oolite).	Marine	Patches in Katrol Hill range

(Compiled After Biswas, 1993)

Jhuran Formation

The Jhuran Fm. rocks are ascribed to Argovian to Neocomian period. The Jhuran formation is deposited in paralic environment representing transition phase of marine to fluviatile environments. The Jhuran Fm. consists of yellow sandstone, grey shale and thick calcareous sandstone. Shale occurs with sandstone as intercalated bands. In study area, the formation occupies 96 sqkm area in north as narrow E-W trending strip of Katrol hill range.

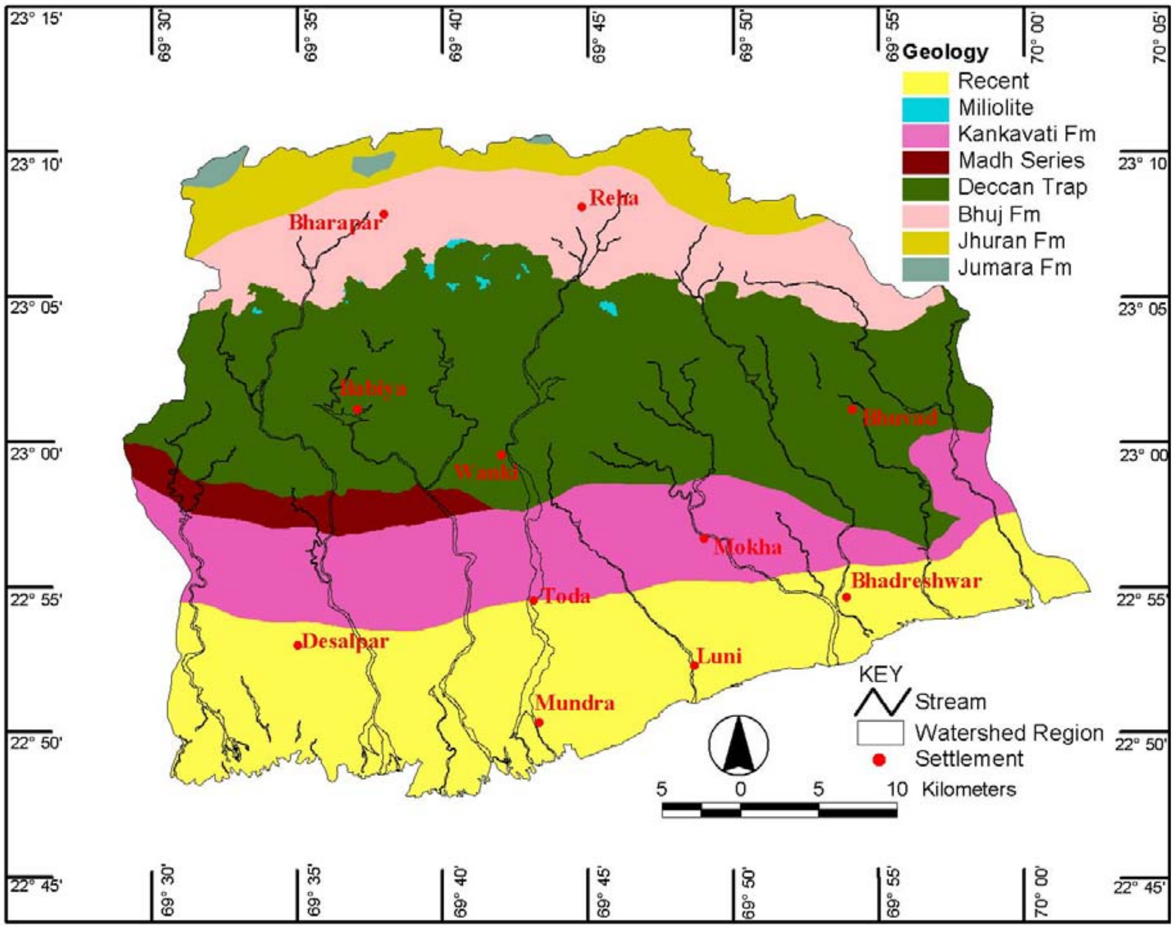


Fig. 3.3 Surface Geology of the Study Area

Bhuj Formation

Bhuj Fm. overlies the Jhuran Fm and represents the youngest Mesozoic formation of the area. Bhuj Fm. represents fluviatile deposits of Neocomian to Santonian period. Lithologically, this formation comprises current bedded coarse grained felspathic white, yellow, purple colored massive sandstone with bands of grey kaolinitic shale, sandy shale and iron (Plate 3.1). The formation occupies almost 214 sq.km. area in north central parts of the study area. Good exposures of this formation occur in River cliff at Kera village, cliffs at Reha village, River cliffs at Chakar- Kotada village. Sandstone unit of Bhuj Fm. shows very well developed ripple marks, current bedding and burrows (Plate 3.2 & 3.3). In borehole lithologs, the maximum sub-surface thickness, 118m at Meghpar in west and 112 m at Wadli village in east has been observed. Shale bands occur as intercalated bed of 3 to 6 m thickness. The formation has been considered as potential deep aquifer distributed mainly in northern part of the study area around Meghapr, Bharapar, Kera, Reha, Kotda, Wada villages.

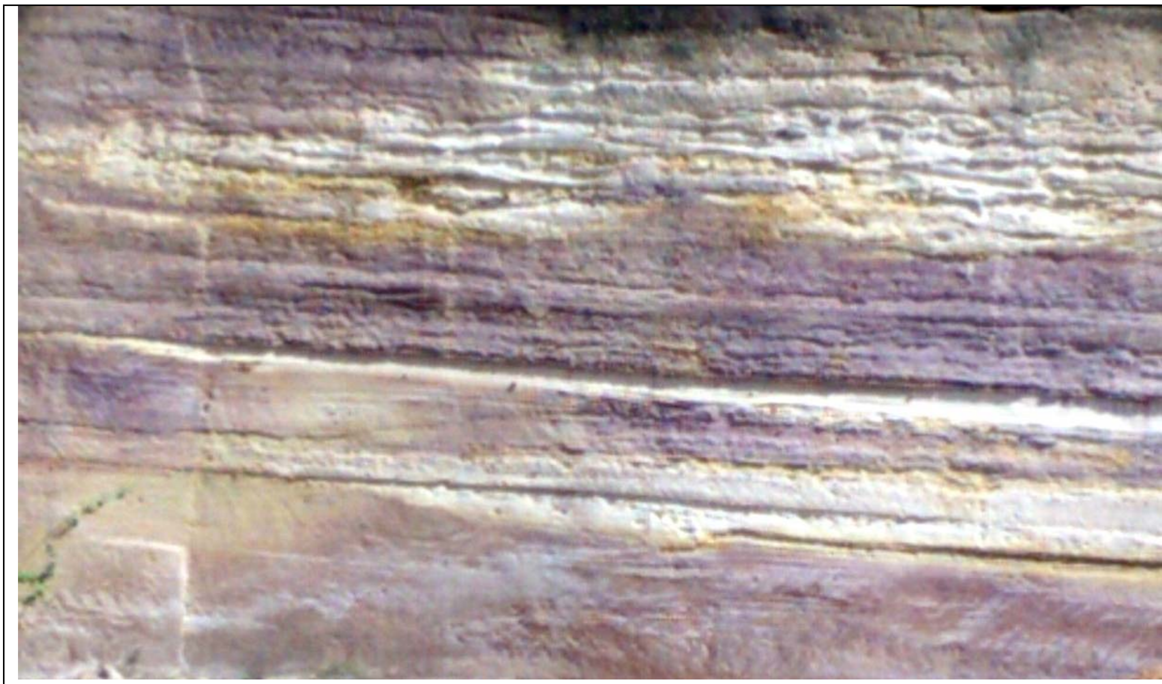


Plate 3.1 A Close View of Bhuj Sandstone Showing Intercalations of Ferrugenized Bands (Loc.- Sedata Village)

Plate 3.2 A View of Bhuj Sandstone Showing Ripple Marks in River at Chakar Village

Plate 3.3 A Close View of Well Developed Ripple Marks in Bhuj Sandstone (Loc.- Chakar Village)

Deccan Trap Formation

Mesozoic sedimentation ends with Deccan Trap which has intruded in Bhuj Fm. Deccan trap consists of terrestrial basaltic lava flows erupted during upper Cretaceous to Paleocene period of Cenozoic era. It is the only formation of volcano- igneous origin. The formation occupies major central part (609 sq.km.) of the study area. It is comprised of dark green and greenish black colored massive basalt, amygdaloidal and vesicular basalt lava flows. Thickness of basalt in the study area is less as compare to western Kachchh where basalt has erupted as plugs (Biswas, 1993). In study area basalt occurs as table land flow and is massive in character. The thickness of basalt in study area tend to decrease towards west. Its maximum thickness has been observed in borehole log at Chunadi village (78m) and Bandra village (75m); while in east it has attain 45 m thickness at Mindiyana village. Top 10- 15 m thick is characterized intense weathering. The weathered and fractured zones in basalt perform as a shallow phreatic aquifers around Babia, Wanki, Bagada, Vaghura villages.

CENOZOIC FORMATIONS

Cenozoic litho-stratigraphy of the study area comprises rock formations belonging to Tertiary and Quaternary age. The Tertiary formations show a marked stratigraphic hiatus having complete absence of Eocene to Miocene age sediments. Therefore, the study area only represents the litho-sequence belonging to Madh Fm. (Paleocene) and Kankavati Fm. (Pliocene). The Quaternary formations in the study are area represented by Miliolite Fm. and Recent sediments. The overall stratigraphy of the study area is given in Table 3.6.

Madh Formation

Madh Fm. sediments are having a base of Deccan Trap Formation. The Madh Fm. comprises brown, red colored laterite, lateritic- trap pebbles, and variegated clays. The lateritic rocks are the residual weathering product of basalt. The basalt outcrops can be seen in the study area as a base of Laterite. The Madh Fm. occur as E-W trending narrow strip of 2-3 km width around Ramania and Bocha villages (Plate 3.4). Laterite outcrops show strong elevation control and outcrops are available in the elevation range between 60 m and 70 m. Weathering of the lateritic rocks has imparted reddish pigmentation to the surface soil (Plate 3.5).

Plate 3.4 A View of Laterite Landscape at Bocha Village

Plate 3.5 Field Photograph Showing Pigmentation in Sandy Alluvium (Loc.- Bhujpar Village)

Kankavati Formation

The rocks belonging to Kankavati Formation (Pliocene age) overlies Deccan Trap and Madh Formations (Plate 3.6). The Kankavati Fm. has been deposited under littoral to tidal flat environments and its upper part only is exposed in the study area (Biswas, 1993). The formation consists of pink, brown colored sandstone with thin intercalations of shale, clay stone, silt stone and conglomerate. The formation predominantly occupies coastal part of the study area sprawling in about 280 sq.km. area and is potential aquifer. The sandstone is fine grained and friable in nature. Due to its friable nature the sandstone outcrops in the area are scanty viz. sandstone with clay intercalations is exposed on the way from Bhujpar to Gelada. It also found at the base of Gelada dam (Plate 3.7). Contact of sandstone and laterite of Madh Fm. can be seen on the way from Gelada to Ramania village (Plate 3.6). Conglomerate unit of Kankavati Fm. having 1 to 1.5 m thickness can be seen as a part of cliff section of Nagmati River, north of Bhujpar village. Based on borehole lithologs, the observed thickness of Kankavati sandstone is 120 m at Gelada, 80 m at Bhujpar Nani (in western part), and 70 m at Luni and 40 m at Bhadreshwar in eastern part of the study area. The formation is overlained by a narrow belt of fluvial sediments of Recent age all along the coast.

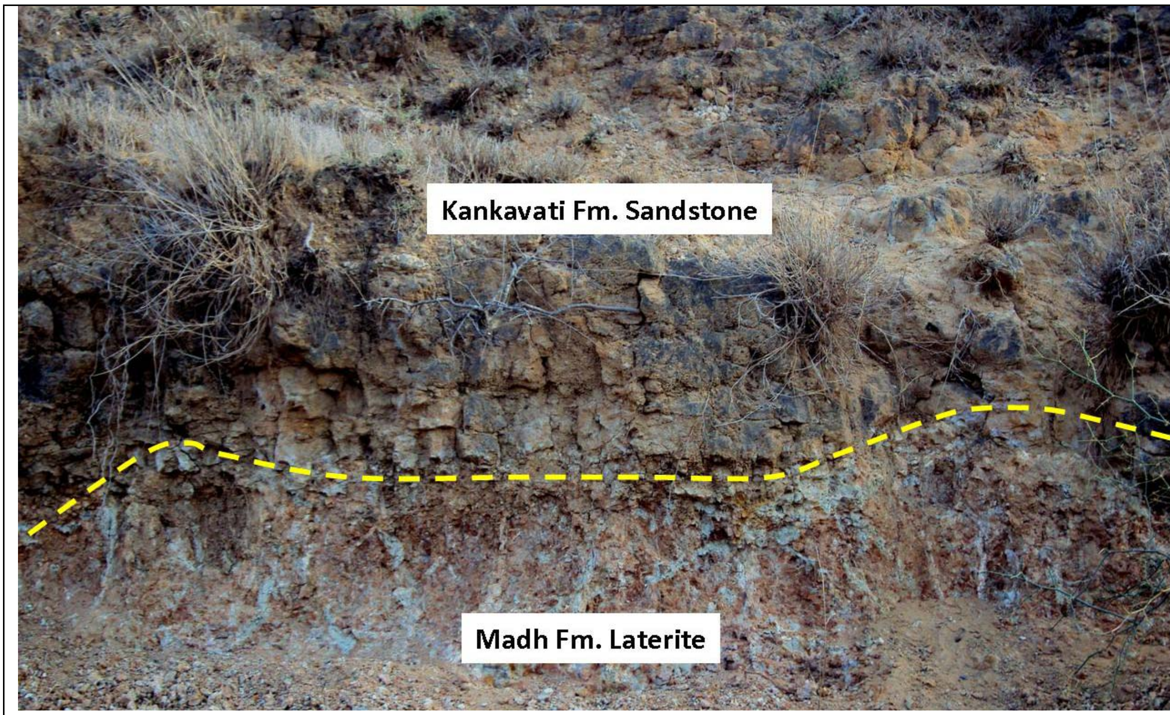


Plate 3.6 Field Photograph Showing Contact Between Madh Fm. (Laterite) and Kankavati Fm. (Sandstone) (Loc.- Gelada Village)

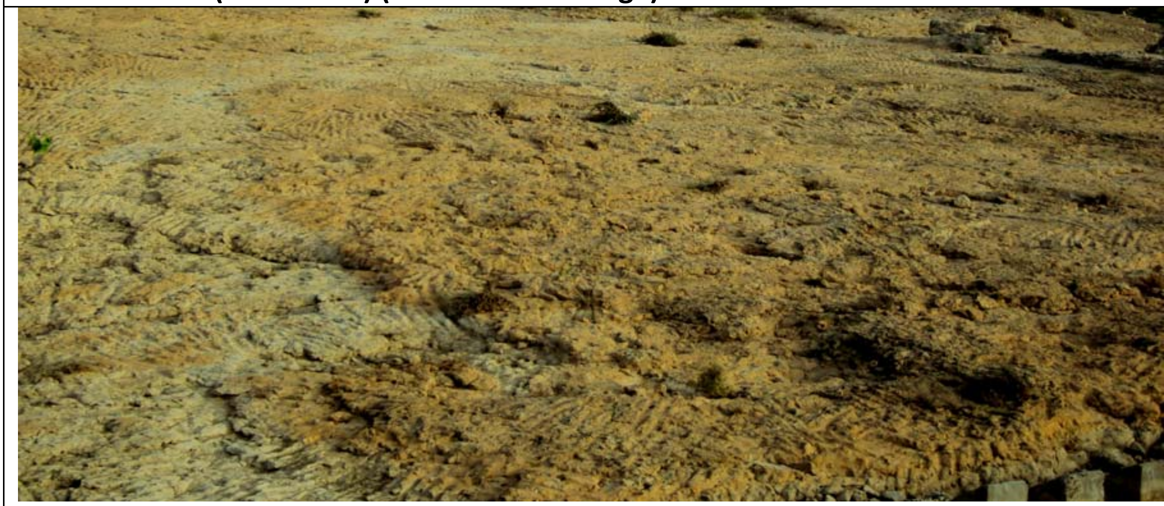


Plate 3.7 A View of Kankavati Sandstone Outcrop in Nagamati River bed (Loc.- Gelada Dam)

Quaternary Sediments

Miliolite limestone and alluvium are considered to be of Quaternary age (Merh, 1995). Miliolite occurs as patchy outcrops in hill sheds, foot hills of Bhuj and Deccan Trap Fms. Important locations of miliolite occurrence are east of Kera, south of Reha, Kanjara and Wadzar villages. Miliolites are white to pale brown in color and deposited by wind comprising sand & calcareous pellets. It shows very well developed cross bedding. The miliolite rocks are extensively queried for building stone around Kanjara and Wadzar villages.

The recent alluvium sediments are dominantly deposited by rivers flowing southerly and ultimately meet to Gulf of Kachchh in south. Coastal region is having aeolian sands deposited under strong wind action from gulf. Alluvium sediments comprise sand, gravel, beach sand, dunal sand and tidal mud. Average thickness of alluvium as deciphered through well inventory and borehole logs is 12 to 15 m around Navinal, Mundra, Luni, and Bhadreshwar villages. The recent flood plain deposits are well exposed in cliff sections of Nagamati, Bhukhi and Phot rivers (Plate 3.8). Mudflats occur south of Mundra, Navinal and Tunda villages. The Quaternary deposits, fluviatile in particular constitutes highly potential aquifer. As the alluvium thickness is very limited (12- 15 m), it constitute a part of phreatic aquifers only. However, alluvium facilitates the groundwater percolation to lower aquifers developed with in the Kankavati sandstone of Pliocene age.

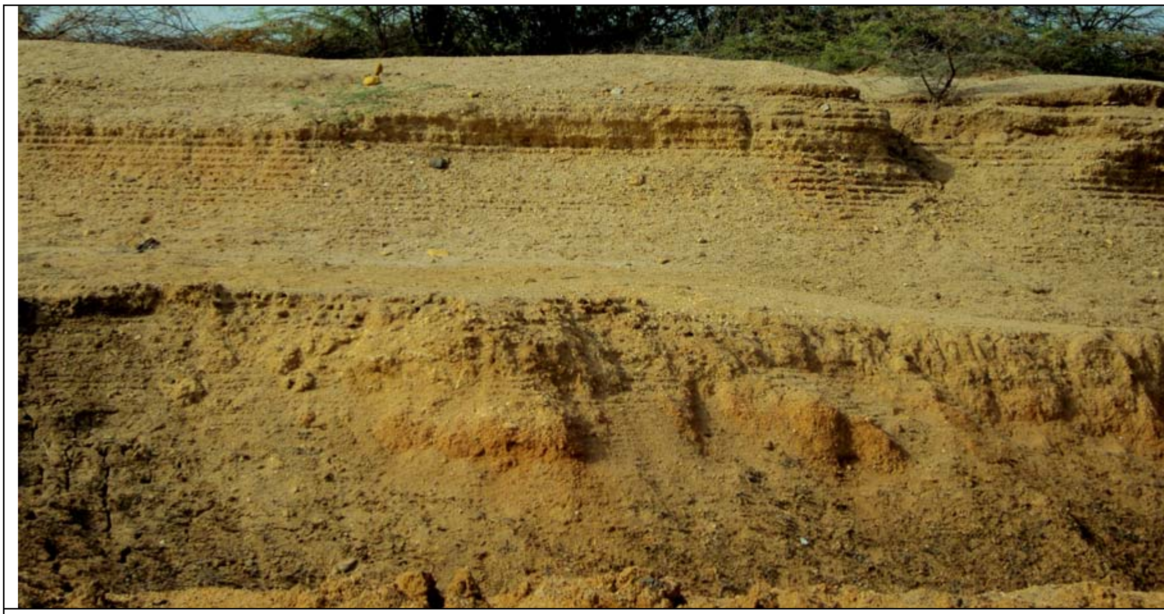


Plate 3.8 A View of Sandy Alluvium Cliff in Phot River Channel (Loc.- Dhrab Village)

Chapter - IV

TERRAIN CHARACTERISTICS

CHAPTER – IV

TERRAIN CHARACTERISTICS

Terrain attributes play pivotal role in overall distribution and development of water resources in the area. As the terrain attributes govern infiltration and overland flow, they also impact socio-economic set up of the local inhabitants. The presented details on study areas' terrain mainly encompasses those geomorphic parameters having strong influence over precipitation and its distribution in terms of surface runoff and infiltration; and with a view to facilitate the candidate in categorizing the study area from the point of view of water resource potential.

PHYSIOGRAPHY

The present landscape of the study area is a result of various endogenic and exogenic geologic processes that continued to operate since Quaternary period. The landscape of study area comprises an array of tectonogenic and geomorphic elements in the form of uplifts and residual depressions. Elevated landforms are occupied by Mesozoic and

Tertiary rocks, whereas the residual depressions or low-lying regions between the uplifts consists of Quaternary sediments marked with alluvial river terraces in the rocky mainland and dunal sands & mud-flats in the coastal areas.

Physiographically, the study area from north to south can be categorized into 04 units (Fig. 4.1) viz;

1. Rocky Uplands (More than 55 m AMSL)
2. Undulating Pediment Plain (30 – 55 m AMSL)
3. Alluvial Plain (30 – 20 m AMSL)
4. Coastal Plain and Marshes (Less than 20 m AMSL)

ROCKY UPLAND

Regionally rocky upland constitutes a part of Kachchh Mainland. In north the study area abuts with Katrol hill range and represents as a large tilted block under the effect of Katrol Hill Fault (KHF) in North and Gulf of Kachchh Fault in south. This physiographic unit is a result of up-liftment of Mesozoic strata along Katrol fault (Biswas, 1980). Further, in south the area represents gently slopping table topped undulated area of Deccan lava flows (Plate 4.1) of Late Cretaceous to Paleocene period. Elevation wise this unit varies between 55 m and + 200 m. Highest peaks are in this unit- Kargariya Dungar (323 m) NE of Bharapar village, north of Jadura Nana (279 m), Dhola Dungar (270 m), Satkhuna (286 m) SE of Bharapar village, and SE of Kotada village (225 m).

UNDULATING PEDIMENT PLAIN

This unit defines southern limits of northern rocky upland region and distinctively but gently sloping southerly. This physiographic unit is characterized by the landscape development of gullies resulting into closely wovened network of small scale drainages (Fig 4.1). Deposition of eroded sediments from rocky upland areas has given rise to these plains.

ALLUVIAL PLAIN

The alluvial plain unit in the study area is signified by relatively flat terrain with thick accumulation of fluvial sediments, having its base over Kankavati Formation of Tertiary age. The unit is characteristics of rich agriculture belt due to fertile lateritic and black cotton soil and better groundwater prospects (Fig. 4.1)

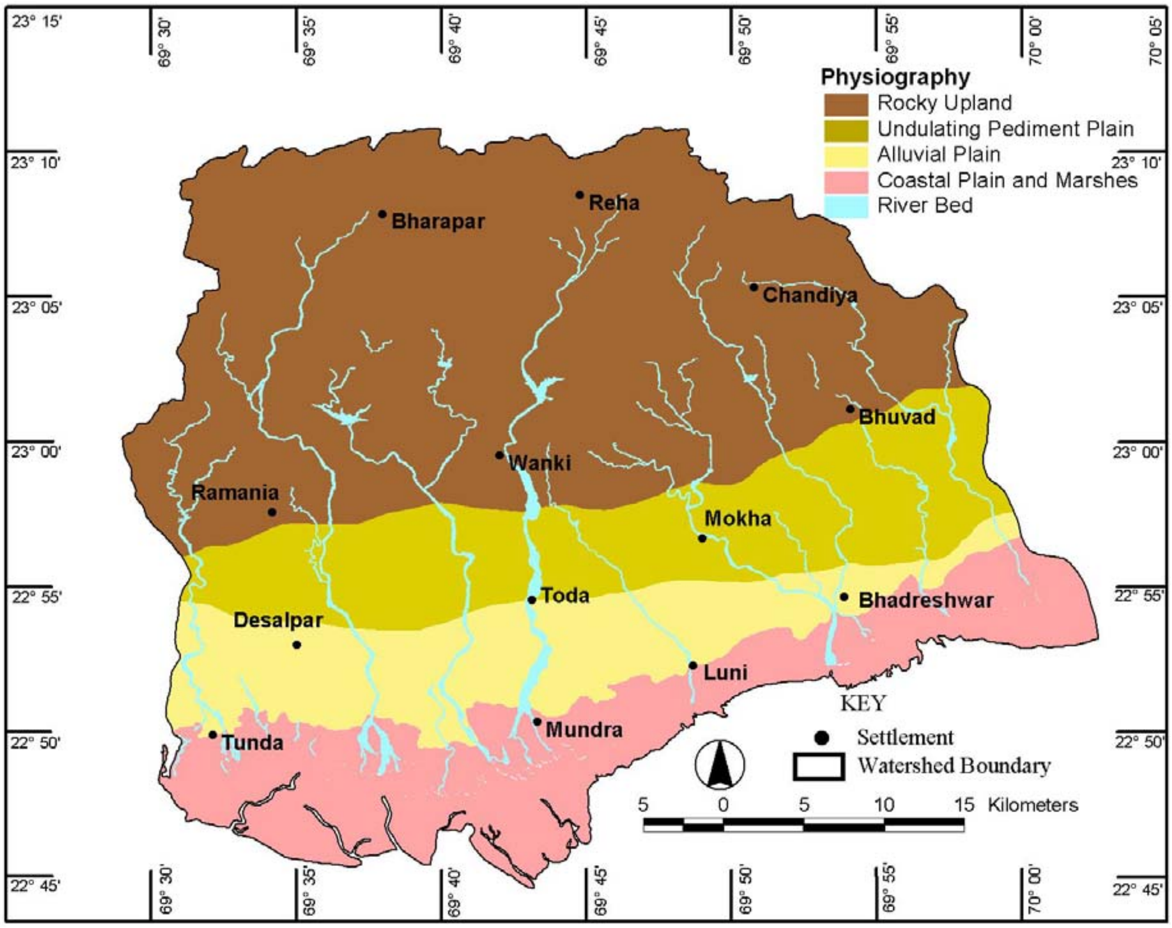


Fig 4.1 Physiography of the Study Area

COASTAL PLAIN AND MARSHES

Coastal plain unit of the study area constitutes a part of Gulf of Kachchh environs. The narrow coastal plains are intermittently infringed by high marshes (palaeo mudflats) and are characterized by an inter-play of fluviatile, marine and aeolian processes. The plains are much porous than other units. Thereby, offer better groundwater recharge conditions to form potential phreatic aquifers. The coastal plain gradually merges to palaeo and present day marshes (Fig. 4.1)

The marshes are characterized by wide tidal flats, back swamps and mangrove swamps. This segment can be considered as a blend of wave as well as tide influenced coast because it has a wide intertidal zone with mangrove forest along with few large sandy ridges, chenniers and actively growing beach-dune complex.

LANDFORMS

Landforms are features on earth surface crafted by various geomorphic processes. In-fact, geological, meteorological, slope and altitude characteristics of any area determine types and diversity in landforms (Thornbury, 1954). Landform characteristics facilitate important hydrologic processes like surface run-off and infiltration. The infiltration helps in soil moisture retention and groundwater recharge. Other significant geomorphic factor, the land use show strong influence of landform characteristics. The landform map of the study area has been prepared with the help of analyzing satellite image and Survey of India's toposheets followed by subsequent ground checks. Candidate has classified the study areas' landforms based on physical process and its spatial distribution. Landform classification based on physical processes is concerned, author has accounted both endogenetic as well as exogenetic processes. The landforms have been classified as depositional, erosional and tectonic types (Table 4.1).

Table 4.1 Landform Classification of the Study Area

Process Mechanism	Landform Characteristics				
	Aerial				Linear
	Local		Regional		Local
	Name	Area Sq.km.	Name	Area Sq.km.	Name
Erosion	----	----	Dissected hills and ridges	216.0	Ridge
					Meandering Scarp
			Inter mountain valley	95.0	Valley
					Rocky Peneplain
Deposition	Sand dunes	6.0	Pediment	865.0	----
			Alluvial Plains	284.0	
	River fans Mouth bars	29.0	Coastal Plain	134.0	
			Mud flats	181.0	
Tectonism	Dyke/Sill & Ravines	46.0	----	----	Fault Scarp

EROSIONAL LANDFORMS

The erosional process by various agents gives rise to different landforms. In the study area, there are mainly two types of erosional landforms present viz; hills and ridges as regional landform and ravines as local landform. The dissected hilly terrain in study area has two parallel ranges from north to south. The northern strip is forming the part of Bhuj ridge whereas middle hilly area is forming southern foot hills of Katrol hill range. The southern most hill range is comparatively narrow and does not extend beyond study area. The northern and middle hill ranges have sedimentary rocks whereas southern range is made up of basalt. Overall all the ranges occupy about 216 sq.km area. In addition to dissected hills and ridges of regional nature; there exists linear landforms viz; ridges, scarps, rocky peneplain and valleys of local scale (Plate 4.1).

Plate 4.1 A View of Landscape Exhibiting Basaltic Hills and Soil Covered Rocky Peneplain in Foreground (Loc.- Kera Village)

DEPOSITIONAL LANDFORMS

The study area is characterized by a variety of depositional landforms. Narrow pediment zone in study area mainly associated with Bhuj ridge in north whereas in upper middle parts it surrounds the dissected hills. Slope of the pediment zone fall in moderate to gentle category. Compositionally, pediment areas are characterized by ill-sorted terrigenous colluvial material deposited under the influence of climate and gravity.

Alluvial plains of the study area have been considered as mega landform deposited by southerly flowing fluvial systems viz; Phot, Nagmati, Bhukhi and Luni. The extent of alluvial area is beyond study area limits in east and west directions. This landform covers about 284 sq km area. Compositionally, alluvial plains are sand dominant in north that gradually decreases with an increase concentration of silt and clay towards south and ultimately merges into coastal plains. This landform sprawls over 134 sq km area. Well inventory data shows an overall thickness of these deposits range between 5 m to 15 m. Considering the slope factor, these plains can further be classified as undulating alluvium plains and gentle even plains. Undulating alluvial plain shows strong control of palaeo land surface configuration.

Patchy occurrences of alluvial material is also associated with inter mountain valley situated between northern Katrol hill range and southern basalt hills. This landform unit sprawls in area about 95 sq. km.

River fans and channel mouth bars in the study area can be seen near the coast where rivers are debouching its load. The localized landforms are sub dude in nature (Plate 4.2).

The study area signifies the development of landforms attributed to marine and fluvio-marine processes. The mudflats (181 sq.km.) between high tide line to low tide line are abutting to Gulf of Kachchh in south. Mostly these are muddy (silt + clay) formations also contains moisture within it (Plate 4.3). There exists large number of minor creeks and depression found within the mudflats. Dunes near coastal areas are other local landforms occur in the study area they occupy about 6 sq km area.

Plate 4.2 Panoramic View of Hook Shaped River Mouth Bar of Mithi River (Loc.-South of Bhadreshwar)

Plate 4.3 A View of Inter-Tidal Mudflats, Mundra Port can be seen in Far Ground (Loc.-South of Mundra)

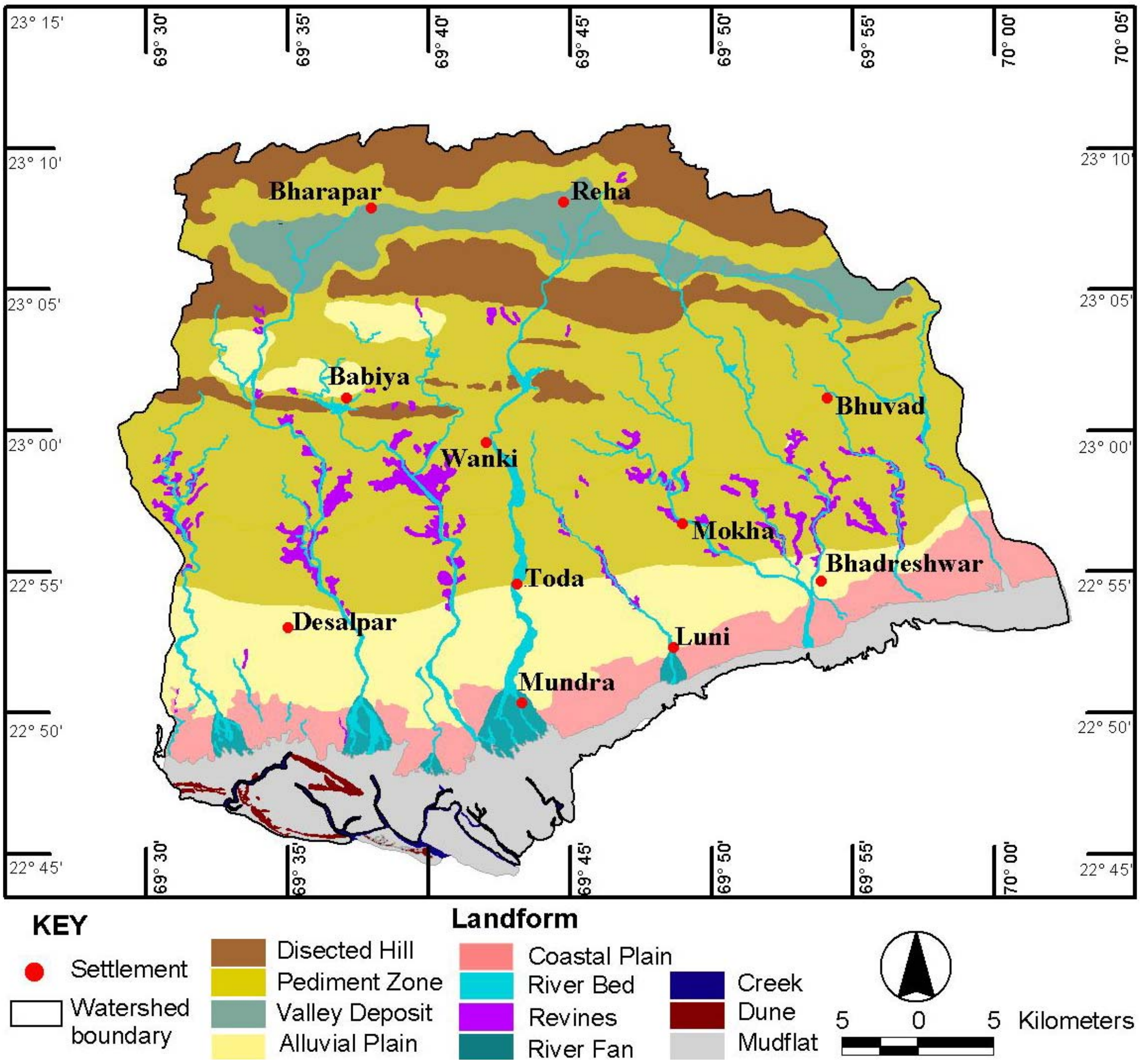


Fig. 4.2 Landform Characteristics of the Study Area

TECTONIC LANDFORM

Dissected hill in northern part of the study area has been considered as tectonic landform resulted due to up-liftment of Mesozoic strata under the influence of Katrol Hill Fault (Biswas, 1993). Ravines are other important landforms resulted on account of upliftment of the land surface (crustal block). The ravines are localized and ubiquitously distributed along the river channels, especially in central part of the study area (Fig. 4.2). The total area occupied by the ravine land s about 46 sq. km.

DRAINAGE

Study of drainage network of study area is very crucial owing to its importance in estimation of recharge – runoff scenario that plays a decision making role in water resource planning. The drainage pattern is the design formed by the aggregate of drainage ways in an area regardless of whether they are occupied by permanent streams (Howard, 1967). Drainage pattern and drainage geometry in study area are highly influenced by tectonic, litho-structural framework and slope of the area. Major fluvial systems of the study area originate from the southern flanks of Katrol hill range and merge into Gulf of Kachchh (Fig.4.3). Drainage systems in the study area are of ephemeral nature and can be rarely seen in flowing mode only during torrential rainfall event.

The study area represents nicely carved drainage network of southerly flowing drainages all finally end into Gulf of Kachchh. General drainage pattern of the region is parallel to sub parallel type. Considering local level litho-structural controls, the study area represents in all seven types of drainage patterns (Fig 4.5).

Dendritic to sub dendritic is dominant pattern of drainage found in study area. Dendritic pattern reflects strong control of joints and topographic slope. This pattern mainly observed in area having pre-dominance of Juran and Bhuj Formations of Mesozoic and Kankavti Formation of Tertiary age.

The parallel to sub- parallel drainage pattern generally indicates moderate to steep slopes or area characterized by parallel, elongated landforms (Howard, 1967). In the upper reaches of the study area, this drainage pattern is reflected by Juran Fm. whereas, in lower reach it is regulated by flat alluvial plain.

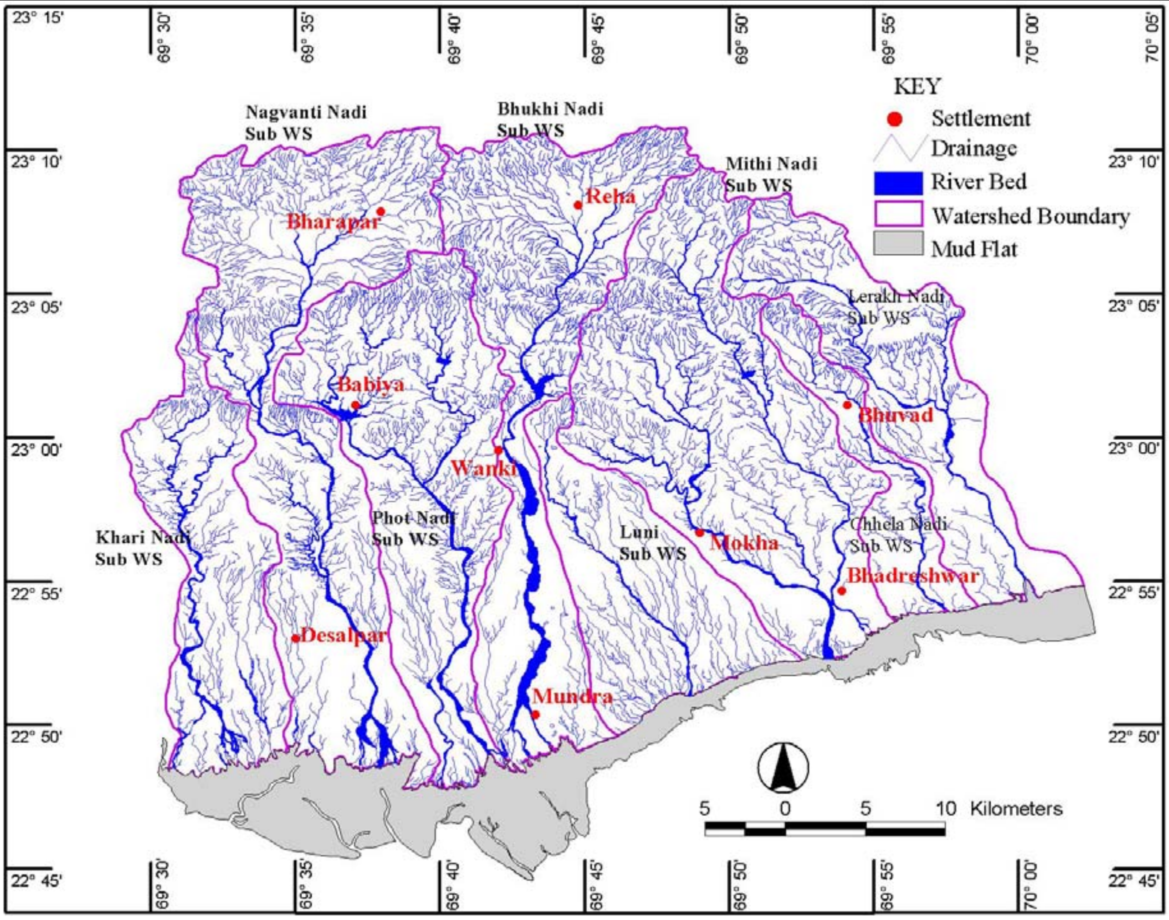


Fig 4.3 Drainage Network in Watershed Region

Pinnate and Trellis drainage patterns are also observed in study area very locally developed. Pinnate pattern characteristically observed in contact zones between rocks of Bhuj Formation and Deccan Trap basalt. The pinnate pattern represents closely spaced and more or less parallel tributaries entering the larger streams at an acute angle (Howard, 1967). The trappean terrain represents a variety of drainage patterns due to high order of fracturing, joints and dome like structures. A domal basaltic hill represents sub radial drainage pattern. Basalt being fractured rock, contorted, directional and fracture trellis drainage patterns have also been observed locally. Directional trellis is conspicuous due to difference in tributary stream lengths in which, tributaries are longer on one side than its counterpart. Table 4.2 summarizes formation wise drainage pattern identified in the study area.

Table 4.2 Rock Specific Drainage Patterns Observed in the Study Area

Formation	Lithology	Identified Drainage Pattern
Juran	Pink, yellow sandstone with shale, calcareous sandstone, grey shale	Dendritic
Bhuj	Coarse grain sandstone, kaolinitic shale, sandy shale, carbonaceous shale	Sub Dendritic
Basalt	Greenish black Basalt, amygdaloidal and fractured basalt	Sub parallel, trellis, directional trellis
Kankavati	Sandstone with shale lenses, conglomerate	Sub Dendritic
Alluvium	Sandy and clayey alluvium	Sub parallel, braided

Drainage texture depends on rock erosion cycle, precipitation characteristics, rock texture, and topography. It indicates difference in rock characteristics and its infiltration capacity. Fine drainage texture indicates higher degree of drainage line mostly found in impervious rocks like shale, clay, compact basalt. Coarse texture drainage are longer, more widely separated and mostly found in permeable strata like sandstone and alluvium (Howard, 1967).

HYPSOMETRIC ANALYSIS

Hypsometric analysis is the relation between horizontal cross section areas of basin to relative elevation. (Strahler, 1957) The analysis has been done for entire basin from summit point to outlet in sea. For considered elevation, relative height is a ration to total basin height, where relative area is calculated above the elevation. The analysis has been done for Phot and Bhukhi River basins (Fig. 4.4).

The plotted curves are suggestive of attaining mature stage of the watershed basins, thereby representing a normal behavior of geomorphic evaluation.

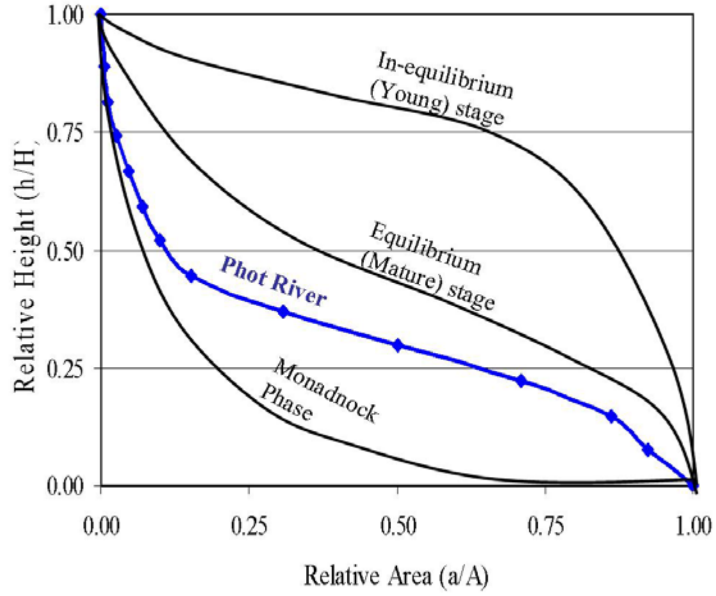
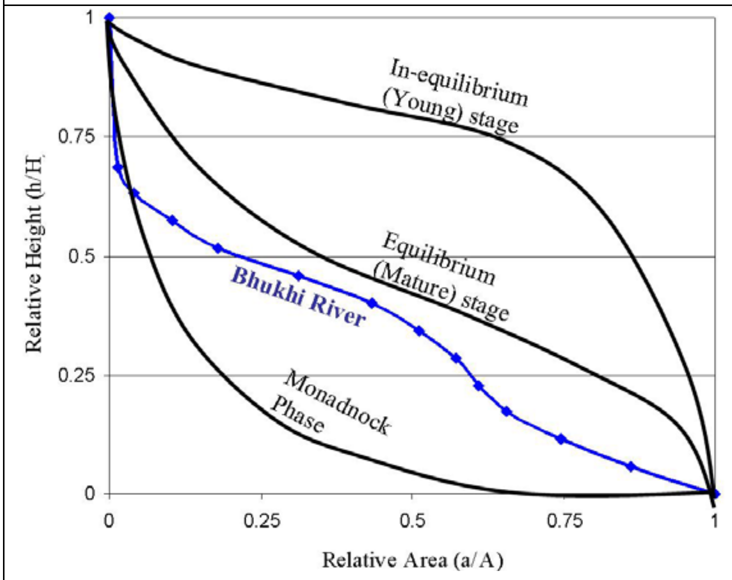
	Hypsometric Curve of Phot River Basin o The curve is positioned between Mature stage and Monadnock phase of erosion cycle of river basin, thereby, indicating that river basin is at present moving towards monadnock phase.
	Hypsometric Curve of Bhukhi River Basin o The curve shows stage between Mature stage and Monadnock phase of erosion cycle of river basin. o The curve shows upward curvature in its middle part attributed to presence of resistant component i.e. basalt.

Fig 4.4 Hypsometric Analysis of Phot and Bhukhi River Basin

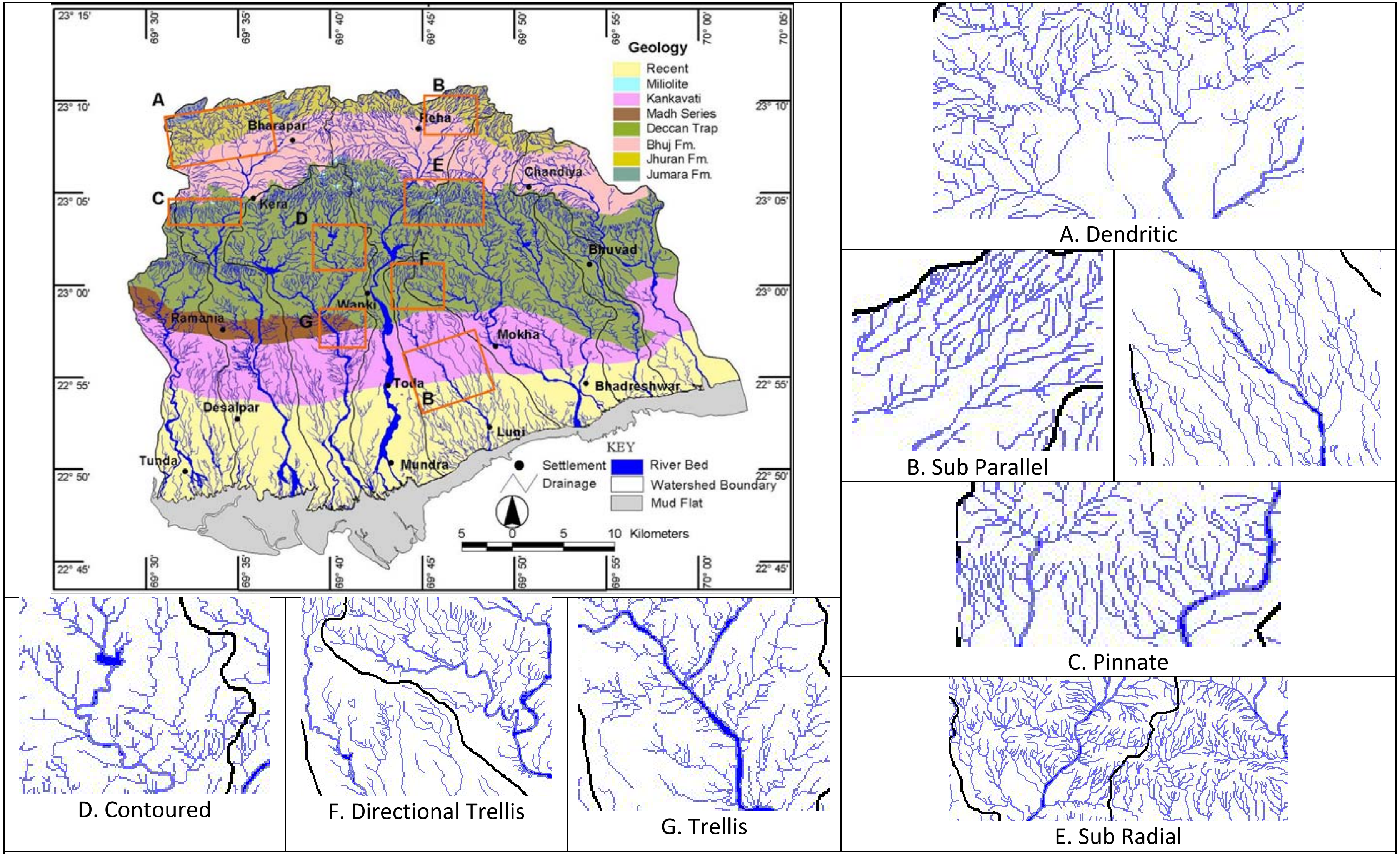


Fig 4.5 Drainage Pattern in Watershed Region

SLOPE

Land slope is an important governing factor that governs the processes of surface run-off and infiltration. Slope and its spatial distribution pattern greatly facilitate in characterization of watershed basins and helps in categorization of an area from recharge and / or discharge point of view. In addition, slope in any area also decides landuse pattern.

The slope and slope aspects were studied through DEM image interpretation using GIS software. Overall slope categorization of the study area representing in all 04 slope classes is given in Fig. 4.6. The quantitative and qualitative interpretations of the various slope categories based on Young (1972) and NATMO (1996) are given in Table 4.3.

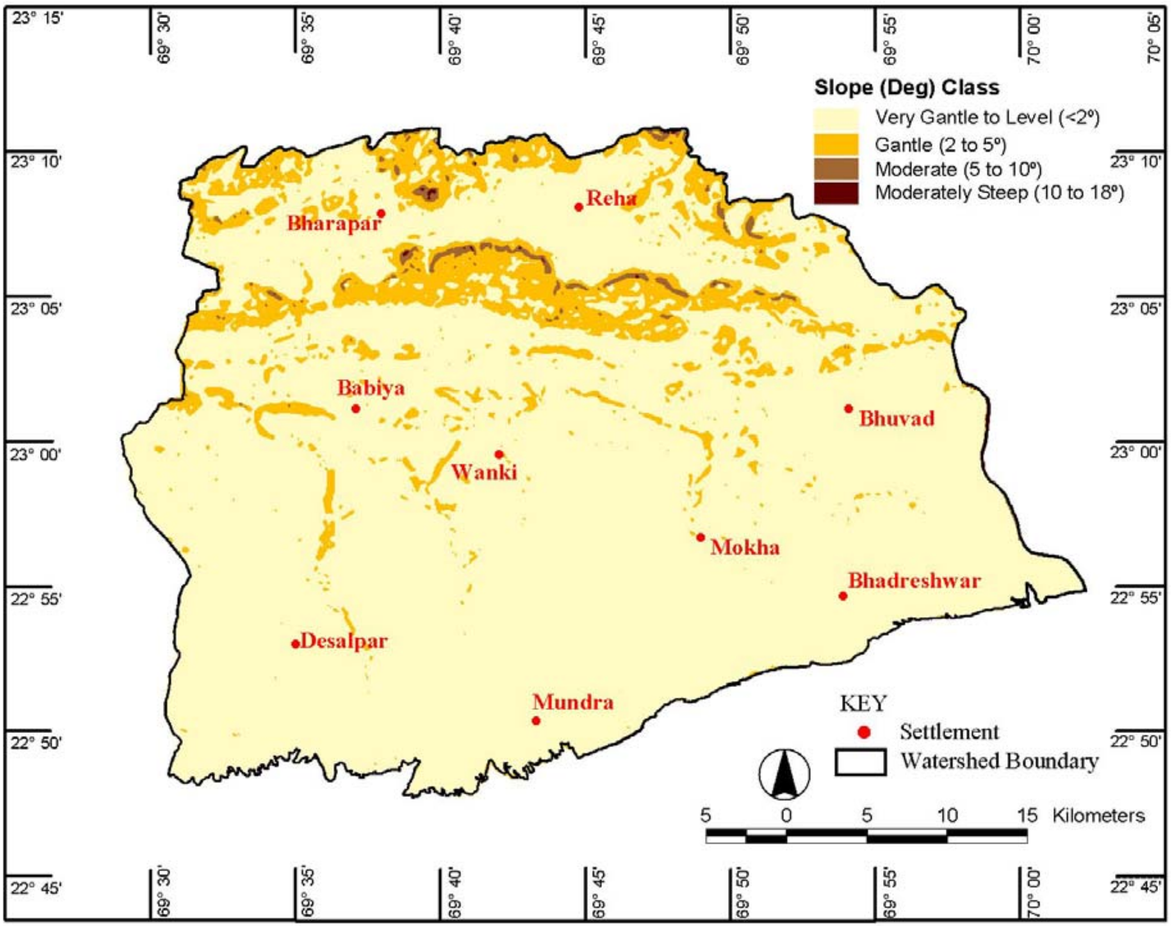


Fig 4.6 Slope Map of the Study Area

Table 4.3 Slope Characteristics of Study Area

Slope	Map Class	Degree	Area Km^2	Geomorphic Characters
Very Gentle to Level	I	< 2º	1468.00	Mudflats and Even alluvium plains
Gentle	II	2°-5°	184.00	Pediments and Rocky uplands
Moderate	III	5°-10°	13.00	Ridges
Moderately Steep	IV	10°-18°	4.00	Hills

The distribution and aerial coverage of various slope categories, more than 80 % part of watershed area is having very gentle to gentle slopes (Class I & II). These slope classes encompasses land attributes like mudflat, undulated and flat alluvial plain and coastal plains. The slope gradually increases up to 5 degree in pediment and rocky upland zone. The study area has very limited area that reflects moderate to moderately steep slopes (class III & IV) encompassing the northern upland region along Katrol hill range.

SOIL

Soil analysis of the study area has been derived based on Soil Bulletin of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP, 1994). Soils of the study area have been categorized into 07 different soil associations (Fig. 4.7). Characteristics of each association are given in Table 4.4. The soils are mostly sandy in nature and are poorly supplied with the nutrient elements mainly in upper and lower reaches of the study area. High grade porosity of sandy soil decreases its moisture holding capacity. Character of the parent rock reflects in soil types. Depth of the soil varies from moderately shallow (10 to 25 cm) to deep (>75 cm). Deep soil normally occurs in valley deposits and coastal area. According to pH rank, mostly soils are slightly alkaline (7.5 - 8.5), while the coastal soils are moderately alkaline (8.5 – 9.5). Soils of rocky area in hilly upland region show moderate erosion while in alluvial plain it shows very low erosion. Soils of coastal area show sodicity and salinity. Salinity hazard in coastal part has made adverse effect on soil nutrients and physico-chemical composition. As per Raju (2003) most of the soils (92.5 %) is problematic from salinity point of view due to alkalinity and sodicity. Use of poor quality of water for irrigation has lead the problems of salinity and sodicity in soils.

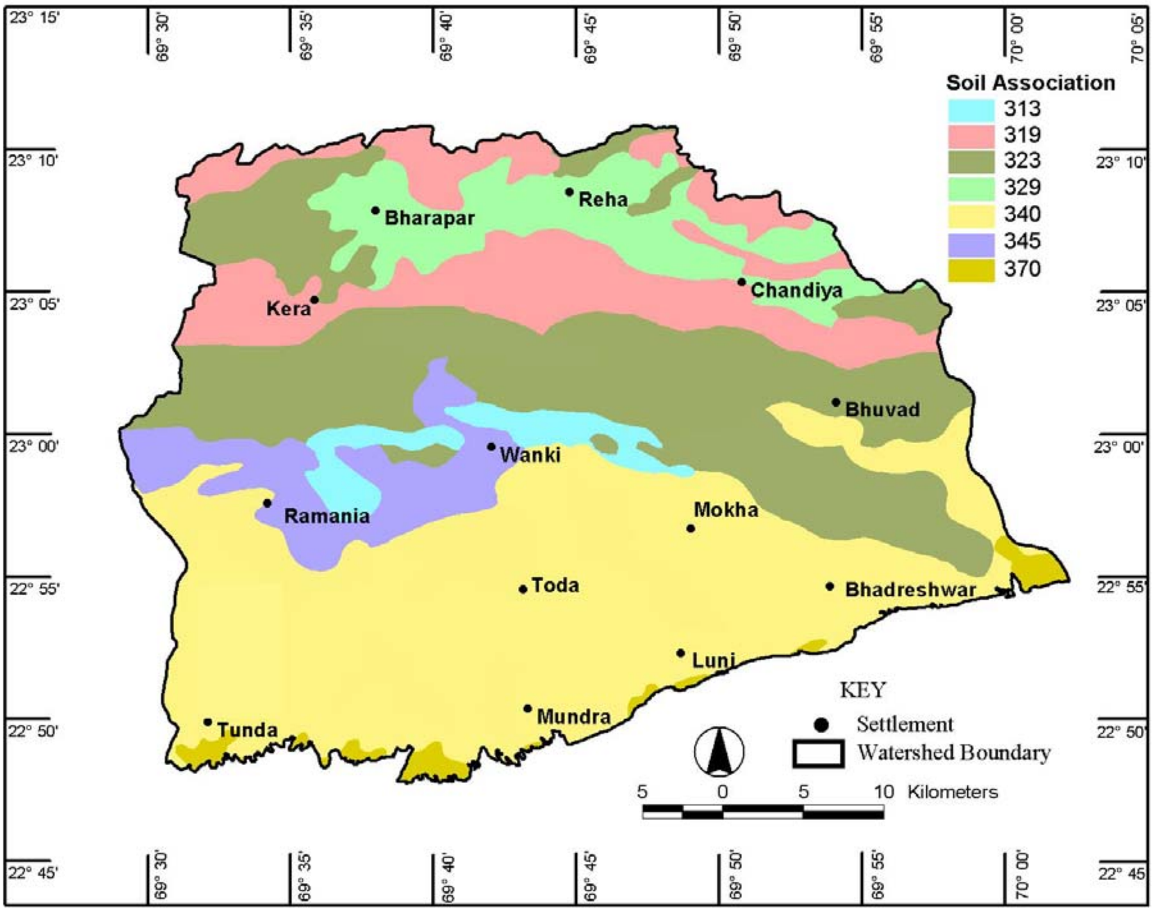


Fig 4.7 Soil Characteristics of the Study Area (After NBBS Publication, 1994)

Table 4.4 Soil Characteristics of the Study Area

Sr. No.	Asso-ciation Code	Parent Rock	Depth of Soil (cm)	Particle	Nature of Soil (Based on pH)	Susceptible to Erosion	Salinity (dsm^{-1})*	Sodicity (esp)*
1	313	Basalt	Moderately Deep 25 – 75	Silty Clay	Slightly Alkaline (7.5 - 8.5)	Moderate	No	No
2	319	Sandstone	Moderately Deep 25 – 75	Loamy	Slightly Alkaline (7.5 - 8.5)	Moderate	No	No
3	323	Basalt, Sandstone	Moderately Shallow 10 – 25	Sandy Loam	Neutral to Slightly Alkaline (7.5 - 8.5)	Moderate	No	No
4	329	Alluvium	Deep >75	Sandy	Slightly Alkaline (7.5 - 8.5)	Moderate	No	No
5	340	Alluvium	Deep >75	Sandy Loam	Slightly Alkaline (7.5 - 8.5)	Low	Low (2 – 8)	No
6	345	Alluvium, Clay	Moderately Deep 25 – 75	Loamy	Slightly Alkaline (7.5 - 8.5)	Moderate	Low (2 – 8)	No
7	370	Marine Sediments	Deep >75	Sandy Loam	Moderately Alkaline (8.5 - 9.5)	Low	Moderate (8 – 15)	Moderate (5 – 15)

(After NBBS Publication, 1994)

***dsm^{-1}: Deci Siemens per meter; *esp: Exchangeable Sodium Percentage**

Chapter - V

HYDROGEOLOGY

<u>**CHAPTER – V**</u>

HYDROGEOLOGY

GENERAL BACKGROUND

Study on hydro-geological aspects of any area play a pivotal role in understanding the various geological controls on groundwater regime. The hydro-geological attributes viz; distribution, chemical content of groundwater and relative potential in time and space serve a basis to formulate appropriate strategies for development and management of resource.

Hydro-geological survey of Mundra Taluka carried out by Arid Communities and Technologies (A.C.T., 2005) has divulged that there are total 7092 sources including open wells, dug cum borewells and borewells. Out of 1773 open wells and 5319 borewells, about 797 open wells and 1576 borewells are now abandoned. Such a huge number of abandoned sources clearly points about depletion in water levels and deterioration in groundwater quality. As per GWRDC the Mundra Taluka has remained as DARK ZONE until 2002 and latter re-graded as SEMI-CRITICAL as a part of groundwater potential assessment during year 2007.

Realizing this very fact, the candidate has carried out a comprehensive hydro-geological study of her study area encompassing following aspects.

- Groundwater occurrence and distribution
- Seasonal and Secular behavior of water levels
- Aquifer characteristics
- Hydro-geological characterization.

OBJECTIVES

Understanding the hydro-geology of the study area in totality necessitates systematic inventory of its various attributes and dependency on secondary data for its long term assessment. Therefore, the candidate has adopted the following procedural mechanism to fulfill the defined objectives.

1. Demarcation of study area based on watershed boundary.
2. Demarcation of ‘Core Area’ based on on-going industrialization vis-à-vis sharp rise in groundwater daft leading to problem of over-exploitation and quality deterioration.
3. Collection of secondary data from various state level groundwater agencies and local NGO’s involved in similar activities.
4. Detailed well inventory of the existing wells to gather first hand information and primary data collection on hydro-geology.
5. Detailed evaluation of primary (well inventory) and secondary data to identify suitable wells (observation wells) for sub-sequent seasonal studies.
6. Establishing a network of observation wells on grid basis having unit area coverage viz; core area (2x2 km) and other than core area (8x8 km).
7. Seasonal monitoring of water levels and groundwater sampling for determining its chemical content.

8. Study on groundwater behavior through construction of selective well hydrographs and static and reduced water level (SWL & RWL) contours to determine spatial and temporal changes in groundwater regime.
9. Study on various geological inputs viz; lithology, structural, and geo-morphologic parameters to derive groundwater potential categories including hydro-geologic sub-surface profiles based on borehole litho-logs.
10. To develop a hydro-geological map of the study area.

GROUNDWATER MONITORING

WELL INVENTORY

Well inventory is a basic and important tool to study prevailing diversity in hydro-geology offered by the study area. Detailed well inventory has been carried out in watershed area and core study area in a prescribed format. Well inventory parameters include information pertaining to ownership and geo-graphical position of well, its dimensional parameters, broad geological subsurface profiles, composition of aquifer and its nature, depth to water table and seasonal fluctuation, quality of groundwater, mode of groundwater withdrawal, discharge rate, hours of pumpage, recuperation time, area under irrigation and crops benefited (Annexure 5.1).

GROUNDWATER MONITORING NETWORK

Groundwater is a dynamic and invisible resource that can be understood through groundwater monitoring only. Through water well monitoring, groundwater situations can be analyzed by generating numerous thematic maps and hydrographs. Groundwater monitoring network has been established for watershed region and core area. Proper methodology has been adopted to set up a network of observation wells. First, the study area has been divided into equal weighted area grids i.e. 8x8 km grid for watershed area and 2x2 km grid for core area. An observation monitoring well has been selected in each grid based on showing least seasonal fluctuation in water levels based on available secondary data (Fig. 5.1 and 5.2). Detailed well inventory information has been recorded for each well through physical verification. The information on observation wells monitoring network of watershed area and core area is provided as Annexures- 5.2 and 5.3 respectively. In watershed area, in all there are 44 observation wells whereas 47 observation wells have been selected for core study area (Table 5.1). Borewells represent deep aquifer conditions having maximum recorded depth of 360 m in sandstone aquifer (Bhuj Fm.) and 150m in sandstone aquifer (Kankavati Fm.). Open wells represent shallow phreatic aquifers of alluvium and weathered basalt. Average observed depth of wells in alluvium is about 10m whereas it’s about 25m in weathered basalt.

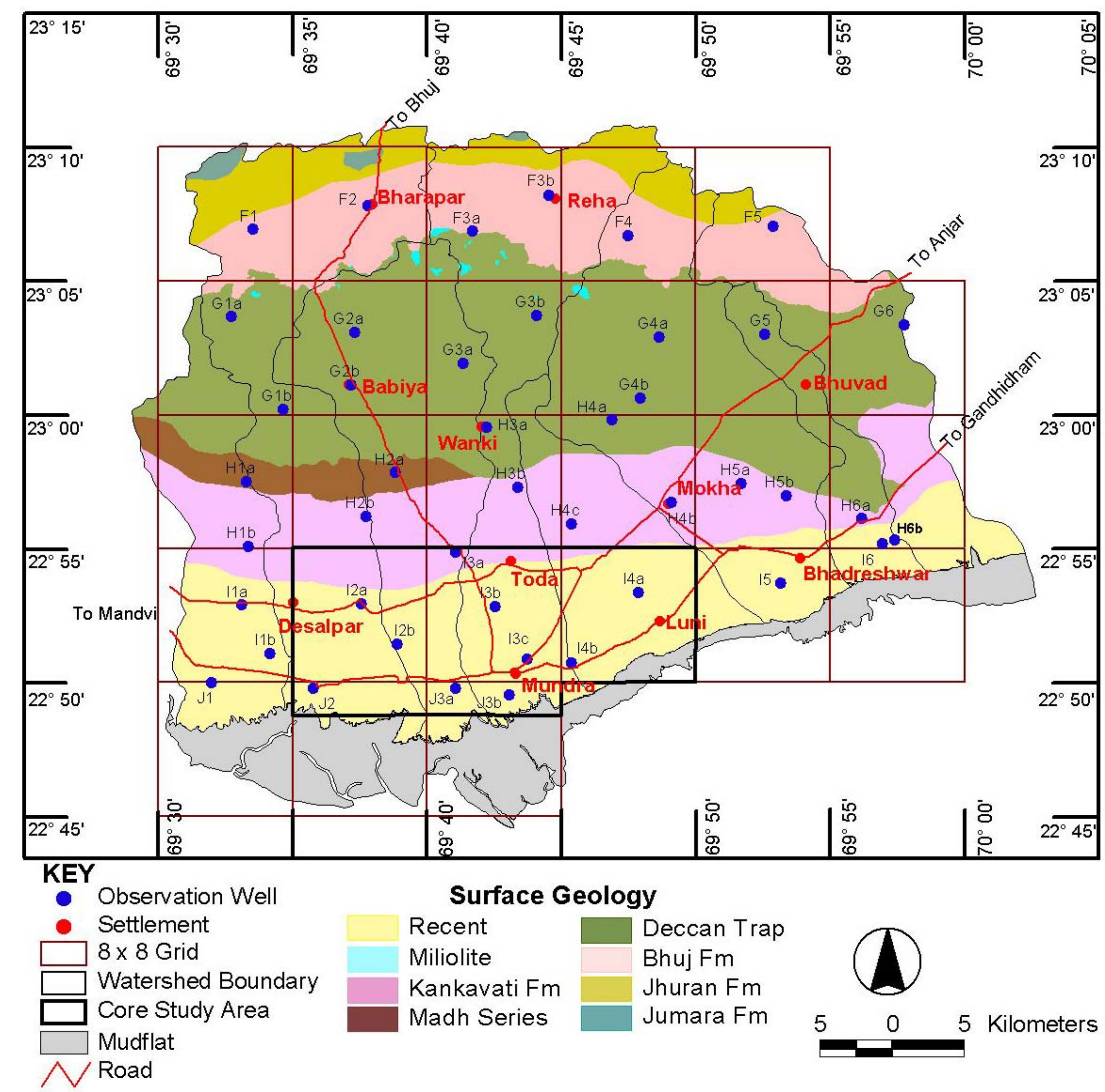


Fig 5.1 Network of Observation Wells for Watershed Region

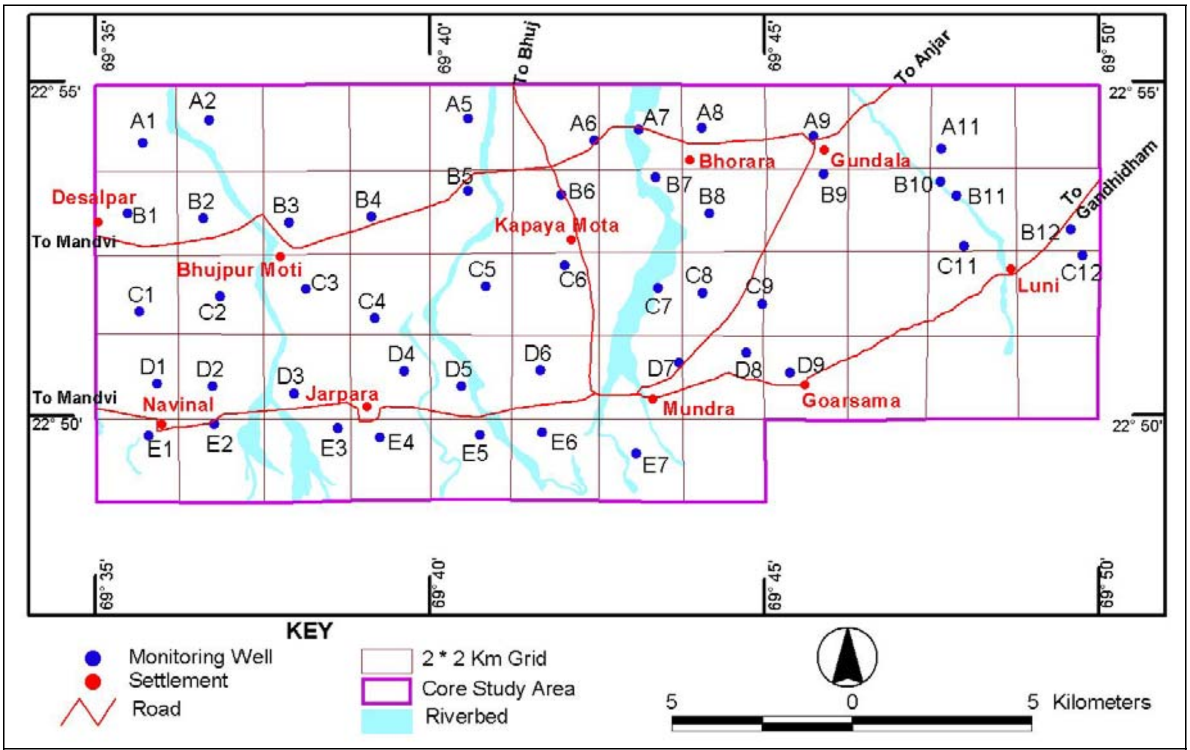


Fig 5.2 Network of Observation Wells for Core Study Area

Table 5.1 Classification of Observation Wells

Parameter	Watershed Region (44 wells)		Core Study Area (47 wells)	
	Open Well	Bore Well	Open Well	Bore Well
Total Nos	08	36	02	45
Aquifer	Alluvium & Basalt	Bhuj Sandstone, Basalt, Kankavati Sandstone	Alluvium	Kankavati Sandstone
Average Depth (m)	8 – 22	40 – 360	6 – 10	50 – 150
Uses of Source				
Drinking	1	4	0	3
Domestic	0	3	0	2
Irrigation	6	27	0	39
Other	0	1	0	1
No Use	1	1	2	0

Note:

1. Mundra Special Economic Zone (SEZ) said to meet its industrial water requirement (>4 Mm^3) through Gujarat Water Infrastructure Ltd. (GWIL).
2. SEZ is having no accessibility for monitoring.

GROUNDWATER OCCURRENCE

Occurrence of groundwater is strictly governed by the position of aquifer defining its depth, thickness and lateral continuity. However, taking into account depth of aquifer as a criterion, the groundwater occurrence can be broadly divided into 02 categories viz; (I) Shallow Aquifers

(II) Deep Aquifers

SHALLOW AQUIFERS

Shallow aquifers are predominantly of phreatic in nature and restricted with in the weathered and/or fractured portions of the rocks. Aquifers being part of open system greatly influenced by marked seasonal changes. Therefore, the water table shows significant change in its level between post monsoon and pre monsoon seasons. At times during the phases of lean monsoon, these phreatic aquifers get dried up. As the phreatic aquifers are governed by the extent of weathering of exposed rocks, their distribution is mainly controlled by its geomorphic environment as well as the material composition. In the study area, the observed depth of shallow aquifers range between 50m and 60m. The spatial distribution pattern of phreatic aquifers has been dealt separately as a part of litho-stratigraphic unit.

DEEP AQUIFERS

Deep aquifers (>60m deep) by its virtue have been considered as potential source of groundwater. These aquifers are litho-specific, by and large characterized by high piezometric/hydro-static pressure. Sediment deposition pattern in the study area invariably has developed semi-confined to confined type of the aquifers. Typical litho-specific environment identified in the study area for such typified aquifer systems are Sandstone-Shale sequence (Bhuj Fm.), Basaltic interflow surfaces (Deccan Trap), and Sandstone-Clay sequence (Kankavati Fm.). The spatial distribution pattern of deep aquifers in the study area along with controlling factors have been dealt separately.

Groundwater occurrence has been discussed in accordance with the geological environment. The study area shows marked presence of well exposed semi consolidated to consolidated sediments viz; Mesozoics Sandstone- Shales (Bhuj Fm.), Cretaceo-Eocene Basalts (Deccan Traps), Tertiary Laterites (Madh Fm.) and Sandstones

(Kankavati Fm.). The Quaternary deposits comprising non-indurated sediments, an admixture of gravel, sand, silt, clay of fluvial, aeolian and eluvial origin.

MESOZOIC SEDIMENTS

Mesozoic sediments particularly sandstone-shale sequence belonging to Bhuj Fm. are the characteristics deep water aquifers with moderate to high potential. The Bhuj sandstone is varying in grain size from medium to coarse. Groundwater occurrence in this rock is under phreatic and confined conditions. The depth to water table varies from 60m to 120m.; localities like Meghpar, Bharapar, Reha, Kotada, Vada are characteristics of phreatic-unconfined aquifers. Whereas further south the aquifers are of confined nature. Important localities having confined aquifers are Chunadi, Kera, Wanki, Varali and Mathada. The well inventory study shows that aquifer thickness is varying from 23 m in Reha Nana (OW. F3b) to 60 m in village Sanosara (OW F3a).

DECCAN TRAP

The Deccan Trap Basalt is characterized as compact, amygdaloidal and fractured types (Biswas, 1990). Weathered and fractured basalt constitutes an important shallow phreatic aquifer ubiquitously seen in the study area. Groundwater occurrence in basaltic aquifers is governed by the depth and degree of weathering, in which the top most layer remains highly weathered. Vesicles and fractures adding more porosity to the aquifer has been observed in the area around Chakar-Kotada and Vaghura villages. Well inventory observations suggest that an average thickness of the basaltic phreatic aquifer range between 5 and 15 m., whereas depth of wells is ranging from 14 m in Vaghura village (OW G4b) to 30 m in Babia (OW G2b). However, maximum depth of well i.e. 275 m has been observed at Moti Tumbadi village where in 70 m thick basalt overlies the Bhuj Sandstone. As per study carried out by Raju (2003), basalt flow thickness is about 70 m in east and 200 m in west side. Average static water table depth ranges from 2 to 15 m that varies according to local prevailing geologic environment. During post monsoon period, groundwater level rises up to ground level.

TERTIARY SEDIMENTS

Groundwater occurrence in Tertiary sediments within Madh Fm. (Laterite) and Kankavati Fm. (Sandstone) is described as under-

Madh Fm. (Laterite)

In the study area laterite is a product of residual weathering of basalt. Laterite in the study area occurs as a narrow strip in central, south-western parts. Typical lateritic outcrops in the study area can be seen around the village Bocha. The lateritic profile is characterized by inter-bedded silica sand layers with variegated clay and lithomarge as base. Groundwater occurrence in laterite is at shallow depth. Overall water quality is poor. The observed average thickness of the lateritic aquifer is about 15 m whereas static water table ranges from 12 m to 20 m. depth.

Kankavati Fm. (Sandstone)

It is typical poorly cemented, friable grey, mottled sandstone with intercalated layers of calcareous grits. The Kankavati formation is the potential aquifer in the coastal tract along the Mundra, Mandvi and Abadasa regions. The Sandstone is deposited in fluvio-marine conditions and having intercalations of clay lenses. The Kankavati Fm. in the study area is exposed between Gelada and Moti Bhujpur village. The study carried out by Raju (2003) based on bore hole records has divulged that the clays are embedded with in the Kankavati Fm have tapering thickness varying from 10 to 25 m at thinner end and maximum (50 m) at center. Such clay layers are observed at various depths i.e. between 60 to 150 m. The clay layer below 50 meter is continuous whereas it occurs as lensoidal body below 60 to 150 m. Raju (2003) has also reported that groundwater extraction from this potential aquifer has gone down from 30 m to 150 m below ground level in last three decades and this over exploitation has lead to its quality deterioration too.

Candidate's analysis of borehole log and well inventory data has established that in the study area the Kankavati Fm. attains a maximum thickness of about 294 m. However the thickness of aquifer ranges from 20 m to 100 m. whereas maximum observed depth of borewell in the study area is 152 m. The exemplary occurrence of potential Kankavati Fm. sandstone aquifer is in core part of the study area. Villages such as Zarpara, Dhrab, Kapaya Nana located in the core area, which were once famous for rich horticulture crops are now no more contribute their agriculture produce due to excessive lowering of groundwater levels and quality deterioration, attributed to over exploitation by the fast developing industrial sector. Fig. 5.3 depicts decadal change in well depths of dug wells and borewells. During the period of 1961-70, average depth of wells, was at 12.6m and there after it shows manifold increase and now it has reached to 152 m. This exceptional lowering of water levels after 1990 has probably initiated the problem of sea water intrusion leading to groundwater quality deterioration.

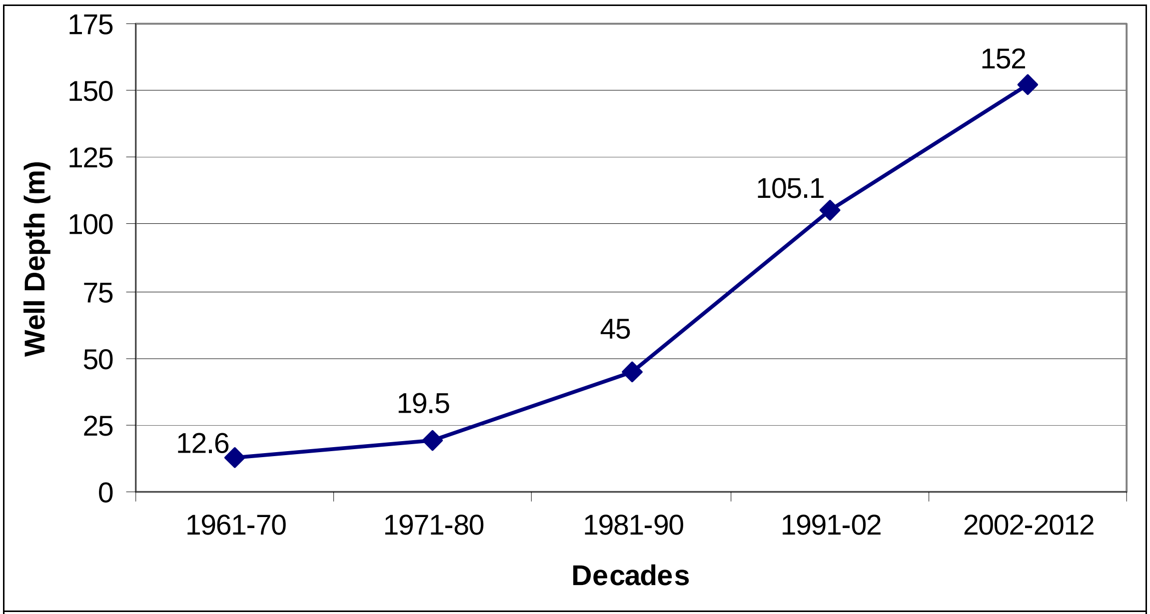


Fig. 5.3 Decadal Change in Depth of Well/Bore wells in the Study Area

(Modified After Raju, 2003)

QUATERNARY SEDIMENTS

In the study area, Quaternary deposits are dominated by sands and clay and Sub-recent weakly cemented coarse grained sandstone. These sediments possess high porosity and have developed shallow aquifers in coastal track. The Quaternary sediments are overlying Kankavati Sandstone particularly in middle and lower reaches of the study area. The thickness of alluvium is varying from place to place. Recorded thickness of the alluvial deposits is about 15 to 25 m which is based on well inventory observations. Average depth to water table ranges between 3 and 12 m. There exists patchy occurrence of Milliolite limestone developed due to cementing of dunal material, normally accumulated in the shadow regions of hills. Being highly porous and permeable, locally these Milliolite serves as potential aquifer.

GROUNDWATER DISTRIBUTION PATTERN

Groundwater resource distribution in the study area show strong influence of physiographic and litho-stratigraphic environments. A detailed account on groundwater resource distribution is given in ensuing paragraphs.

HILLY UPLAND TERRAIN

The hilly area generates high rate of runoff that ultimately brought to low lying valley areas commonly referred as recharge zone. Groundwater distribution pattern in hilly area is patchy and depending on local geological conditions. Hilly upland region mainly dominated by Katrol hill range comprising sedimentary sequence of Bhuj Fm. and extrusive basalts. Inter- mountain valley separating Katrol hill range and Deccan basalts has better groundwater potential. However, intercalations of shale layers within the Bhuj sandstone deteriorate groundwater quality due to its inherent salinity. In adjacent basaltic trappean terrain, the aquifers are patchy and restricted with in weathered and fractured basalts and having good quality groundwater. The thickness of such aquifers is of about 15m. Important localities for such aquifers are around Tumbadi, Babia, Kanjara, Wanki and Bhalot villages.

UNDULATING PEDIMENT PLAIN

This physiographic unit receives run off from hilly upland region and constitutes favorable region for groundwater recharge. Although this unit is predominantly rocky having moderate overburden. Compositionally it is comprised of varied lithology viz; highly weathered basalt, laterite and Kankavati sandstone. In laterite aquifers, groundwater occurs in pockets. However, lithomarge clay associated with laterite invariably degrades groundwater quality owing to high salt concentration. The depth of lateritic aquifers is about 15-20 m. Kankavati Sandstone has a good lateral expanse deep groundwater occurrence. Important localities having such potential aquifers are Deshalpar, Bhujpar, Bhorara and Bhadreshwar villages.

ALLUVIAL PLAIN

Large low altitude sector of the study area inhibits thick accumulation of alluvium. Almost all major and minor fluvial systems having their source in northern hinterland debouch its load to this relatively flat terrain that constitute a major discharge area of groundwater abstraction. These non-indurated Sub-recent to Recent sediments attain an overall thickness of about 25 m with Kankavati Sandstone as a base. Important localities like Mundra city, Sadau, Luni, Navinal, Jharpara and surrounding villages fall within alluvium aquifer zone.

HYDROGEOLOGICAL SUB-SURFACE PROFILES

Bore hole logs gives an excellent opportunity to understand subsurface hydrogeology from the point of view of deriving inferences on (i) Thickness and lateral extent of an aquifer; (ii) Vertical litho-facies changes facilitate in establishing aquifer types and level of hydrostatic pressure. The candidate has made efforts in collecting large numbers of borehole logs from State Water Resource Departments Viz; GWRDC & GWSSB and the Kachchh area NGO's. Based on borehole data, candidate has drawn in all 05 sub-surface hydro-geological profiles (Fig. 5.4). The salient sub-surface characteristics derived from borehole profiles are discussed as under-

(I) PROFILE A-A'

This E-W trending profile represents sub-surface hydro-geological characters of Cretaceous sandstone terrain beginning from western ridgeline near Meghpar village to eastern boundary near Wada village (Fig 5.5). The depicted sedimentation pattern shows 80 m thick sandstone (aquifer) followed by about 5 m thick band of shale (aquiclude) as base. The top of sandstone has a cap of thick discontinuous layer of shale. Above this shale unit lies the younger unit representing an intercalated sequence of sandstone and shale attaining a thickness of about 40m. The overall disposition pattern of sediment units are suggestive of phreatic – unconfined nature of aquifer. Water table shows a perceptible control of topography.

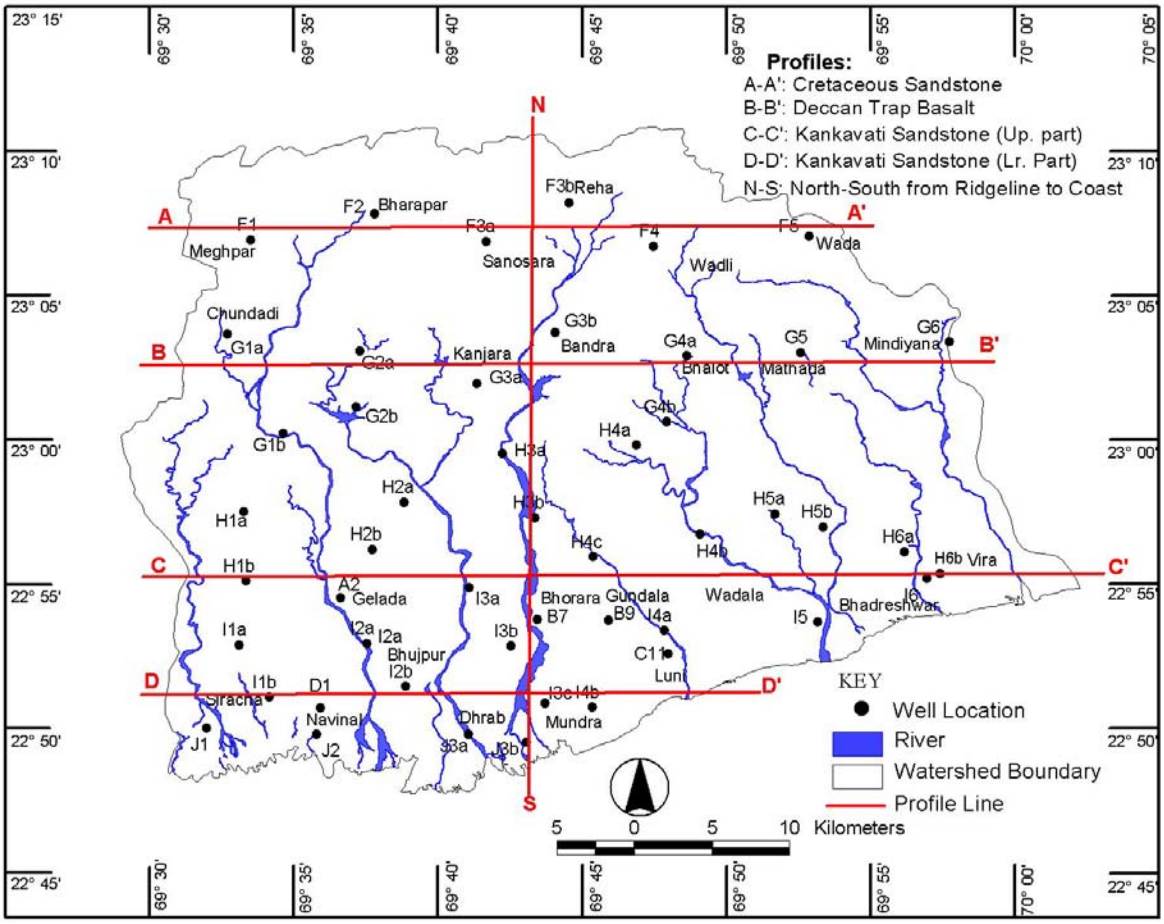


Fig. 5.4 Map Depicting Positions of Sub-surface Hydrogeological Profiles

(II) PROFILE B-B'

Profile B-B' (Fig. 5.6) represents hydro-geological conditions of basaltic terrain occupying central part of the study area. The plotted profile depicts two contrasting lithologic environments viz; bottom sedimentary and igneous at the top, thereby representing a disconformable sequence. Lower unit of Cretaceous sandstone (Bhuj fm.) is concealed below a massive/compact basalts hence developed a confinement.

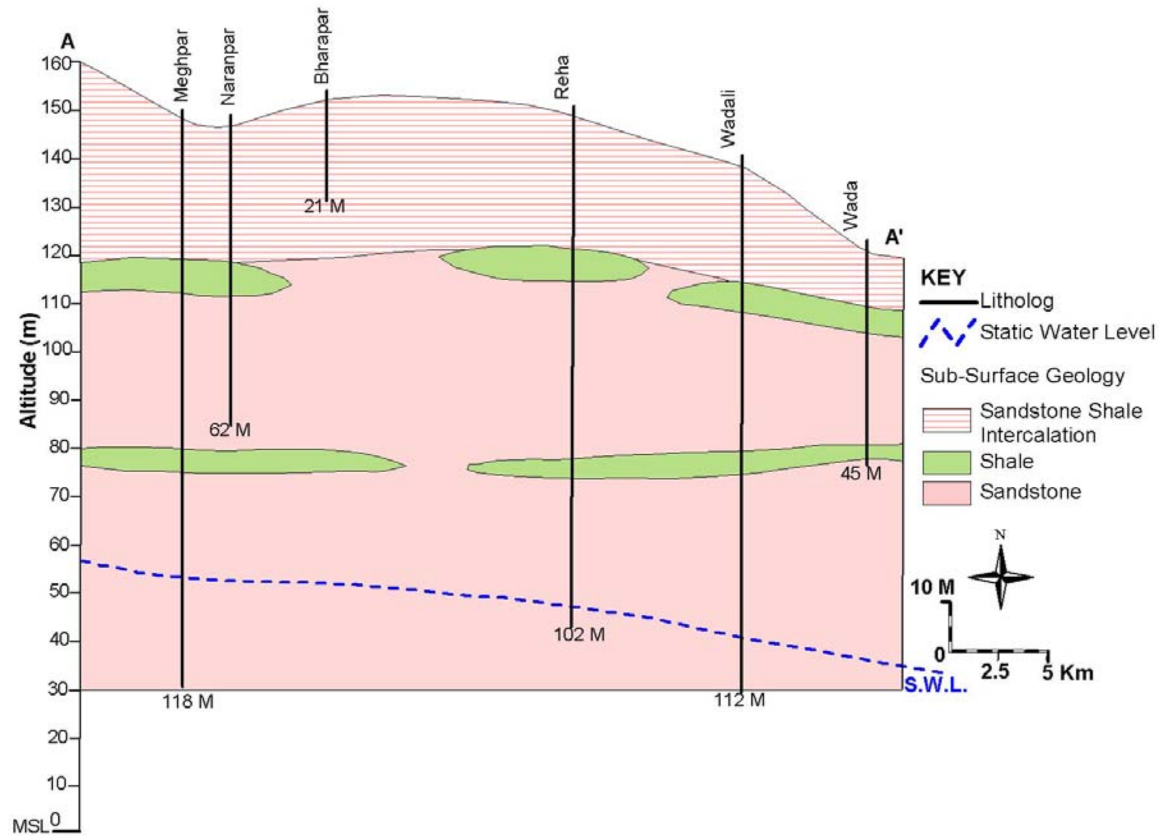


Fig. 5.5 Sub-Surface Hydrogeological Profile (A-A') Between Meghpar and Wada Villages

Therefore, the sandstone aquifer shows a definite hydrostatic pressure/piezometric surface lying within the basaltic domain. The encountered thickness of this sandstone aquifer is in the range between 25 and 45 m and characterized by patchy occurrence of shale bands. The development of aquifer in basalt is solely governed by the extent and thickness of weathered/ fractured zones. However, the aquifers developed within basalt are phreatic-unconfined in nature having an overall thickness between 8 and 15 m. The fractured basalt beneath the weathered zone has an average thickness of 10-15m. The groundwater table in basaltic aquifer show strong control of topography. Therefore, under this geological environment one can typify 02 aquifers viz; top phreatic and below confined to semi-confined one.

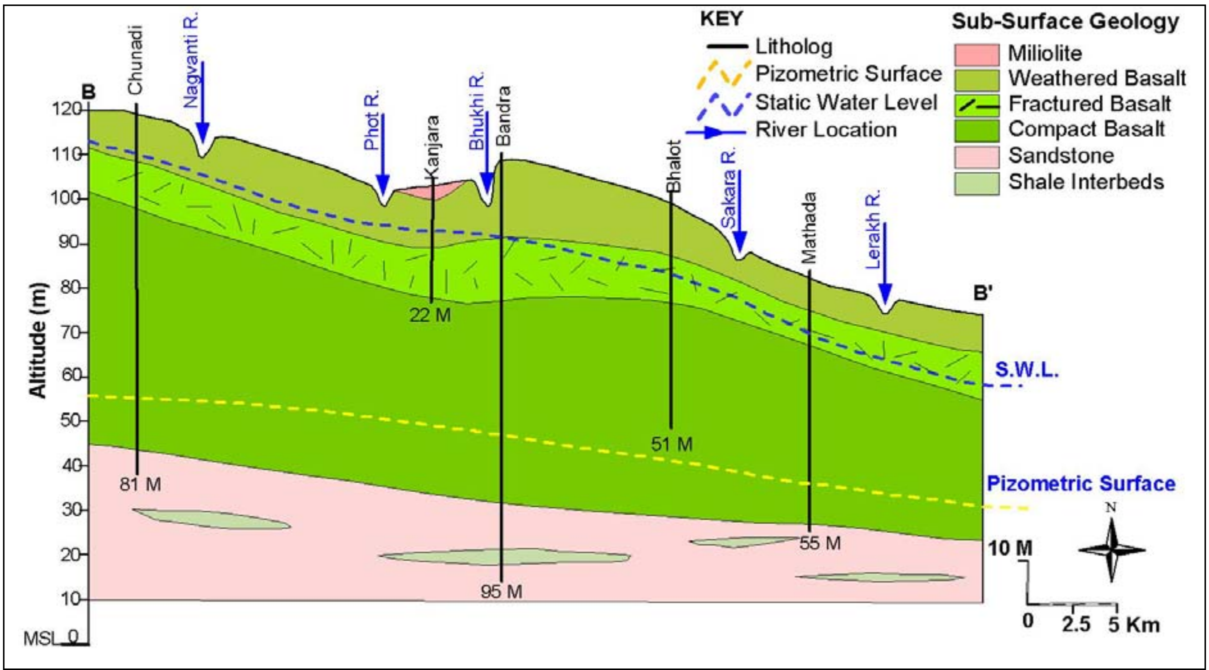


Fig. 5.6 Sub-Surface Hydrogeological Profile (B-B') Between Chunadi and Mindiyana Villages

(III) PROFILE C-C'

The profile falls within the domain of Tertiary Kanakavati Sandstone between Gelada village in west and Vira village in east (Fig. 5.7). The sub-surface section extends up to 132 m depth. The top most horizon is characterized by alluvium having 5 to 6 m thickness. This is followed by thick Kankavati sandstone whose thickness tends to increase towards west. This is on account of presence of trappean base, representing palaeo land surface. The sandstone is characterized by intercalations of clay, appears to be lensoidal bodies of varied thickness. The trappean base appears to slope towards west, however not encountered in the borehole log at Gelada. Therefore this sudden disappearance of trap further west of Bhorara village may be attributed to local faulting having its down throw side towards west (Fig. 5.7). The behavior of Bhukhi and Phot rivers and appearance of distributory channel network between Gelada and Bhorara villages further corroborate this fact. The aquifer development is of phreatic in nature and associated with Kankavati sandstone as well as basalts. The water table tends to show shallow depth (~40 m) in east whereas it is at depth in west i.e. ~80 m.

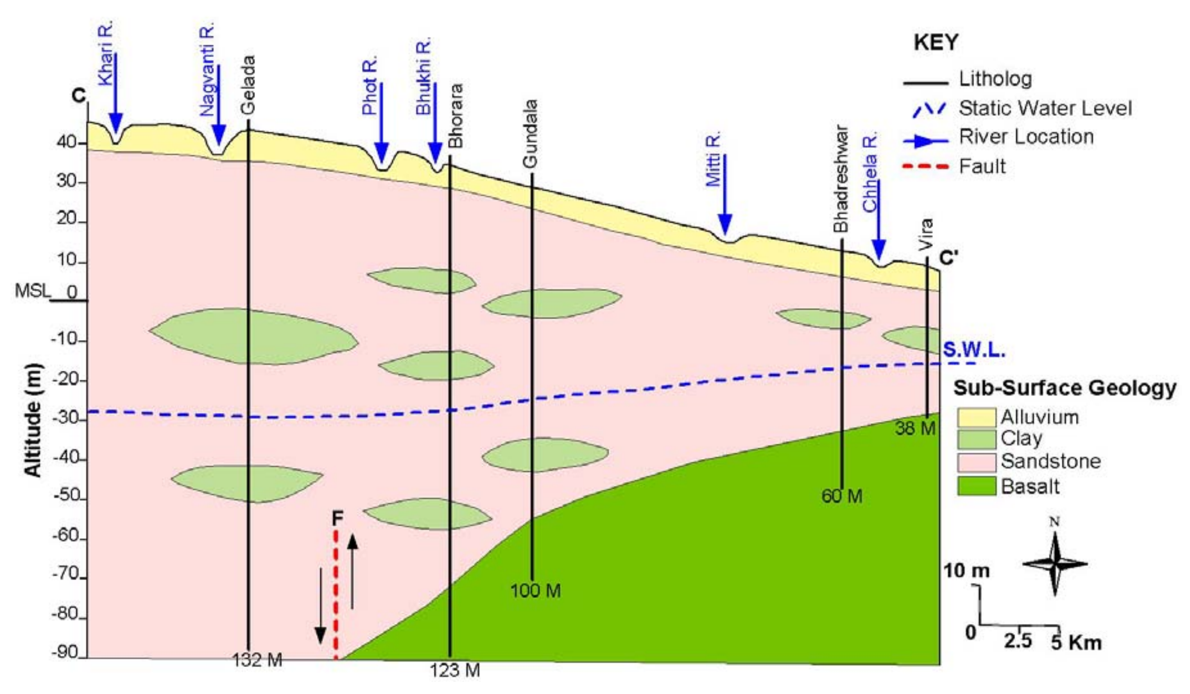


Fig. 5.7 Sub-Surface Hydrogeological Profile (C-C') Between Khari and Chhela Rivers

(IV) PROFILE D-D'

This is the southern most sub-surface profile representing coastal plain area characterized by a thick Recent to Sub-recent alluvium followed by the Kankavati sandstone. The deepest section (95m) is seen at Bhujpar Nani. The sedimentation pattern represent more or less similar nature as that of profile C-C' i.e. sand with lenses of clays. The aquifer is of unconfined in nature and having deeper water table i.e. 68-49 m below ground level.

(V) PROFILE N-S

The profile represents sub-surface hydro-geological characters on profile line north (ridgeline) to south (coast) crossing all the existing geological formations (Fig. 5.9). It starts from Cretaceous sandstone at Reha village in north and end with Recent alluvium at Mundra in south. The depicted profile show 80m thick sandstone (aquifer) occurring below 8 m thick shale layer. The aquifer is of phreatic-unconfined nature. The aquifer has 40 m thick shale sandstone intercalated strata as top most layer. As one moves towards south, Bhuj Formation sandstone is seen intruded by basaltic lava flows.

Basaltic aquifer has developed in weathered and fractured zones. This phreatic-unconfined aquifer has a thickness of 10 to 15 m of weathered zone and 10 to 18 m of fractured zone. Further south, extent and thickness of aquifer is increasing. As the basalt intrusion forms a wedge with Bhuj sandstone and due to its inclined geometry, there is a presence of Bhuj sandstone below the trap i.e. between Chakar and Bandra villages; therefore, the deeper bore wells have penetrated the basalt and reached to the basal unit of Bhuj sandstone having hydrostatic pressure conditions. Further south, the basalt occurs as a base for younger Kankavati sandstones i.e. borehole log at Lakhapar village. Although, Kankavati sandstone has clay bands, but due to its discontinuous nature, the aquifers are un-confined in character. The pattern of groundwater table in southern part of the profile show strong control of topographic slope.

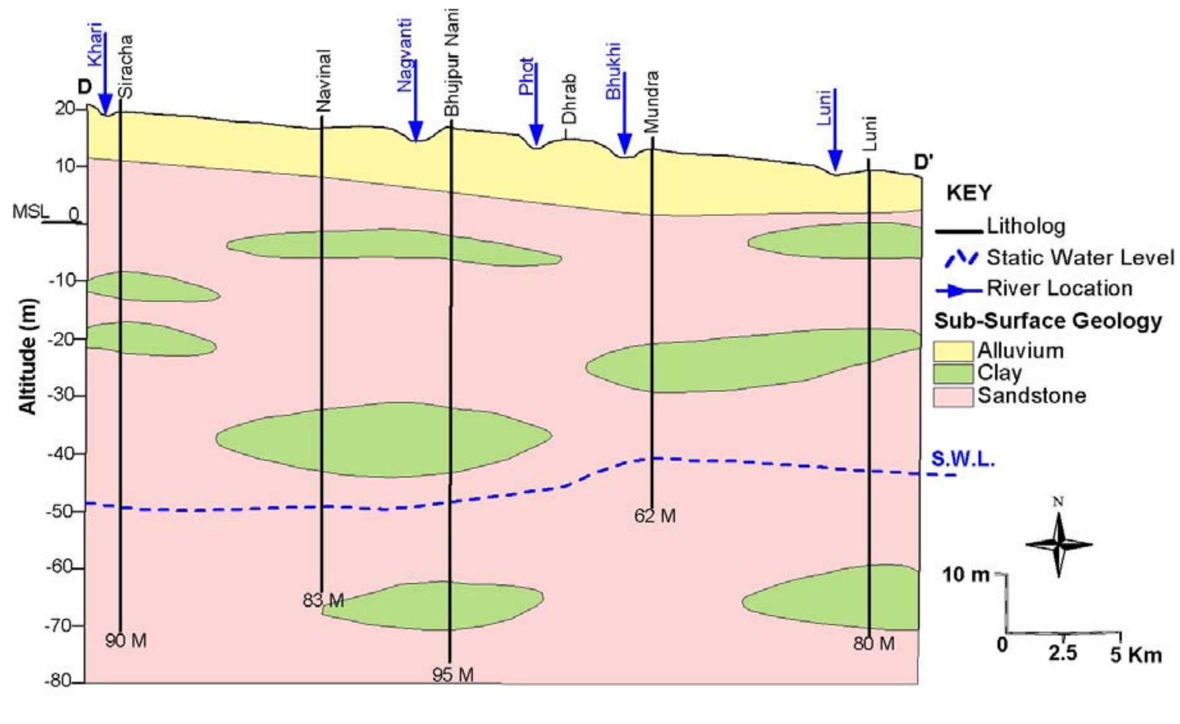


Fig. 5.8 Sub-Surface Hydrogeological Profile (D-D') Between Siracha and Luni Villages

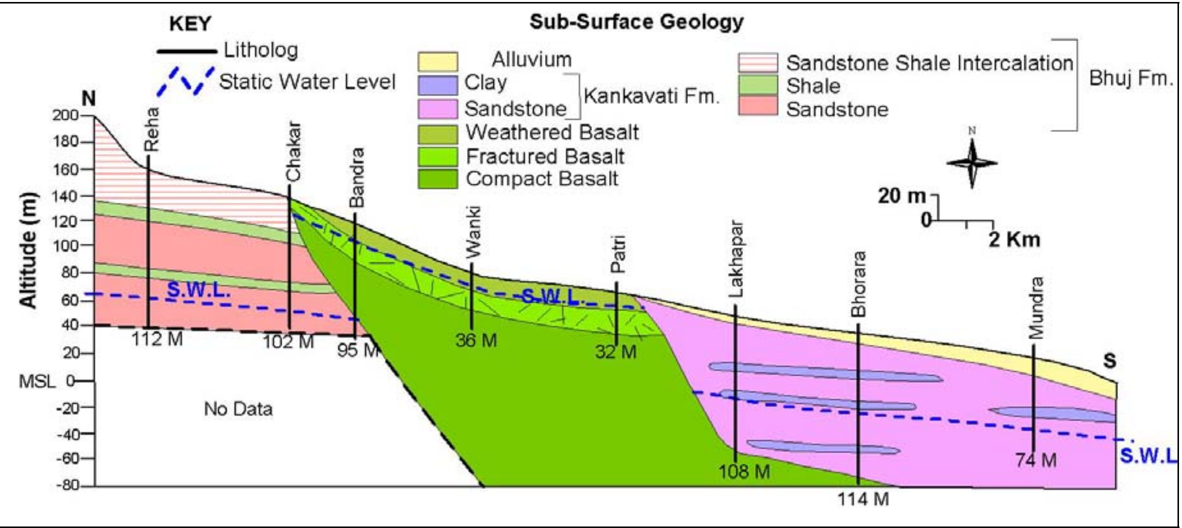


Fig. 5.9 Sub-Surface Hydrogeological Profile (N-S) Between Reha and Mundra Villages

WATER LEVEL FLUCTUATIONS

As it has already been eluded that the study area is characterized by 02 aquifer types viz; phreatic - unconfined and confined - semi confined. Major part of the study area has a significant development of phreatic- unconfined type of aquifers and constitutes a major source of groundwater resource.

Unconfined aquifers been considered as a part of open system and therefore, greatly influenced by seasonal changes in water levels. Water level fluctuation in any area also dependent on recharge due to rainfall as input parameter and the groundwater abstraction as out put parameter. A summary on various factors influencing water level fluctuation is given in Table 5.2

Therefore, to understand spatial and temporal behavior in groundwater level fluctuation and its pattern, the candidate has carried out seasonal monitoring of water table through establishing network of observation wells. The candidate has recorded water level changes for 03 different seasons viz; Summer (pre monsoon) in June, Post monsoon in October and Winter (Spring) in February months between the years 2008 and 2011 i.e. 04 years duration (Annexure 5.6).

Table 5.2 Water Level Fluctuations: Categorizations and Causative Factors

(Modified After Todd & Mays, 2012)

Time Variation of Levels	Governing Factors	Process Mechanism	Conditions
Diurnal or Short Term	Stream Flow	Bank Storage	Geology, Rainfall and abstraction dependent
		Base Flow	
	Evapo - Transpiration	Evaporation	Climate and Land use dependent
		Transpiration	
	Meteorological	Atmospheric Pressure	Climate and Terrain Dependent
		Rainfall	
		Wind & Frost	
	Ocean Tides	River Flooding	Magnitude of Tide and Geology Dependent
	Urbanization	Abstraction	Management Dependent
	Earthquake	Liquefaction	Geology Dependent
	External Load	Pore water pressure	Geology and Stress Dependent
Seasonal and Long Term	Rainfall	Recharge	Rainfall Pattern and Geology Dependent
	Utilization	Abstraction	Management Dependent

Seasonal observations on groundwater level fluctuations and its change in chemical content provides long term scenario, the secular change. Understanding the secular changes in water levels and its quality in terms of overall rise, decline and/or no change is very vital to identify the issues relevant to environmental degradation, water resource development and management of the study area (Table 5.3). Therefore, candidate apart from collecting her own primary data has to depend on secondary data of previous years collected by the State Water Resource Department i.e. GWRDC and local NGO's. The candidate could able to collect secondary data since 1990 from GWRDC and Arid Communities and Technologies and Shri Vivekanand Research and Training Institutes, both NGO's, for working out the secular changes.

Further, the seasonal changes in groundwater levels greatly influence the chemical content in groundwater, particularly the coastal aquifers. Therefore, candidate has also carried out seasonal groundwater sampling to work out detailed groundwater chemistry and analyze the data from the point of view its seasonal and long term variation in its quality, if any.

Table 5.3 Environmental Implications of Water Level Fluctuation

Water Level Changes	Pattern (Trend)	Factors	Environmental Implications	Water Management Strategies
Seasonal	Rise (Recharge)	Rainfall and inundation	May cause soil salinity	Surface Drainage and conjunctive Use
		Return irrigation seepage		
	Fall (Discharge)	Exploitation	Water quality deterioration may turn brackish/Saline particularly in coastal aquifers	Conjunctive use and crop management, Artificial recharge
		Evapo- transpiration		
		Sub-surface runoff		
Secular (Long Term)	Rise (Recharge)	Groundwater – under exploitation	Water logging: Increase in soil and water salinity, land degradation, health and socio-economic impacts	Conjunctive use and crop management
		Excess Irrigation through canal		
	Fall (Discharge)	Over exploitation	Sea water intrusion (coastal aquifers), groundwater salinity (Inland Aquifers), land degradation, socio-economic impacts and land subsidence	Conjunctive use and crop management, Artificial recharge
		Poor land and water management		

Amongst the water resource institutions, GWRDC has maintained long period of records of groundwater monitoring and has been monitoring the study area since year 1990. However, GWRDC's observation wells are scattered and are less in numbers (Annexure 5.4). Beside this, ACT has also set up the groundwater observation network in the study area during year 2005 (Annexure 5.5).

The candidate has taken pre monsoon (1995) as base for her study and computed secular change till pre monsoon (2010) a total of 15 years. Subsequently 05 yearly scenarios have been worked out through analyzing hydro-isobath maps and accordingly discussed. Same way seasonal groundwater fluctuations have been assessed by analyzing well hydrographs for the selected observation wells characterized by specific geological environments.

SEASONAL BEHAVIOR OF GROUNDWATER LEVELS

Phreatic aquifers, been a part and parcel of open system display marked change in water table seasonally. Although, water table fluctuation signify equilibrium state of dynamic atmospheric and hydrostatic pressure regimes. However, it does show influence of rainfall recharge and groundwater draft as a part of annual cycle.

Well Hydrographs

The candidate has analyzed selective observation well hydrographs based on aquifer composition. Further, the aquifers tend to spread laterally along E-W axis hence; wells falling on these lines have been included to draw hydrographs for their seasonal fluctuations (Fig. 5.10; 5.11 & 5.12).

The well hydrographs of Bhuj sandstone aquifer shows gradual depletion in water levels (Fig. 5.10). Water level depletion from pre monsoon of year 2008 to 2012 is ranging between 5 and 20 m and it is observed maximum in OW - F4 (Warli) and OW- G5 (Mathada). The deepest water level is observed in OW- F3b at Reha village, whereas it is the shallowest in OW- G5 at Mathada village (Fig. 5.10). Almost all well hydrographs show an overall decline in water levels during pre monsoon (15 – 35 m) and then an overall rise (15 – 30 m) during post monsoon season. Therefore, it has been established that the seasonal water level fluctuation is purely rainfall dependent. In general the observed seasonal water level fluctuation is of higher order in the western parts of the study area.

Well hydrograph of Basalt aquifers show high order of fluctuation, a typical character of shallow phreatic aquifer (Fig. 5.11). Observation wells viz, G3a (Kanjara) and H4a (Bagada) show overall rise (3 – 4 m) in water table while observation wells of Vaghura (G4b) and Vanki (H3a) show overall depletion about 3 to 6 m. Maximum groundwater recharge due to rainfall has been observed in year 2011.

The well hydrographs of Kankavati Sandstone aquifer is given in Fig. 5.12. Hydrographs of OW-I2a (Moti Bhujpur) and OW- I1b (Siracha) are suggestive of groundwater depletion at the rate of 5 – 8 m/year in spite of area observed high rainfall since year 2008. The observation wells situated in western part of the study area viz, Siracha, Bhujpur, Mundra represent a case of over exploitation. Whereas, observations wells situated in eastern part show stability in water levels which, may be attributed to specific and perennial recharge conditions.

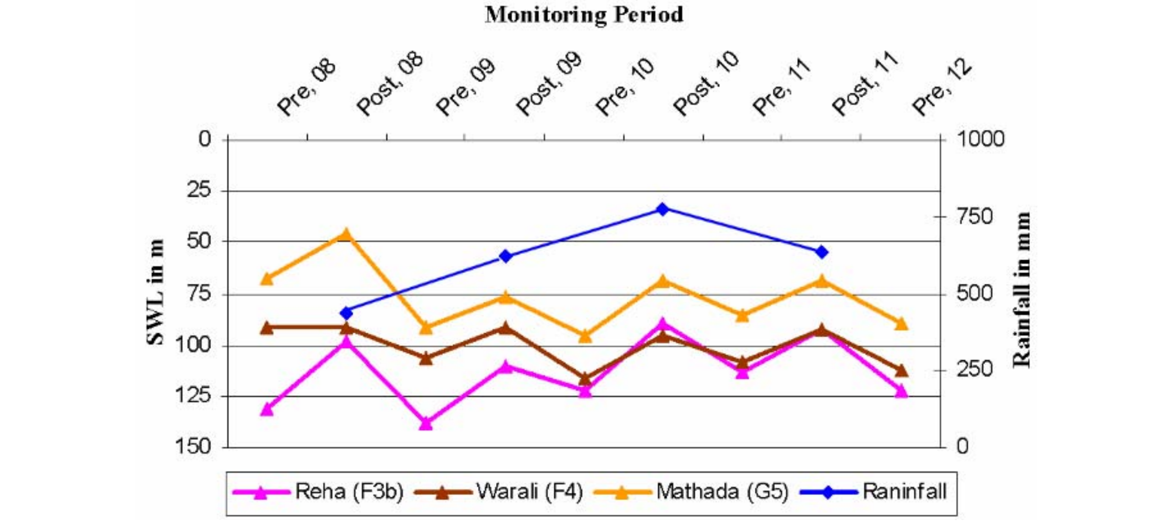


Fig. 5.10 Well Hydrographs Showing Seasonal Change in SWL in Bhuj Sandstone Aquifer

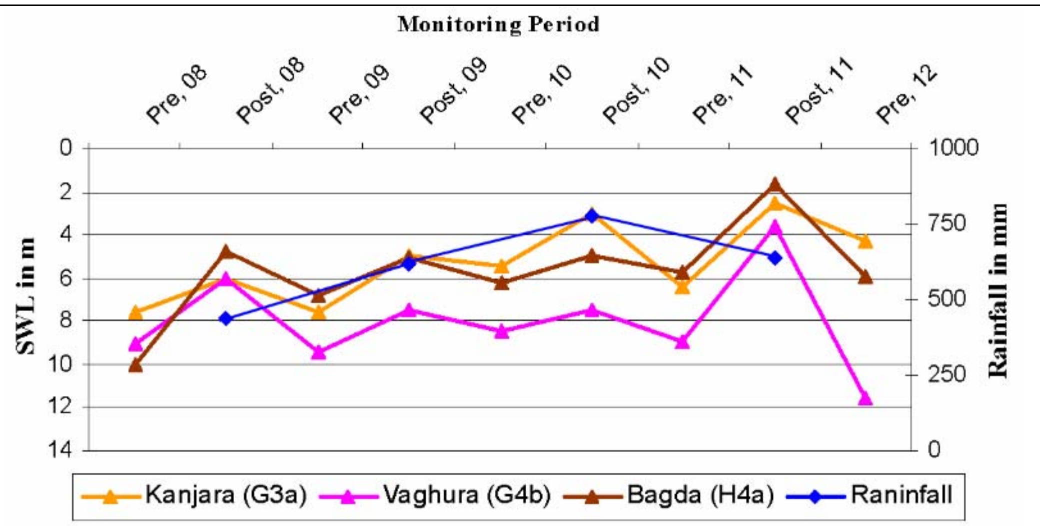


Fig. 5.11 Well Hydrographs Showing Seasonal Change in SWL in Basalt Aquifer

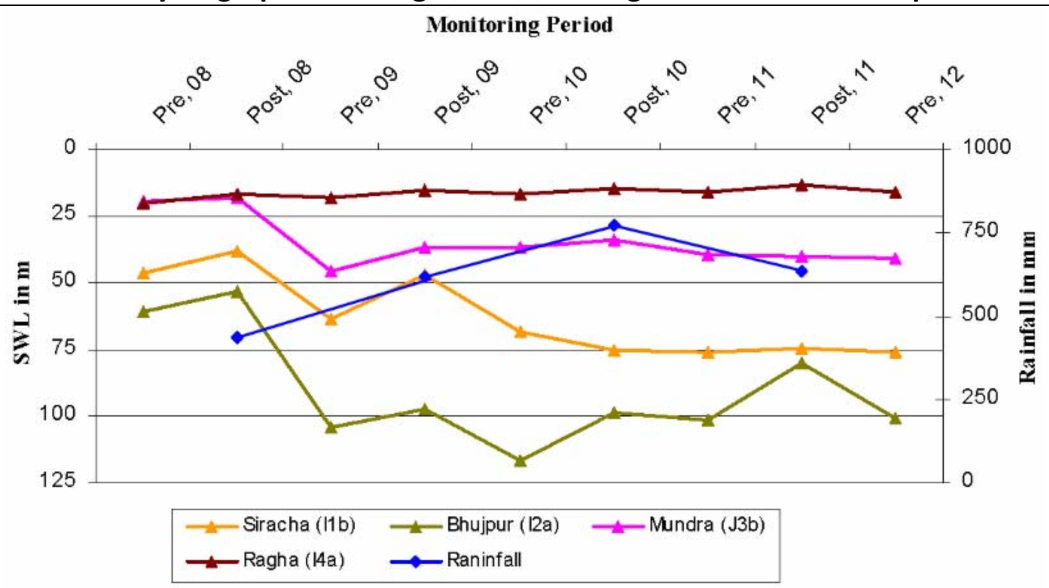


Fig. 5.12 Well Hydrographs Showing Seasonal Change in SWL in Kankavati Sandstone Aquifer

Spatial Distribution Pattern

Spatial distribution pattern of seasonal behavior of water levels on an annual basis gives an insight in demarcating the areas inflicted from the problems of over exploitation and the balanced utilization of groundwater resource.

Based on seasonal monitoring of static water levels, the candidate has constructed hydro-isobaths for the seasonal change in groundwater storage for the years 2008 and 2009 (Fig. 5.13 & 5.14). In all 05 hydro-isobath categories have been derived and their characterization has been made (Table 5.4).

Hydro-isobath for the seasonal changes (Fig. 5.13 & 5.14) suggests that the rainfall input and the groundwater draft have remained the prime factors in developing spatial patterns. The observed rainfall in the study area for the year 2008 was 438 mm and thereafter it was 620 mm (year, 2009), which was almost 40 % higher to that of year 2008. Therefore, hydro-isobath categories > 20 m show a marked seasonal change from 2008 to 2009 in the northern parts of the study area comprising pre dominantly phreatic aquifers. Hydro-isobath categories showing 20 m change are deeper aquifers and forming a part of alluvium plains hence, marked with delayed response. In the southern coastal plains, localities around Bhujpur (2008) and Bhadreshwar (2009) being a part of SEZ show negative and/or higher order of change which is attributed to over exploitations.

Table 5.4 Seasonal Changes in Water Table: Spatial Distribution Pattern in Watershed Region

SWL Fluctuation (m)	Spatial Distribution (Km^2)		Aquifer Nature	Locality Name
	Year 2008	Year 2009		
>30	26.4	138.0	Bhuj Sandstone	Bharapar, Reha, Wadva
20 - 30	71.8	241.5	Bhuj Sandstone, Kankavati Sandstone	Meghpar, Kotada, Bandra, Samagogha
10 – 20	516.2	504.0	Bhuj Sandstone, Kankavati Sandstone	Kera, Chandia, Khedoi, Kapaya, Jarpara, Tunda
< 10 m	1012.7	768.0	Bhuj Sandstone, Basalt, Kankavati Sandstone	Wadali, Babia, Wanki, Bhalot, Ramania, Navinal, Gelda, Bhujpar, Mokha, Luni,
(-) Change	42.0	18.0	Kankavati Sandstone	Khakhar, Bhadreshwar

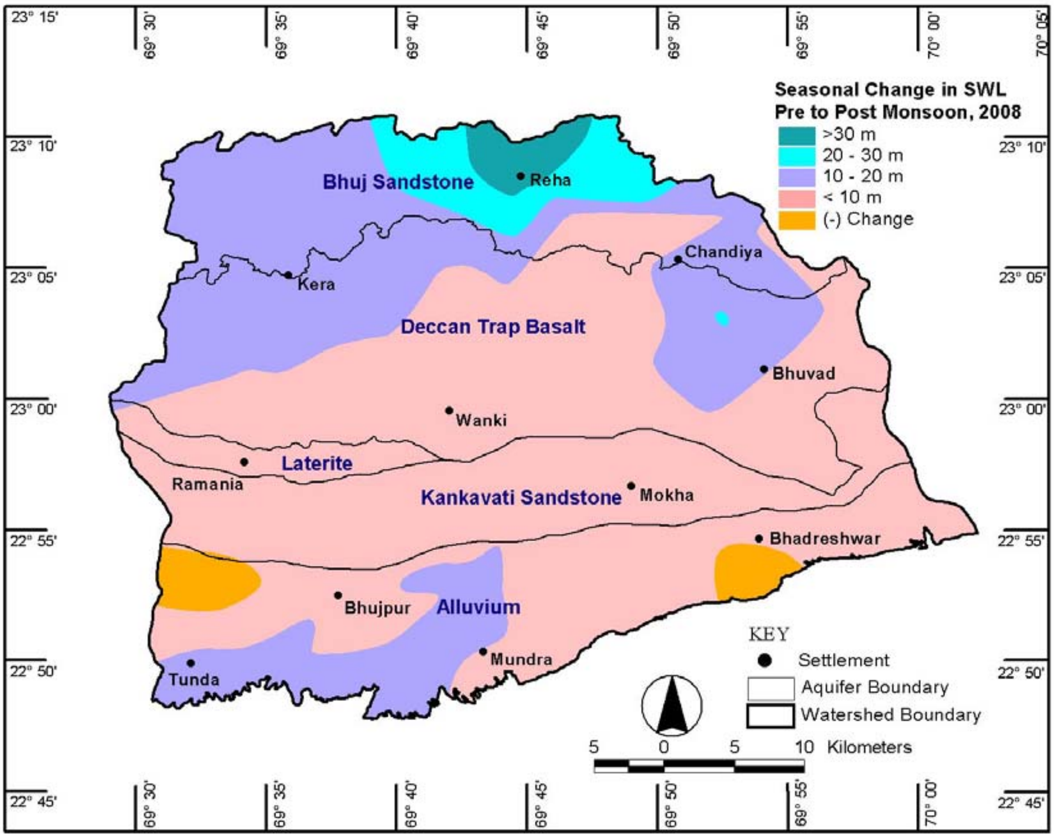


Fig. 5.13 Isobaths of Seasonal Change in Static Water Levels from Pre to Post Monsoon, Year 2008

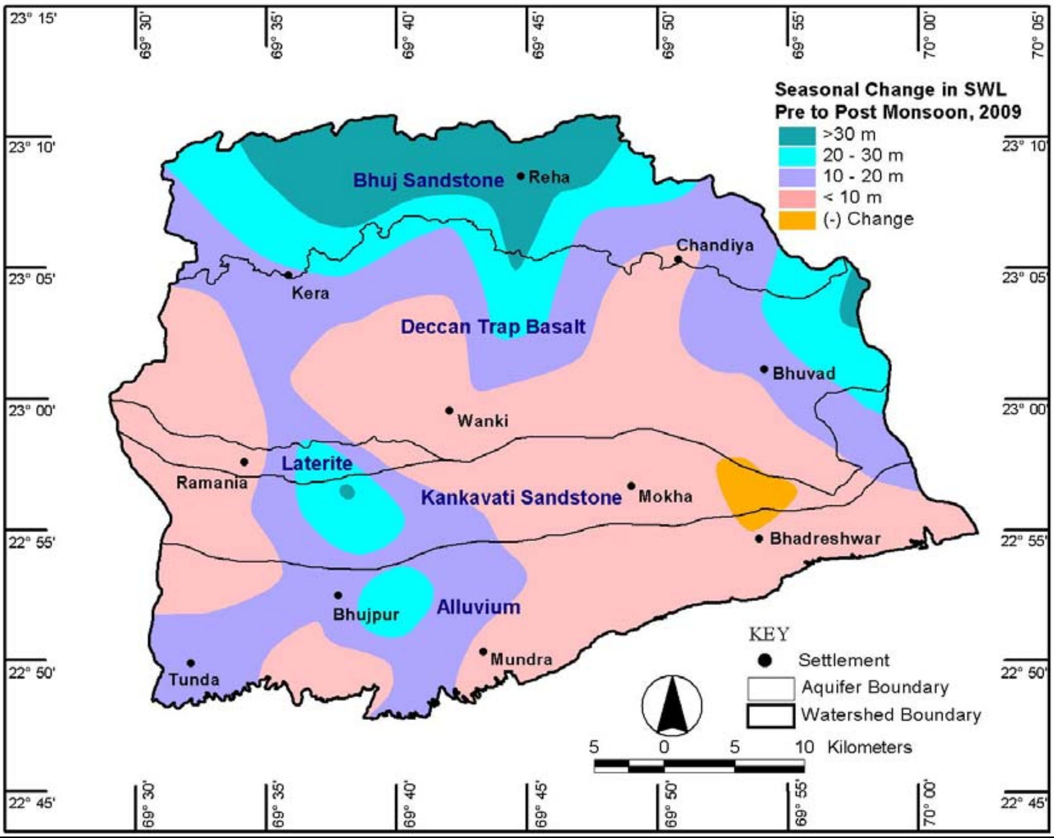


Fig. 5.14 Isobaths of Seasonal Change in Static Water Levels from Pre to Post Monsoon, Year 2009

Table 5.5 Seasonal Fluctuations (m) in Groundwater Level in Watershed Region

Sr. No.	Code	Village	Depth (m)	Year 2008			Year 2009		
				SWL Pre	SWL Post	Change (m)	SWL Pre	SWL Post	Change (m)
1	F1	Meghpar	130.0	95.0	----	----	108.5	----	----
2	F2	Sujapar	120.0	93.2	79.3	13.9	113.0	74.0	39.0
3	F3a	Sanosara	152.4	96.2	81.2	15.0	101.2	79.8	21.4
4	F3b	Reha nana	146.0	131.1	98.0	33.1	147.7	110.0	37.7
5	F4	Varali	305.0	91.5	91.5	0.0	106.7	91.0	15.7
6	F5	Wada	107.0	73.2	62.3	10.9	85.4	72.0	13.4
7	G1a	Chunadi	81.0	58.0	38.3	19.7	55.0	45.0	10.0
8	G1b	Tumbadi Moti	12.2	7.0	0.0	7.0	dry	0.0	12.0
9	G2a	Kera	360.0	99.6	79.3	20.3	122.0	110.0	12.0
10	G2b	Babiya	20.0	10.2	5.7	4.5	9.1	5.8	3.3
11	G3a	Kanajra	15.2	7.6	6.0	1.6	7.6	5.0	2.6
12	G3b	Bandra Nana	293.0	30.0	23.4	6.6	73.0	45.0	28.0
13	G4a	Bhalot	24.0	13.0	11.5	1.5	21.5	17.4	4.1
14	G4b	Vagura	14.0	9.0	6.0	3.0	9.4	7.5	1.9
15	G5	Mathada	152.0	67.1	45.7	21.3	91.5	76.0	15.5
16	G6	Mindiyana	122.0	79.3	73.2	6.1	109.0	76.0	33.0
17	H1a	Ramaniya	16.0	3.5	2.5	1.0	6.4	5.0	1.4
18	H1b	Depa	91.5	86.9	82.3	4.6	87.2	79.8	7.4
19	H2a	Bocha	27.4	18.3	18.3	0.0	22.3	15.0	7.3
20	H2b	Gelda	122.0	45.7	43.3	2.4	76.2	45.0	31.2
21	H3a	Vanki	18.3	3.0	2.5	0.5	13.6	5.5	8.1
22	H3b	Kandagara Nana	70.1	24.4	24.4	0.0	28.4	27.4	1.0
23	H4a	Bagda	21.3	10.0	4.8	5.2	6.8	5.1	1.7
24	H4b	Mokha	30.5	12.2	----	----	----	----	----
25	H4c	Ratadiya	91.5	24.4	16.9	7.5	24.7	22.6	2.1
26	H5a	Vovar	27.4	9.0	5.0	4.0	4.6	4.5	0.1
27	H5b	Bharudiya	30.5	----	----	----	10.1	12.2	-2.1
28	H6a	Hatadi	39.6	4.0	----	----	5.5	4.7	0.8
29	H6b	Kuvai	12.8	3.5	2.5	1.0	7.1	4.2	2.9
30	I1a	Khakhar Moti	106.7	39.6	45.7	-6.1	45.7	41.7	4.0
31	I1b	Shiracha	121.0	46.5	38.1	8.4	63.3	47.2	16.1
32	I2a	Moti Bhujpur	100.6	60.9	53.2	7.7	114.0	97.4	16.6
33	I2b	Pratappar	106.7	63.5	59.8	3.7	89.1	63.2	25.9
34	I3a	Baraya	79.3	----	----	----	61.0	45.0	16.0
35	I3b	Mota kapaya	168.0	54.9	42.7	12.2	67.1	51.0	16.1
36	I3c	Mundra	73.0	38.1	27.3	10.8	38.1	31.2	6.9
37	I4a	Ragha	35.0	20.3	16.8	3.5	18.0	15.2	2.8
38	I4b	Goyersama	61.0	30.5	24.5	6.0	24.4	21.3	3.1
39	I5	Bhadreshwar	51.8	7.0	7.6	-0.6	16.8	16.0	0.8
40	I6	Kukadasar	8.2	7.3	5.5	1.8	6.1	3.9	2.2
41	J1	Tunda	76.2	50.5	38.1	12.4	64.5	45.0	19.5
42	J2	Navinal	109.8	51.1	38.1	13.0	38.1	35.0	3.1
43	J3a	Dharub	122.0	67.1	48.0	19.1	54.9	42.0	12.9
44	J3b	Mundra	107.0	19.0	18.3	0.7	45.7	36.6	9.1

SECULAR CHANGE IN GROUNDWATER REGIME

Change in groundwater storage has been calculated over last 15 years (1995 – 2010). The data used for deriving groundwater storage change - GWRDC (year 1995 & 2005), Arid Communities and Technologies (2005) and self monitored data (2010). For this, periodic static water level isobaths have been generated viz; 15 year (1995- 2010), 10 years (1995-2010) and 5 years (2005- 2010). Along with hydro-isobaths, selective observations well hydrographs have also been drawn to demarcate area specific change.

Observation Well Hydrographs

Well hydrographs have been prepared for selective wells belonging to varied geological environments showing ideal response to recharge and groundwater abstraction. In order to check influence of rainfall as recharge impacting water table fluctuation, annual rainfall curve has also been plotted and analyzed. Information on observation wells utilized for plotting well hydrographs along with other details is given in Table 5.6.

Table 5.6 Details on Observation Wells Utilized for Well Hydrographs

Observation Well	Aquifer Nature	S.W.L. (m)							
		Year 1995		Year 2000		Year 2005		Year 2010	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Rainfall mm	206.1		581.9		490		776	
Meghpar (F1)	Bhuj Sandstone	61.4	58.9	77.0	77.0	55.0	54.5	92.0	75.1
Reha (F3b)	Bhuj Sandstone	----	----	59.1	60.8	65.7	65.3	120	89.4
Mindiyana (G6)	Bhuj Sandstone	31.0	30.6	32.8	32.8	53.7	53.2	83.0	64.1
Vaghura (G4b)	Basalt	11.9	5.5	16.4	16.7	16.2	15.8	8.5	7.5
Bagada (H4a)	Basalt	10.4	8.6	11.8	9.7	10.4	9.5	6.2	6.0
Desalpar (A1)	Kankavati Sandstone	28.9	27.1	31.9	31.6	63.8	63.3	85.4	71.5
Bhujpar	Kankavati Sandstone	22.0	21.2	53.9	52.4	68.5	71.4	116.8	98.5
Zarpara (E4)	Kankavati Sandstone	11.6	11.4	32.3	32.1	41.6	41.4	74.9	59.3
Bhadreswar (I5)	Kankavati Sandstone	6.3	6.1	9.8	7.9	11.0	10.7	21.0	12.0

Well hydrographs for Bhuj Sandstone aquifer have been prepared by using long term seasonal water table data of the wells at Meghpar, Reha and Mindiyana villages along with rainfall curve (Fig. 5.15). The hydrographs clearly shows depletion trend in groundwater levels in spite of increase in rainfall therefore, water level fluctuations do not show any impact of rainfall pattern. However, there has been an overall decrease in groundwater storage that may be attributed to over exploitation.

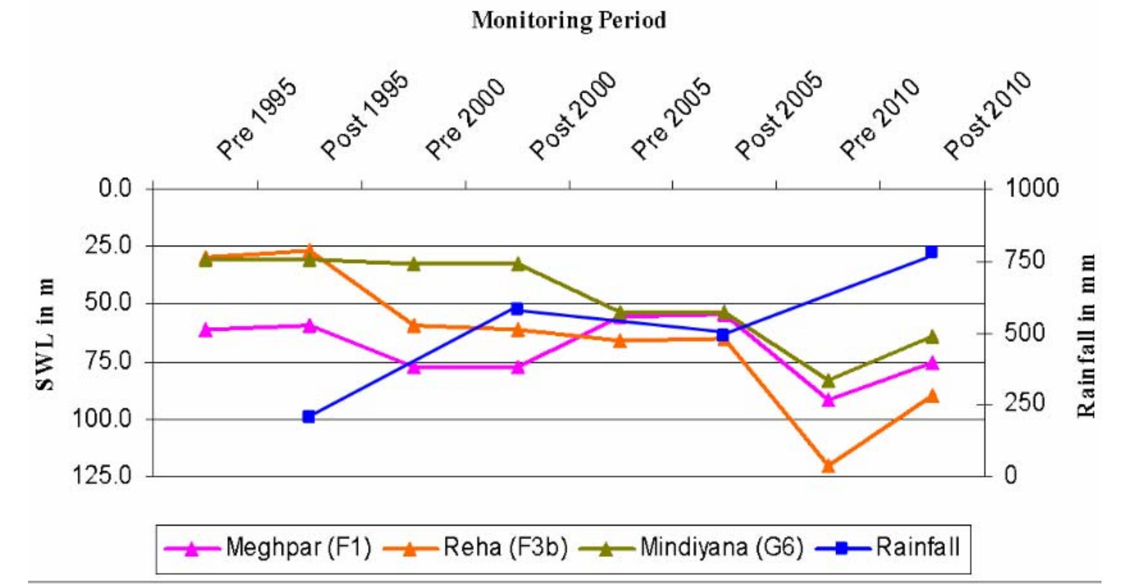


Fig. 5.15 Well Hydrographs of Long Term Change in SWL in Bhuj Sandstone

Well hydrographs of basalt aquifer have been prepared by using water level data of Vaghura and Bagada villages (Fig. 5.16). The hydrographs although in harmony with the rainfall but still show the impact of over exploitation due to below average rainfall receiver by the area during 1995.

Well hydrographs of Deshalpar, Bhujpur, Zarpara and Bhadreshwar villages represent Kankavati sandstone aquifer (Fig. 5.17). The hydrographs show an overall declining trend in groundwater storage, irrespective of rainfall input. These progressive lowering of water levels except the Bhadreshwar observation well can be attributed to increase in industrial sectors' demand, leading to over exploitation.

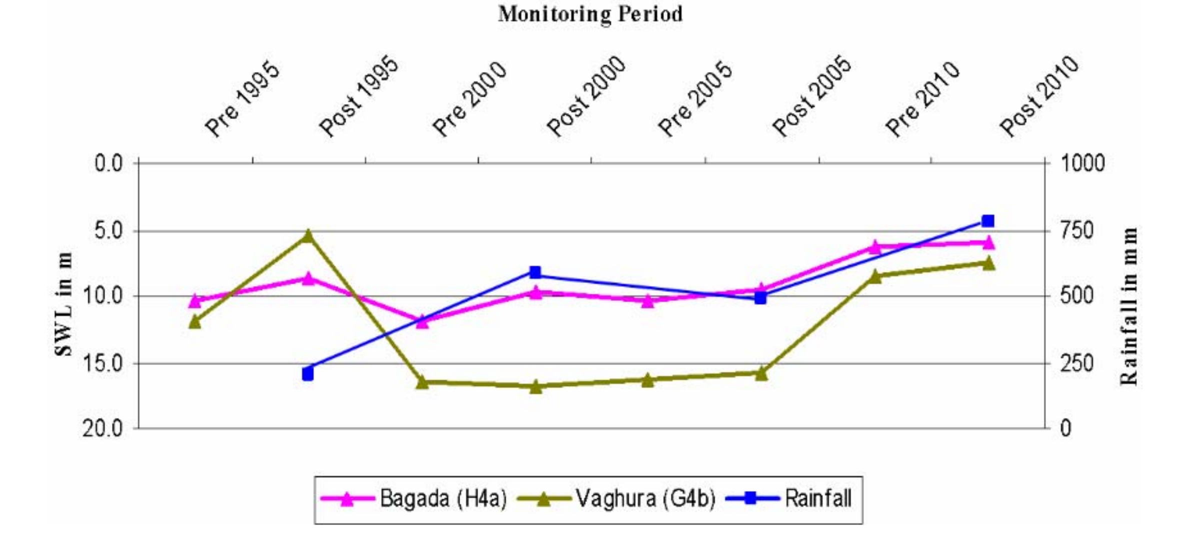


Fig. 5.16 Well Hydrographs of Long Term Change in SWL in Basalt Aquifer

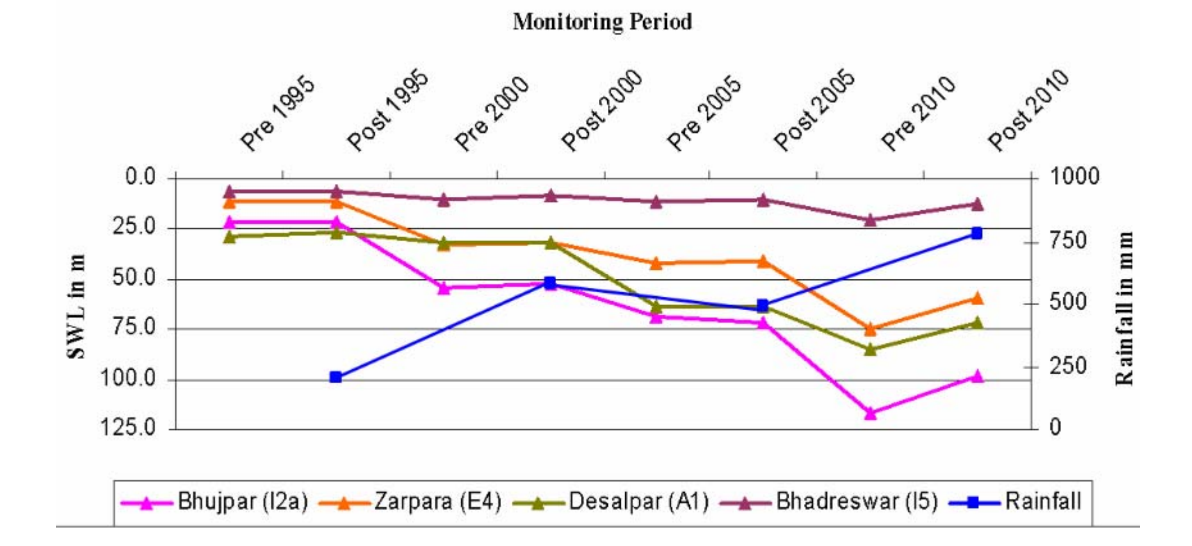


Fig. 5.17 Well Hydrographs of Long Term Change in SWL in Kankavati Sandstone Aquifer

Hydro-Isobaths

Hydro-isobath map is considered to be the most ideal way of presenting secular changes in groundwater storage. The advantage of hydro-isobath map is that it provides spatial picture of the entire area for an individual temporal phase. Realizing this very fact, the candidate has constructed the hydro-isobath maps for 03 different temporal phases viz; 1995-2005, 2005-2010 and 1995-2010 (Fig. 5.19 – 5.21).

Hydro-isobath map (Fig. 5.19) for phase (1995 – 2005) is the period prior to industrial development representing water demand in irrigation and domestic sectors. However, this represented 10 years scenario display quite an alarming situation of lowering of water table in the study area. Although 41.8 % of the study area has witnessed rise in water table, remaining 58.2 % study area has suffered from the problem of water table decline (Table 5.7). The south western coastal plain region covering about 340 sq.km. area (20 %) shows declined in groundwater levels more than 20 m. This point to very fact of significant rise in number of bore wells leading to increase in groundwater draft.

Hydro-isobath map (Fig 5.20) representing phase (2005-2010) demonstrate further deteriorating situation of groundwater storage. There has been a perceptible rise in all the categories pointing to lowering of groundwater levels. Even the area showing rise in water table for the period (1995-2005) has reduced significantly. This sharp decline particularly the categories >40 m depletion (Table 5.7) during 05 years i.e. (2005-2010) may be ascribed to rise in industrial and domestic demands as a part of industrial development in the study area.

Hydro-isobath map (Fig. 5.21) is representing cumulative 15 years (1995-2010) scenario superimposed with 1995 SWL contours. The map clearly depicts that the study area has suffered severely from the problem of lowering of groundwater levels ranging between < 20 m to >80 m. Where in the area around Reha (Bhuj Fm.) in north and in south around Bhujpur (Kankavati Fm.) water table has been lowered to the tune of >80 m, thereby covering an overall area of about 110 sq.km (Table 5.7) and with an average lowering rate of 5 m/year.

Table 5.7 Summarization of Change in Static Water Level

SWL Change Category	Change in Groundwater Storage					
	1995 – 2005		2005 – 2010		1995 – 2010	
	Area (km^2)	% of Total Area	Area (km^2)	% of Total Area	Area (km^2)	% of Total Area
Rise	698	41.8	198	11.9	Nil	---
<20 m depletion	634	38.0	836	50.1	458	27.4
20 to 40 depletion	202	12.1	349	20.9	469	28.1
40 to 60 m depletion	100	6.0	205	12.3	377	22.6
60 to 80 m depletion	35	2.1	81	4.9	256	15.3
> 80 m depletion	----	----	----	----	109	6.5
Total	**1669**	**100**	**1669**	**100**	**1669**	**100**

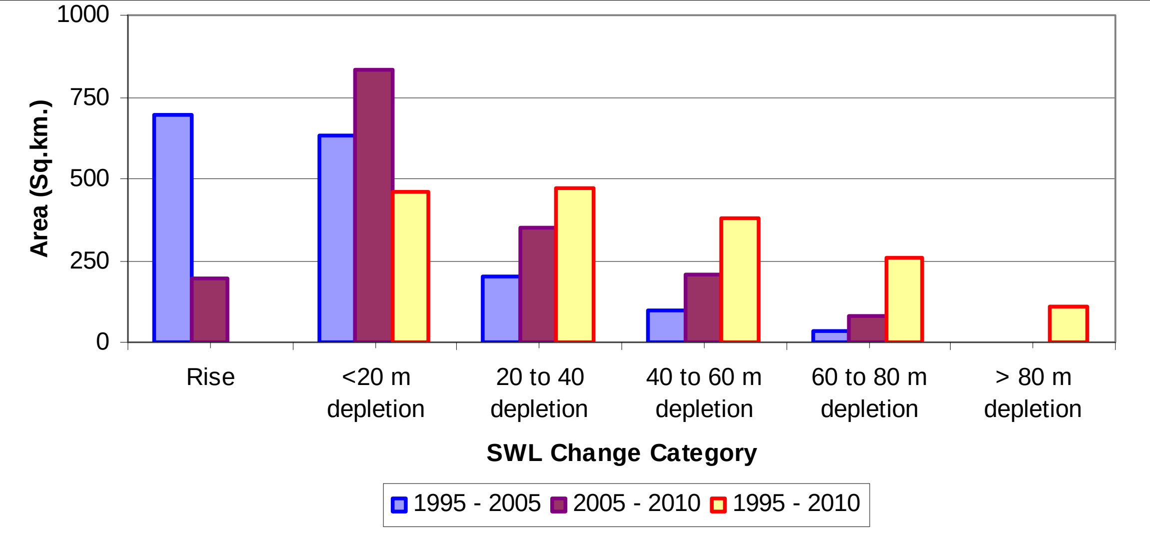


Fig. 5.18 Bar Diagram Depicting Temporal and Spatial Change in Groundwater Storage

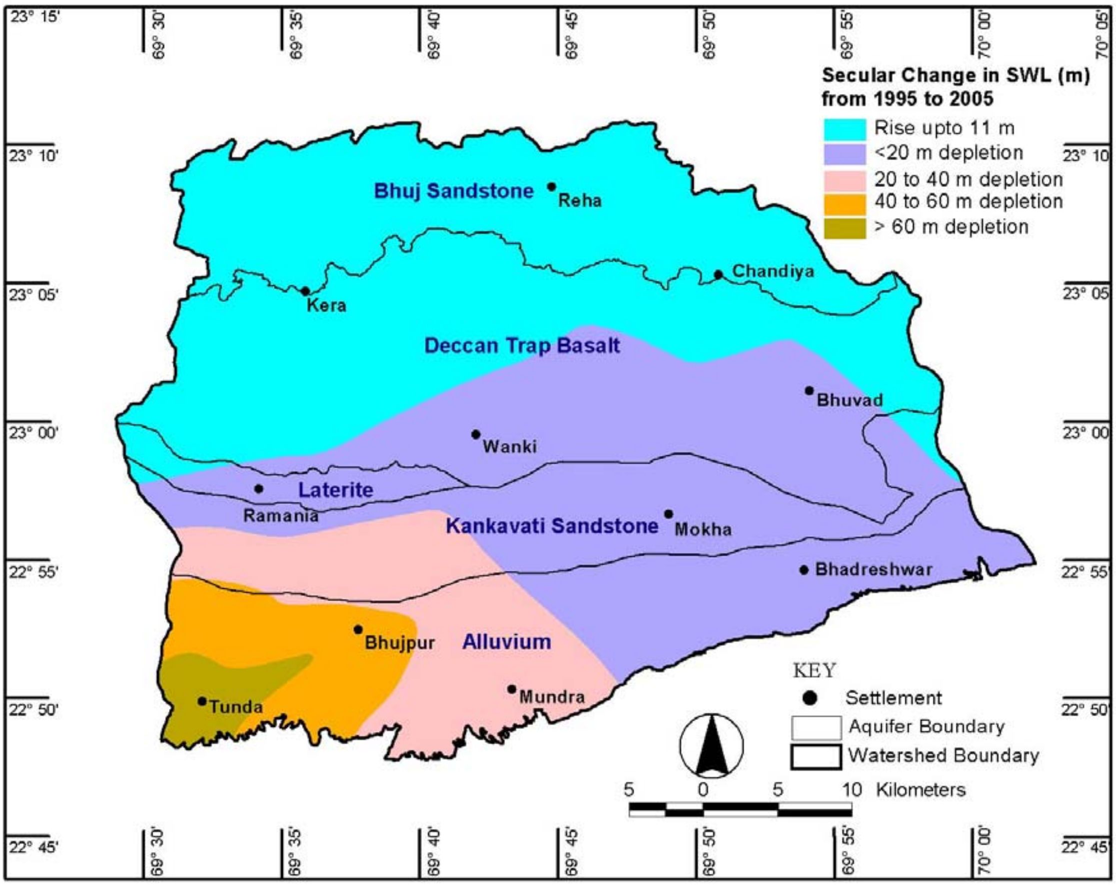


Fig. 5.19 Isobaths of 10 Yearly Change in Static Water Levels from Pre Monsoon 1995 to 2005

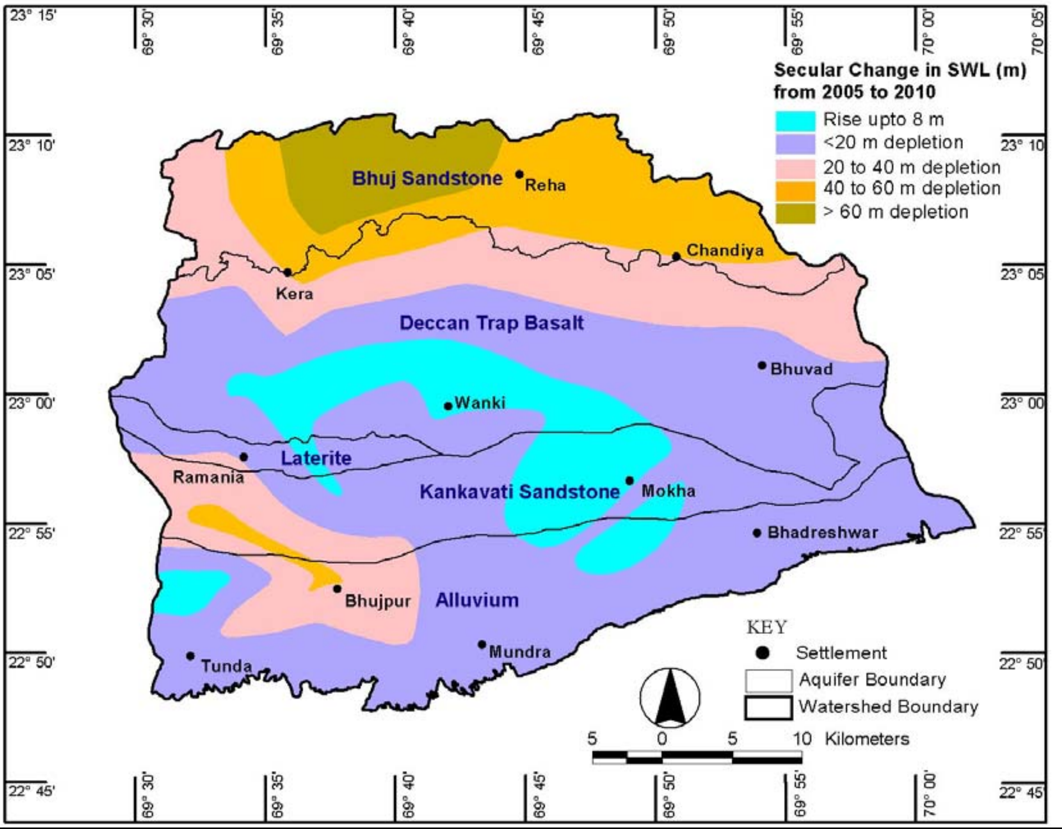


Fig. 5.20 Isobaths of 05 yearly Change in Static Water Levels from Pre Monsoon 2005 to 2010

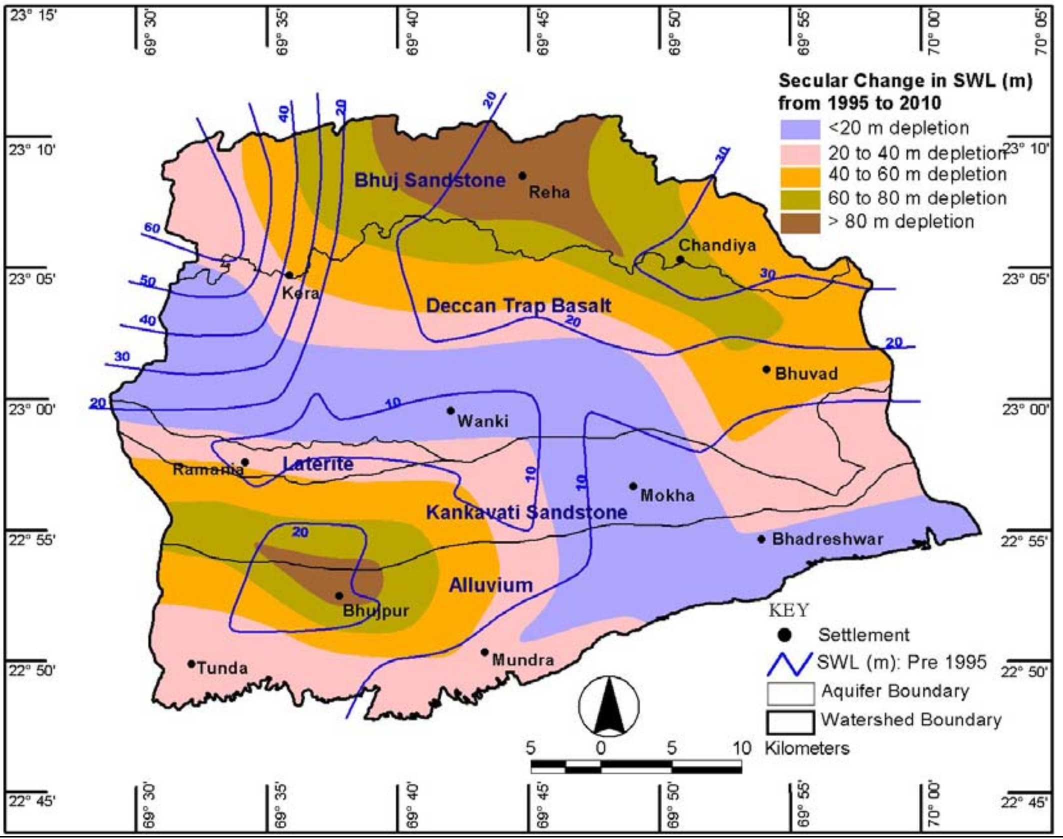


Fig 5.21 Isobaths of 15 Yearly Change in Static Water Levels from Pre Monsoon 1995 to 2010

REDUCED WATER LEVEL

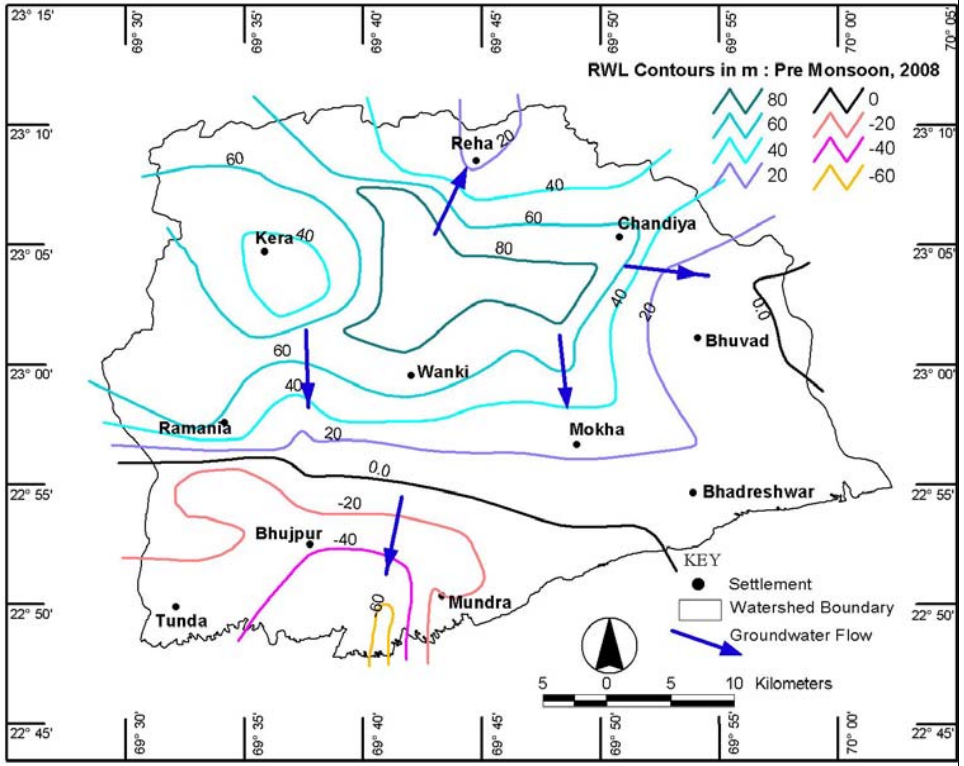
Groundwater been a part of hydrologic cycle is considered to be a dynamic resource. Therefore, its movement, movement direction and gradient show an explicit control of geological environment.

In order to study the behavior pattern of groundwater vis-à-vis the geological controls in the study area; the candidate based on altitude of observation wells has computed Reduced Water Level (RWL) i.e. height of SWL from Mean Sea Level and accordingly developed RWL contours for pre and post monsoon seasons for different years (Fig.5.22 to 26).

The emerged contour patterns display strong controls exercised by the factors of topography and lithology. The contour patterns have divulged more or less similar trends, irrespective of season and year. Reduced water levels in the watershed region range between + 80m to -80m. RWL are distributed in accordance with the altimetric trends in the study area i.e. northern upland regions positive levels and southern coastal plains having negative values. Similarly, a very strong control of lithology is observed. The Deccan Trap basalts occupy the elevated region and the elevation progressively decreases towards the northern watershed boundary (Bhuj Fm.) till it abuts the Katrol hill range. On the southern and eastern parts, the Deccan Trap sharply merges into Tertiary (Kankavati Fm.) rocks. This observed diverse nature of altimetric patterns have governed the groundwater movement directions as well as its gradient. The derived interpretations on RWL contours are summarized in Table 5.8.

Table 5.8 Reduced Water Level Contour Patterns and Characteristics

Sr. No.	Watershed Region	RWL Range (m)	Contour Pattern	Groundwater Movement Direction	Groundwater Gradient	Lithologic Domain	Remark
1	Northern part around Kera	80 to 20	Circular	Internal	1: 58 (East) & 1: >200	Deccan Trap & Bhuj Fm.	Minima (Subsurface Depression)
2	Northern Central part around Wanki	80 to 40	Broad Circular	Outward (Radial)	1: 200	Deccan Trap	Topographic Slope Controlled (Maxima)
3	East central part around Hatadi and Kuvai	60 to 20	Broad Circular	Easterly and Southerly	1: 140	Kankavati Fm.	Topographic Slope Controlled (Maxima)
4	West central part between Ramania, Bocha and Kandagara	60 to (-)20	Straight Linear (E-W)	Southerly	1:50	Deccan Trap & Kankavati Fm.	Topographic Slope Controlled
5	Southern coastal part around Bhujpar	00 to (-)80	Circular	Internal	1: 225 1: 125 (Bhujpur)	Alluvium	Minima (Subsurface Depression)



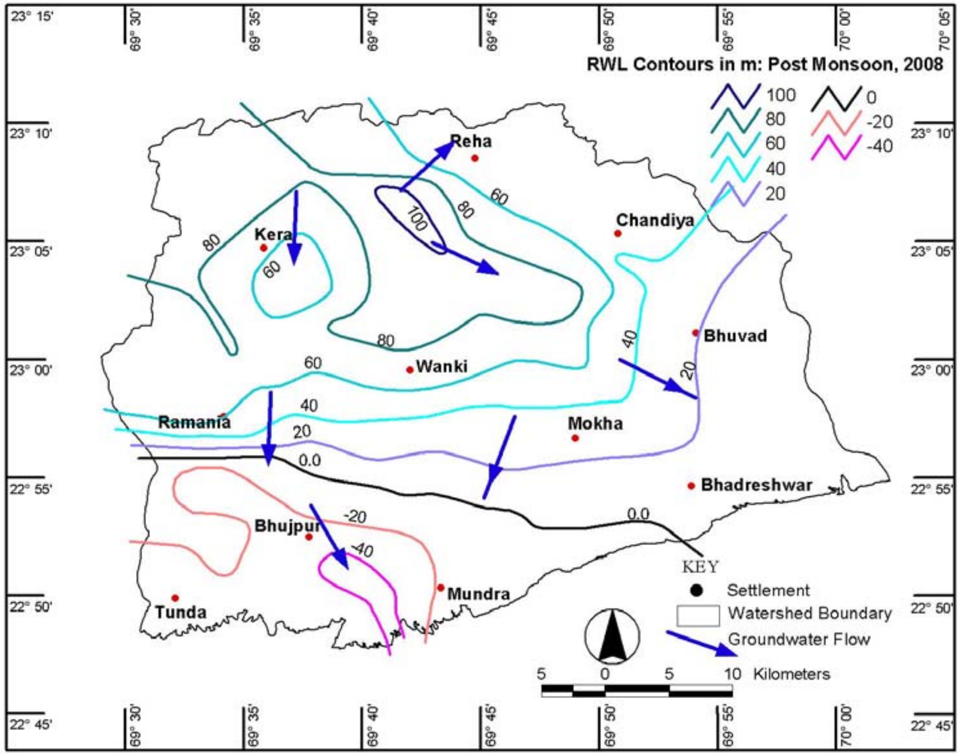


Fig. 5.22 RWL Contours of Watershed Region (Pre Monsoon, 2008)	**Fig. 5.23 RWL Contours of Watershed Region (Post Monsoon, 2008)**

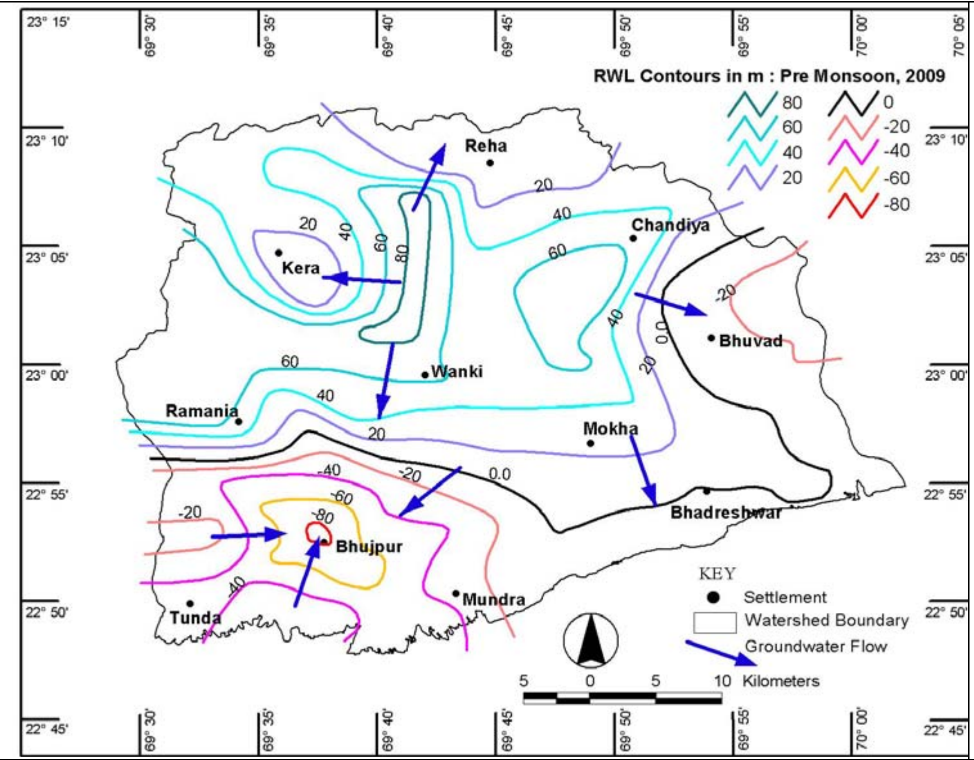


Fig. 5.24 RWL Contours of Watershed Region (Pre Monsoon, 2009)

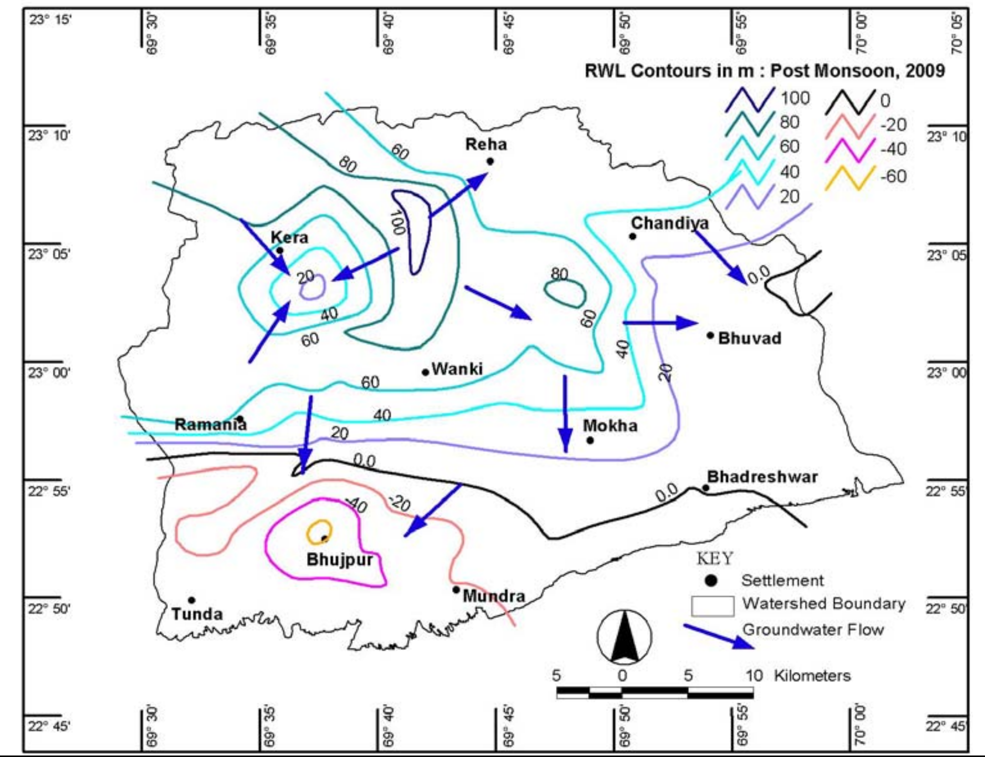


Fig. 5.25 RWL Contours of Watershed Region (Post Monsoon, 2009)

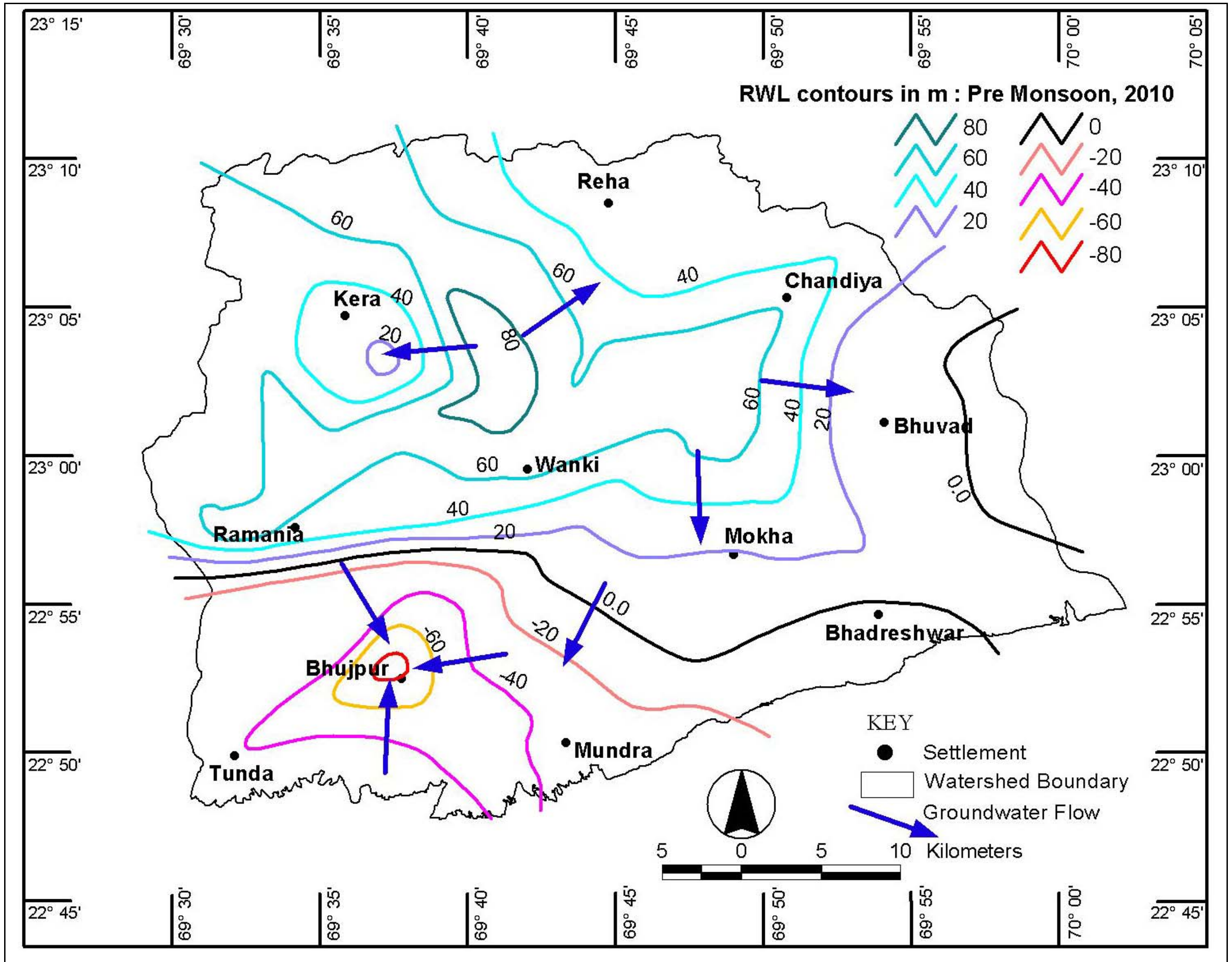


Fig. 5.26 RWL Contours of Watershed Region (Pre Monsoon, 2010)

Table 5.9 Reduced Water Levels of Observation Wells in Watershed Region

Sr. No.	Code	Village	RL m	Reduced Water Level (m)				
				Pre, 08	Post, 08	Pre, 09	Post, 09	Pre, 10
1	F1	Meghpar	145.0	50.0	----	36.5	----	53.0
2	F2	Sujapar	160.0	66.8	80.7	47.0	86.0	70.1
3	F3a	Sanosara	190.0	93.8	108.8	88.8	110.2	67.3
4	F3b	Reha nana	150.0	18.9	52.0	2.3	40.0	28.0
5	F4	Varali	140.0	48.5	48.5	33.3	49.0	24.1
6	F5	Wada	120.0	46.8	57.7	34.6	48.0	37.7
7	G1a	Chunadi	120.0	62.0	81.7	65.0	75.0	57.2
8	G1b	Tumbadi Moti	80.0	73.0	80.0	67.0	80.0	72.1
9	G2a	Kera	120.0	20.4	40.7	-2.0	10.0	12.8
10	G2b	Babiya	80.0	69.8	74.3	70.9	74.2	70.4
11	G3a	Kanajra	100.0	92.4	94.0	92.4	95.0	94.6
12	G3b	Bandra Nana	120.0	90.0	96.6	47.0	75.0	59.0
13	G4a	Bhalot	100.0	87.0	88.5	78.5	82.6	79.8
14	G4b	Vagura	80.0	71.0	74.0	70.6	72.5	71.5
15	G5	Mathada	80.0	12.9	34.3	-11.5	4.0	-15.4
16	G6	Mindiyana	75.0	-4.3	1.8	-34.0	-1.0	-8.0
17	H1a	Ramaniya	68.0	64.5	65.5	61.6	63.0	61.3
18	H1b	Depa	47.0	-39.9	-35.3	-40.2	-32.8	-38.4
19	H2a	Bocha	65.0	46.7	46.7	42.7	50.0	40.6
20	H2b	Gelda	55.0	9.3	11.7	-21.2	10.0	-20.1
21	H3a	Vanki	75.0	72.0	72.5	61.5	69.6	61.8
22	H3b	Kandagara Nana	57.0	32.6	32.6	28.6	29.6	18.0
23	H4a	Bagda	62.0	52.0	57.2	55.2	56.9	55.8
24	H4b	Mokha	37.0	24.8	----	----	----	----
25	H4c	Ratadiya	42.0	17.6	25.1	17.3	19.4	13.7
26	H5a	Vovar	35.0	26.0	30.0	30.4	30.5	26.8
27	H5b	Bharudiya	23.0	----	----	12.9	10.8	----
28	H6a	Hatadi	19.0	15.0	----	13.5	14.3	----
29	H6b	Kuvai	9.0	5.5	6.5	1.9	4.8	3.5
30	I1a	Khakhar Moti	30.0	-9.6	-15.7	-15.7	-11.7	-23.0
31	I1b	Shiracha	19.0	-27.5	-19.1	-44.3	-28.2	-49.2
32	I2a	Moti Bhujpur	29.0	-31.9	-24.2	-85.0	-68.4	-87.8
33	I2b	Pratappar	16.0	-47.5	-43.8	-73.1	-47.2	-58.1
34	I3a	Baraya	38.0	----	----	-23.0	-7.0	----
35	I3b	Mota kapaya	26.0	-28.9	-16.7	-41.1	-25.0	----
36	I3c	Mundra	13.0	-25.1	-14.3	-25.1	-18.2	-32.7
37	I4a	Ragha	20.0	-0.3	3.2	2.0	4.8	3.2
38	I4b	Goyersama	12.0	-18.5	-12.5	-12.4	-9.3	-24.6
39	I5	Bhadreshwar	10.0	3.0	2.4	-6.8	-6.0	-11.0
40	I6	Kukadasar	8.0	0.8	2.5	2.0	4.1	3.5
41	J1	Tunda	10.0	-40.5	-28.1	-54.5	-35.0	-38.8
42	J2	Navinal	9.0	-42.1	-29.1	-29.1	-26.1	-29.1
43	J3a	Dharub	6.0	-61.1	-42.0	-48.9	-36.0	-50.3
44	J3b	Mundra	5.0	-14.0	-13.3	-40.7	-31.6	-31.6

AQUIFER CHARACTERISTICS

Groundwater accessibility depends on hydraulic properties of an aquifer. The important hydraulic properties like porosity, permeability, transmissibility and storativity make geological materials to become and aquifer.

Aquifer based on composition of overlying and underlying geological materials is further divided into 03 categories viz;

1. *Unconfined:* Having a base of aquiclude / aquifuse and greatly influenced by atmospheric changes. Therefore show marked seasonal fluctuation in SWL.
2. *Semi- Confined (Leaky):* Having a cap of aquitard layer with aquiclude / aquifuse as base, partially influenced by atmospheric changes. Therefore characterized by low hydrostatic pressure.
3. *Confined:* Sandwitched between 02 aquiclude / aquifuse layers and remained un-effected from atmospheric changes. Therefore, characterized by high hydrostatic pressure. At times hydrostatic pressure reaches above the ground surface then it is termed as an artesian aquifer.

The candidate based on well inventory data and collected borehole litho-logs made an attempt to classify the prevailing aquifer systems in the study area. Candidate has also collected data on hydraulic characteristics of different aquifers (GWRDC, 1987, 2002 and Raju, 2003) and has summarized information accordingly (Table 5.10). Aquifer specific salient characteristics of the study area are discussed as under.

ALLUVIUM

Aquifers are predominantly distributed in the southern part of the study area. Owing to limited thickness and in spite of possessing better hydraulic characteristics, the aquifers do not provide a sustainable yield. The aquifers show average hydraulic conductivity 19.7 m/day, transmissivity 82.9 m^2/day and discharge 900 to 1100 LPM (GWRDC, 1987, 2002; and Raju, 2003).

LATERITE

The occurrence of Laterite aquifer in the study area is very limited as east –west narrow strip and are residual weathering product of basalt. Very few wells exist in lateritic aquifers. Groundwater from this aquifer is slightly brackish due to presence of salts in associated clays. Average values of hydraulic properties of laterite aquifer are hydraulic conductivity (155 m/day), transmissivity (535 m^2/day) and discharge (275 to 300 LPM).

BASALT

In the study area, Deccan Trap basalt is one of the most potential shallow unconfined aquifers restricted within the weathered and fractured zones of the rock. These basaltic aquifers display marked seasonal changes in water levels. Aquifers are characterized by transmissivity (190 m^2/day) and discharge (250 to 350 lpm). The flow of groundwater is governed by the intensity and extent of weathering and jointing.

SANDSTONE

In the study area, sandstone of Bhuj Fm. has high potential of groundwater. These aquifers are of considerable thickness and at places it is concealed under the basalts. Owing to basaltic cover and intercalated shale, aquifers are semi confined to unconfined in nature. The hydraulic characteristics show discharge (up to 2000 lpm), hydraulic conductivity (16.5 m/day), transmissivity (34 m^2/day).

The Kankavati Sandstone (Kankavati Fm.) of Tertiary age being poorly cemented and friable in nature is the most potential aquifer in the coastal region as well as the study area. The hydraulic characteristics of this aquifer show hydraulic conductivity (20 m/day), transmissivity (55 m^2/day) and discharge (up to 1000 lpm).

Based on studied aquifer characteristics and range of hydraulic properties; the candidate has developed an overall hydro-geological map of the study area (Fig. 5.27). Important parameters considered for this, apart form above mentioned one are aquifer specific geology, lineaments, elevation, pre & post monsoon' SWL and chemical content in terms of chloride, pH and total dissolved solids (TDS).

Table 5.10 Aquifer Properties of the Study Area

Parameters	Alluvium	Kankavati Sandstone	Laterite	Weathered Basalt	Bhuj Sandstone
Type	Unconfined	Semi confined	Unconfined	Unconfined	Semi confined
Characteristic	Sandy, mixture of clay, iron concretion	Red, Buff colored, coarse grain, Marine	Sorted in Iron concretion and variegated clays	Dark green, fractured, amygdaloidal volcanic rock	Pink, white colored fresh water rock
Exposed Area (Sq.Km.)	364	319	46	620	214
Important Locality	Coastal track in southern side of Deshalpar to Hatadi village	South to Ramaniya to Karagogha and Chandroda village	About 2.5 km. wide belt between Bocha and Ramaniya village	10-15 km wide belt from West - Dahisara, Nani Tumbadi to East- Sinugra, Mindiyana Villages	5-8 km wide belt from Meghpar, Kera in West to Ningal, Khedoi in East
Range of SWL Fluctuation (m)	2 to 10	(-) 6 to +20	3 to 8	2 to 10	10 to 35
Hydraulic Conductivity (K)	19.7 m/day	20.3 m/day	155 m/day	<10 m/day	16.6 m/day
Transmissivity (T)	82.9 m^2/day	55.3 m^2/day	535 m^2/day	190 m^2/day	34 m^2/day
Discharge (Q)	900-1100 lpm	800-1000 lpm	275-300 lpm	250-350 lpm	1700- 2000 lpm

Source: GWRDC, 1987, 2002; and Raju, 2003

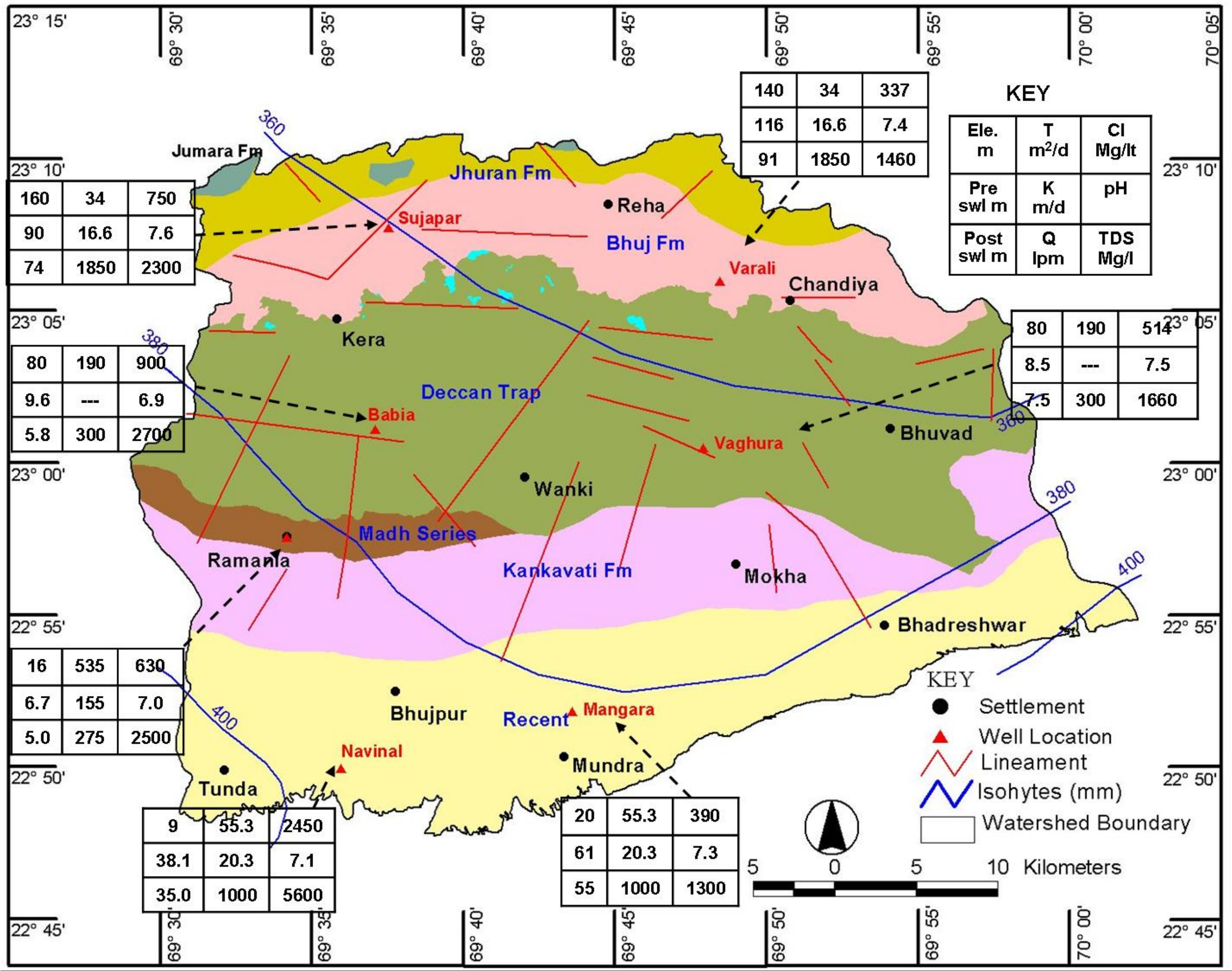


Fig. 5.27 Hydro-geological Map of the Study Area

Chapter - VI

HYDROMETEOROLOGY
&
WATER BALANCE

CHAPTER - VI

HYDRO METEOROLOGY AND WATER BALANCE

GENERAL BACKGROUND

On this planet earth, water is rated as second most important resource next to air. It generally refers to that part of fresh water which replenish annually and encompasses surface water, soil water and underground water. Atmospheric precipitation (rainfall, snowfall, and other forms) constitutes the only source of all fresh water on the earth.

The science of hydrometeorology is an important link between increasing use of meteorology to the problems of hydrology. In the present context the candidate in her study, restricted the scope of meteorology limited to the processes of rainfall and evaporation. Hydrologic cycle, a function of meteorological processes is characterized by the intensity of various input and output parameters that are essential in developing basic understanding on qualitative and quantitative assessment of areas resources, particularly the land and water resources.

An assessment of water budget in a true sense, is accounting of all the water that flows into and out of an area under natural process and by human being. Developmental activities in any region have a potential to alter the natural supply of water and can severely impact an area, especially surface and groundwater resources. Therefore, to determine the magnitude of these impacts on water resource and to evaluate possible mitigation actions; the candidate has carried out water budgeting of the study area and has subsequently incorporated the outcomes in proposed action plan for necessary remediations and management actions, discussed elsewhere.

Groundwater is a renewable natural resource and can be categorized as (01) dynamic and annually replenishable at shallow depths; and (02) Static, which accumulate over a period of time at greater depths (Raju, 1998). Recharge is a process by which artificial or natural increment takes place to the resource against resource utilization and natural outflow. For quantifying the increment and/or decrement to the groundwater resource, it is essential to develop detail understanding on principal resources of natural recharge, hydro-geological framework, aquifer conditions and the factors governing the recharge to and discharge from the groundwater regime.

As it has already been elucidated that, the groundwater in the study area occurs in unconsolidated sediments (alluvium), semi-consolidated sediments (laterites - shallow depths, and sandstone at deeper depths) and consolidated sediments (basalt lava flows). The quantification of groundwater in study area is relatively difficult task due to diverse hydro-geological conditions. Some important factors that offer limitations in water balance study are listed below.

- Erratic rainfall pattern, wide variation in its intensity and unequal distribution in different micro watersheds cause limitations in computation of infiltration rate.

- Variation in geo-hydrological characteristics viz. hydraulic conductivity, porosity, specific yield, etc. of different aquifers that limits uniform considerations for entire area.
- Wide variation in weathering, extent and its products vis-à-vis impact on hydro-geological characteristics of particular aquifer.
- Lack of information on aquifer boundary conditions and its lateral extent, resulting into segregation issue between different catchments of the study area.
- Diversity in seasonal and area specific vegetative cover creating difficulties in computation of various losses like evapo-transpiration and overland flow.

WATER BALANCE STUDY

There exists two main approaches for water budgeting of any area i.e. (01) water balance approach and (02) water table fluctuation / specific yield approach. Both the approaches are useful tool for estimating groundwater resource of any area (Charlu & Dutt, 1982).

WATER BALANCE APPROACH

Water balance technique is one of the main subjects in hydrology that deals in identifying solution for important theoretical and practical hydrological problems. Based on the water balance approach it is possible to make a quantitative assessment of water resources and its change under the influence of anthropogenic activities. However, as far as water balance approach is concern, many scientists have proposed various theoretical as well as empirical equations for resource estimation. In general it is an established fact that there exists a balance between the quantity of water supplied to the basin, and the quantity of water stored in a basin against quantity of water outflow from the basin over a specific period. In general for balance, all in-flowing and out-flowing parameters are considered. Hence, simplified equation for water balance can be expressed as-

Change in Storage (±) = (Inflow into basin - Outflow from basin).

Author has reviewed prevailing standard water balance approaches suggested by different workers. The candidate in proceeding paragraphs has reviewed 03 main approaches in vogue viz; (i) Schist and Walton Approach; (ii) UNESCO Approach; and (iii) Michigan Agriculture University Approach

However, Water Balance Approach as suggested by Schicht and Walton, (1996) has been adopted for the presented water balance study of the area due to its versatility and accounting numerous parameters.

Schicht and Walton, (1996) have described groundwater balance as volume of water that gained by an aquifer as a part of hydrological cycle. Generally in hydrologic cycle rainfall distribution takes place when it reaches to surface. This involves many processes such as some water reaches to the land surface, some rainwater percolates and reaches to groundwater regime, some water return to atmosphere through evapo-transpiration; some quantity traps into soil as soil moisture; some part is stored into water impounding reservoirs; whereas remaining part flow out from the catchment as runoff and as sub-surface flow. To estimate water balance for any area, Schicht and Walton (1996) have proposed following equation (1)

$$Rr + Re + Ri + I + Si = Se + O + Et + Dp + \Delta S \qquad (1)$$

Where,

Rr = Recharge due to rainfall

Re = Recharge due to canal seepage

Ri = Recharge due to return flow of applied irrigation waters

I = Inflow from areas outside the basin

Si = Recharge due to inflow seepage from rivers, streams, reservoirs, lakes and ponds etc.

Se = Groundwater flow due to effluent seepage

O = Outflow to the areas outside basin

Et = Evapo-transpiration losses

Dp = Groundwater draft (pumpage)

ΔS = Change in groundwater storage.

UNESCO, (1970) has interpreted that water balance equation for any basin or water body indicates the relative values of inflow, outflow and change in water storage for the area or body. In general, the inflow part of the water balance equation comprises precipitation (P) as rainfall actually received at the ground surface, and surface and subsurface water inflow into the basin or water body from outside (QS1 and QU1). The outflow part of the equation includes evaporation from the surface of the water body (E) and surface and subsurface outflow from the basin or water body (Qso and Quo).

When the inflow exceeds the outflow, it means the total water storage in the body increases; an inflow less than the outflow that result in decreased storage (Δs). All the water-balance components are subject to errors of measurement or estimation, and the water-balance equation should therefore include a divergence term (η). Consequently the water balance for any water body and any time interval in its general form may be represented by the following equation: (2)

$$P + Q_{SI} + Q_{U1} - E - Q_{so} - Q_{UO} - \Delta s - \eta = 0 \qquad (2)$$

Land and Water Management Division of Michigan Agriculture University (2010) has also suggested general guidelines for calculating a water budget and an equation. According to this approach water budget describes the various components of the hydrologic cycle. The water budget includes Precipitation (P); Evaporation (E); Evapo-transpiration (ET); Surface runoff (SRO); Groundwater flow (GF):

$$\Delta S = P - E - ET \pm SRO \pm GF \qquad (3)$$

Where, ΔS is the change in storage. For example, if the expression on the right-hand side of the equation is positive, ground storage will increase and the water level in the area of interest will rise. A positive change in storage is often termed a surplus, while a decrease in storage is termed a deficit.

WATER BALANCE STUDY USING SCHICHT AND WALTON APPROACH

Input Parameters

In the study area, rainfall is major input source and in the process of hydrological cycle distribution of water takes place in the form of groundwater recharge through various processes such as direct recharge through infiltration through soil, seepage from canal, return flow of applied irrigation water. It is also important to clarify that inflow parameter i.e. groundwater flow due to affluent seepage (*Si*) has not been considered for recharge estimates since the streams in the study area are not perennial and river courses remain dry during most of the time. Whereas occurrence of groundwater in study area is restricted within watershed basin area and therefore, inflow from outside the basin area (I) may not contribute in groundwater recharge to the study area. However, external surface water supply to the basin area especially, Narmada canal water supply has been considered. Keeping this in mind remaining input parameters have been computed for groundwater recharge estimation.

Recharge Due to Rainfall (Rr): Rainfall, the primary source of water that occurs as a result of condensation of atmospheric moisture, is governed by the science of meteorology and, therefore, is considered to be one of the most important meteorological elements. Similarly, the amount and distribution of rainwater on and beneath the earth's surface is governed by the science of hydrology and geology. The author has estimated average annual rainfall of the study area based on last hundred year's data collected from Indian Meteorology Department (IMD). The average annual rainfall of the taluka is 440 mm/year (Annexure 2.1). It is important to mention that there has been a perceptible increase in average annual rainfall since last one decade. The average annual rainfall for the last five years is more than 500 mm while it is 464 mm in last ten years. Therefore, author has considered 440 mm rainfall as an input parameter to estimate recharge due to rainfall. The recharge due to rainfall is also dependent on the nature and composition of land surface and sub-stratum. The lower middle and southern parts of study area are characterized by sandy clayey type of alluvium where as upper middle to upper part is characterized as soft and hard rock areas. According to norms as proposed by ARDC (1982) for sandy clay alluvial areas

(20%) and for hard rock areas (10 %) of normal rainfall can be considered as recharge due to rainfall. Therefore, recharge to the groundwater due to rainfall in the study area stand at 89.44 MCM (Table 6.1).

Table 6.1 Estimated Groundwater Recharge Due to Rainfall (Rr) in Study Area

Area Type	Total Area (Sq km)	Average Annual Rainfall (m)	Total Rainfall Received (MCM)	Recharge (%)	Total Recharge (Rr) (MCM)
Sandy clay type of alluvial areas	363.9	0.44	160.1	20	32.02
Soft and hard rock areas	1305.0	0.44	574.2	10	57.42
Total					**89.44**

<u>Recharge Due to Canal Seepage (Re):</u> Water flow from irrigation canal in-filter some water to groundwater system is considered as one of the inputs to groundwater recharge. There are eight irrigation structures in study area (Table 6.2) having canal provision. Total length of the canal of all irrigation structures is about 56.38 km. Further considering average width of canal as 5 m. and schemes being minor irrigation type, the availability of irrigation supply is only during winter season that to for 60 days/yr only. As per ARDC, (1982) norms normal soil @ 15 to 20 ham/day/sq km for wetted area as seepage from canal. Considering average of 17.5 ham/day/sqkm as seepage from total length of canal, total groundwater recharge due to canal seepage (Re) stand at 2.96 MCM/year (Table 6.2).

Table 6.2 Groundwater Recharge due to Irrigation Schemes' Canal Seepage in Study Area

Sr. No.	Irrigation Scheme	Canal Length (km)	Total Area (km^2)	Seepage/Day @ 0.175 MCM/day/ km^2	Average Irrigation (Days/year)	Recharge From Canal Seepage (Re) (MCM)
1	Khengarsagar	16.41	0.082	0.014	60	0.86
2	Serai	5.63	0.028	0.005	60	0.30
3	Chhasra	8.05	0.040	0.007	60	0.42
4	Phot	1.64	0.008	0.001	60	0.09
5	Kanjhara	4.83	0.024	0.004	60	0.25
6	Ratdia	1.61	0.008	0.001	60	0.08
7	Gajod	15.92	0.080	0.014	60	0.84
8	Jamora	2.29	0.011	0.002	60	0.12
Total		**56.38**	**0.282**	**0.049**	**60**	**2.96**

Source: GoG, Irrigation Department, 2005

Recharge Due to Return Flow of Applied Irrigation Waters (Ri): The agriculture land in study area is under irrigation through various sources such as wells and tube wells as well as government canals. Total agriculture area under irrigation is about 302.10 sq km. (Table 6.3). Return Irrigation Seepage (RIS) has been calculated by adopting ARDC, (1982) norms which is based on irrigation source viz, (i) 35 % of total water delivered at irrigation field from the gravity canal and (ii) 30 % of total water delivered at irrigation filed from wells and bore wells. Accordingly total groundwater recharge due to return irrigation seepage stand at 101.39 MCM (Table 6.3).

Table 6.3 Groundwater Recharge (Ri) Estimation from Return Irrigation Seepage (RIS)

Irrigation Source	Total Water Delivered (MCM)	Rate of RIS (%)	Total Ri (MCM)
Gravity Canal Irrigation	55.07	35	19.27
Irrigation through well/ bore wells	273.71	30	82.11
Total	**322.76**	**----**	**101.39**

Recharge Due to Seepage from Surface Water Storage (Si): According to land cover analysis of satellite image, water bodies in the study area occupy about 25.70 sq km area. The surface storage includes irrigation dam, check dams, storage tanks in villages and in pasture land. As per the ARDC (1982) norms, groundwater recharge (Si) is about 44 to 60 cm per year over the total water spread. Looking to sandy porous substratum, the candidate has adopted an average 55 cm/year as recharge over the total water spread. The computed recharge from surface storage (Si) is-

Recharge (Si) = 0.55 m x 2,57,00,000, m^2 i.e. **14.14 MCM**

Therefore, total In-flow in to basin through recharge is -

Rr + Re + Ri + Si = 89.44 + 02.96 + 101.39 + 14.14 = **207.93 MCM**

Output parameters

Overland Flow (O)/ Surface Runoff: The term overland flow (runoff) means the draining or flowing out of precipitation from a catchment area through a surface channel after filling all surface and sub surface losses. (Dubayah, et al, 1997) Runoff contributing areas including river basins primarily are the result of two processes which produce overland flow. The first process is infiltration-excess overland flow, which occurs when precipitation intensity exceeds the rate of water infiltration into the soil. This process may be dominant in basins where the land surface has been disturbed (for example, plowed cropland) or where natural vegetation is sparse. The second process is saturation-excess overland flow, which occurs when precipitation falls on temporarily or permanently saturated land-surface areas that have developed from "outcrops" of the water table at the land surface (Hornberger et al, 1998).

The spatial extent and pattern of runoff-contributing areas are affected by climate, soil, and terrain characteristics. Contributing areas of infiltration-excess overland flow are normally determined by the interaction of rainfall intensity and soil permeability. The least-permeable soils in a basin are the most likely to contribute infiltration-excess overland flow. As rainfall intensity increases, areas with more moderate permeability also may contribute overland flow (Hornberger et al, 1998).

Land use system of the area is another important factor that affects runoff within a basin, both physically and chemically. Physically, such characteristics as vegetative cover, soil permeability, and the amount and connectivity of impervious surfaces combine to determine the relative magnitudes of runoff for various types of land use. For example, cropland and urban land uses generate higher runoff volumes than grassland and forest. Chemically, land use is an important determinant of the sources, types, and amounts of contaminants that affect the water quality of runoff.

Runoff occurs when precipitation falls on to the land surface and moves toward surface waters. Runoff is affected by a wide variety of factors (Taylor and Schwatz, 1952), such as:

- Soil type and depth
- The presence or absence of vegetation
- The presence or absence of impervious surfaces such as pavement or buildings
- Basin geometry, drainage pattern, expanse of flood plain governing Bank Storage, Depression storage and blind drainage runoff (Horton, 1937)

- The intensity of the precipitation
- The form of the precipitation (such as snow or rain)
- The amount of moisture in the soil just before the precipitation, and

Because of these factors, runoff from two similar storms in the same watershed and season can be very different. Therefore, method of runoff calculation depends on its use in study, such as runoff calculations for storm water and flood management are generated for specific storms in a specific watershed attend to stream flows over very short time periods (such as by the hour). While runoff calculations for water supply purposes usually focus on more long-term (daily, weekly, monthly or annual) conditions in larger watersheds.

In the present case the candidate has estimated run off keeping in to mind groundwater management aspects in study area, where the water demand has increased manifold due to on-going industrialization. Very limited attempts have been made to undertake such estimation of runoff in the study area. Jadeja, (2005) has attempted runoff estimation in Pachchham region of Kachchh district by using theoretical approaches like Barlow's Method (1912), Lacey's Method (1939), Strange's Table (1928), Infiltration Method (1940) and CW & PC Curve Method. In case of Mundra region (study area), author has made an attempt to collect runoff data from the Stream Gauge Division of State Irrigation Department. The record of stream gauge stations of last several years show surface run off from different rivers has remained below measurement points. Therefore, author has adopted empirical approach of Barlow (1912) to compute the runoff using following equation- $R = kP$

Where, R= Runoff; P= Precipitation; k= Percentage Coefficient

Barlow has also classified watersheds into five categories as per land use characteristics (Table 6.4) and has suggested values of co-efficients for each category. In addition to catchment characteristics Barlow has also classified rainfall as light (<25 mm/day), medium (25-75 mm/day) and continuous down pour (> 75 mm/day). Using these two considerations, values of rainfall co-efficients have been derived empirically for each catchment types and for different rainfall nature.

Table 6.4 Estimation of Percentage Coefficient (*k*) for Surface Runoff Computation (After Barlow, 1972)

Nature of Rainfall	Computed Rainfall Coefficients				
	Catchment Class				
	A	B	C	D	E
Light rain	7	12	16	38	36
Medium Rainfall	10	15	20	35	45
Continuous down pour	15	18	32	60	81
A: flat cultivated and black cotton soil, B: flat, partly cultivated soil, C: average catchment, D: hills and plains with little cultivation, E: hilly and steep regions with hardly any cultivation					

Looking to the rainfall pattern, various catchments of the study area can be categorized in to C, D and E classes. As the rainfall of the Mundra region is characterized as low but high intensity rainfall, it falls in continuous down pour category. Rainfall coefficients of adopted categories are - 32 % for C type, 60 % for D type, and 81 % for E type, while 57.66% for catchments falls under mix category of C, D and E has been considered. Thus, the estimated run-off for study area using Barlow's approach stand at 423.40 MCM (Table 6.5).

Table 6.5 Catchment Wise Estimated Surface Runoff in the Study Area

Sr. No.	Name of the Catchment	Area Sq. km.	Total Rainfall (MCM) @ 0.44 m	Estimated Runoff (MCM) @ 57.66%
1	Mithi Nadi	311.55	137.08	79.04
2	Lerakh Nadi	165.64	72.88	42.02
3	Phot Nadi	244.40	107.54	62.01
4	Khari Nadi	154.24	67.86	39.13
5	Bhukhi Nadi	255.55	112.44	64.83
6	Nagvanti Nadi	324.62	142.83	82.36
7	Luni Nadi	143.18	63.00	36.33
8	Chhela Nadi	69.72	30.67	17.69
Total		**1668.89**	**734.31**	**423.41**

Evapo-transpiration (Et): It is the process by which a substance changes from the liquid state to the vapor state. Evaporation of surface water from the oceans, lakes, rivers, etc. by the heat of the sun is the cause of water vapor in the atmosphere. The rate of evaporation is measured by the Pan-measurement Method or Weather Pan. Evaporation is commonly used to determine water losses from lakes, ponds, and reservoirs as well as in assessing the water requirements of crops. The rate at which evaporation takes place greatly depends upon the meteorological elements of temperature, radiation, humidity, vapor pressure, sunshine hours, cloud cover, and wind velocity (Michael, 1983). These meteorological elements are of great value in estimating evaporation indirectly for hydrologic studies where direct measurement of evaporation is not possible.

Evapo-transpiration (Et) is a combination of two terms – evaporation and transpiration. Evaporation involves the transformation of surface water to atmospheric water. Transpiration (consumptive use) occurs when water in plants move from shallow soils to the root system to the leaves, transporting nutrients and energy, and then evaporates from the leaves. The two terms are usually considered together in water budget calculations. Both evaporation and transpiration tend to be higher during periods of hot weather, low humidity and high wind (Linsley et al, 1958). The evapo-transpiration can be computed as Potential Evapo-transpiration (PET) and Actual Evapo-transpiration (AET).

PET is the maximum rate at which plants transpire when there is unlimited supply of water and favorable conditions of growth, and give the maximum rate of evapo-transpiration, which is not necessarily the true input for the water balance equation; Whereas AET is dependent on the water supply, vegetation (type of agriculture crops and forestry) and soils. AET is calculated by applying respective crop factors 'K' (WMD, 1971) in the agriculture land, forest etc. in relation to their percentage area coverage, and in any case AET has a maximum value equal to PET (Michael, 1983).

The landuse pattern based on vegetation class is most important aspects to estimate evapo-transpiration. The vegetation of study area can be categorized into two categories as agricultural and non agricultural vegetations. As per landuse pattern of study area, dominant corps of the study area are millet, sorghum, cereals in rainfed agriculture whereas wheat, cotton, groundnut in irrigated areas. In addition to field crops, Mundra area is also popular for horticulture corps. In case of evpo-transpiration estimation, this area is considered with forest area since it has large tree plantation. Jadeja, (2005) has attempted water balance studies for Pachchham Island and attempted through various approaches of estimation of evapo-transpiration like

Hergreaves Pan Evaporation (1956), Blaney-Criddle equation (1950), Christiansen (1968) and Thornthwaite (1948) approach. After comparing all results, Jadeja (2005) recommended Pan Evaporation Method suits best for the area. Considering previous experiences author has also adopted Pan Evaporation method for computing PET and AET for study area.

Evaporation pan provide a measurement of evaporative water loss, which is the integrated effect of radiation, wind, temperature and humidity from a specific open water surface. To relate pan evaporation (E pan) with reference to crop evapo-transpiration (Eto), taking into account climate and pan environment practically derived coefficients (Kp) are given. In this method crop evapo-transpiration (Eto) has been obtained by using following equation.

$$Eto = k \times Epan$$

Where,

Epan = pan evaporation in mm/day and represents the mean daily value of the period considered;

k= consumptive use coefficient

Hargreaves, (1956) proposed monthly consumptive use coefficient k for various crop groups, which when multiplied with monthly pan evaporation values provide PET. The value of consumptive use coefficient (*k*) for any crop depends on plants characteristics, phenology stage, environment and geographical location. Consumptive use value is low during the early stage of crop growth and tends to increase as the plant approach maturity (WMD, 1971). To estimate evapo-transpiration of study area author has utilized the monthly pan evaporation data recorded at Bhuj Meteorological Station (Table 6.6).

To estimate overall volume of water loss through transpiration, crop wise PET has been multiplied with the respective crop and vegetation areas. This estimated figure stands at 1146.82 MCM. Whereas evaporation loss has been estimated by multiplying water column (i.e. 2.25 m/year) with the total submergence area covered by water bodies i.e. 25.7 sq.km. The estimated loss by evaporation in the study area is about 57.83 MCM. Therefore, total loss due to evaporation and transpiration (AET) is 1204.65 MCM.

Table 6.6 Estimated Values of PET and AET for Study Area (Hergreaves Pan Evaporation Method, 1956)

MONTH	**Crop**	**Wheat**		**Millet**		**Maize**		**Cotton**		**Castor**		**Groundnut**		**Seaseme**		**Sorghum**		**Horticulture/ Forest**		**Grass**	
	Area km^2	**66**		**92**		**136**		**108**		**130**		**53**		**92**		**159**		**169**		**309**	
	k	**0.61**		**0.7**		**0.82**		**0.8**		**0.85**		**0.7**		**0.67**		**0.75**		**0.5**		**0.85**	
	Pan Evapo-ration cm	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**	**PET cm**	**AET MCM**
Jan	11.4	7.0	4.6					9.1	9.8	9.7	12.6							5.7	9.6	9.7	29.9
Feb	12.7	7.7	5.1					10.2	11.0	10.8	14.0							6.4	10.7	10.8	33.4
Mar	19.3											13.5	7.2					9.7	16.3		
Apr	20.6											14.4	7.6					10.3	17.4		
May	25.4											17.8	9.4					12.7	21.5		
Jun	26.7											18.7	9.9					13.4	22.6		
Jul	22.9			16.0	14.7	18.8	25.5	18.3	19.8	19.5	25.3			15.3	14.1	17.2	27.3	11.5	19.4	19.5	60.1
Aug	20.0			14.0	12.9	16.4	22.3	16.0	17.3	17.0	22.1			13.4	12.3	15.0	23.9	10.0	16.9	17.0	52.5
Sept	23.9			16.7	15.4	19.6	26.7	19.1	20.6	20.3	26.4			16.0	14.7	17.9	28.5	12.0	20.2	20.3	62.8
Oct	15.2			10.6	9.8	12.5	17.0	12.2	13.1	12.9	16.8			10.2	9.4	11.4	18.1	7.6	12.8	12.9	39.9
Nov	15.2	9.3	6.1					12.2	13.1	12.9	16.8							7.6	12.8	12.9	39.9
Dec	11.4	7.0	4.6					9.1	9.8	9.7	12.6							5.7	9.6	9.7	29.9
Total		**30.9**	**20.4**	**57.4**	**52.8**	**67.2**	**91.4**	**106.2**	**114.7**	**112.8**	**146.6**	**64.4**	**34.1**	**54.9**	**50.5**	**61.5**	**97.8**	**112.4**	**189.9**	**112.8**	**348.5**
Total AET (MCM)																				**1146.82**	
Total Evaporation from Surface water spread (25.7 sq.km. @ 2.25 m /year) in MCM																				**57.83**	
Total Evapo-Transpiration (MCM)																				**1204.65**	

<u>Groundwater Draft (Dp):</u> There are about 11,703 wells and bore wells in study area where 7,457 are operational. Out of total operational structures about 43 wells and 82 bore wells are in drinking and domestic water use, whereas 1132 wells and 6,200 bore wells are in use for irrigation purpose. Open wells are operated with diesel pumps and having low potential of discharge as compared to submersible pump operated bore wells. Based on information gathered from farmers during well inventory, an average pumping duration for open wells is about 2 to 2.5 hour/day. While average pumping hours for deep bore wells is about 8 hour/day, as electricity availability is only for 8 hours/day. Average discharge from wells and bore wells has been based on pumping machinery capacity and has been computed in field using discharge table. Detailed quantification on groundwater extraction in study area through different modes is given in Table 6.7.

Table 6.7 Estimated Groundwater Draft (Dp) in Study Area

Water Structure	Use	Total Nos	Pumping (hr/day)	Total Days	Average Discharge (LPM)	Groundwater Draft (MCM)
Dug Wells	Domestic	43	2.5	365	360	0.85
	Irrigation	1132	2	120	360	5.87
Bore wells	Domestic	82	8	365	750	10.77
	Irrigation	6200	8	120	750	267.84
Total						**285.33**

Note: For domestic wells, draft is calculated for entire year and for irrigation wells it has been calculated for one season (i.e. Rabi season) of 120 days.

<u>Change in Groundwater Storage (ΔS):</u> Annual Change in Groundwater storage in the study area has been computed based on changes in groundwater levels from post monsoon (2008) to pre monsoon (2009) and post monsoon (2009) to pre monsoon (2010). Further, change in groundwater storage has been calculated for each aquifer type, based on specific yield and aquifer's aerial expanse, using Water Table Fluctuation/ Specific Yield Approach.

$$R = A \times Sy \times (h_1\text{-}h_2)$$

R = Recharge due to rainfall

A = Aquifer area under evaluation

Sy = Specific yield of the aquifer

h_1 = Post monsoon groundwater level

h_2 = Pre monsoon groundwater level

The estimated average annual change in groundwater storage in study area in different aquifers is given in Table 6.8.

Table 6.8 Change in Groundwater Storage in Study Area

Aquifer	Area (Sq. km.)	Specific Yield (%)	Post 08 to Pre 09		Post 09 to Pre 10		Average Change (ΔS) (MCM)
			h1-h2 (m)	Change (MCM)	h1-h2 (m)	Change (MCM)	
Laterite	8.00	7.03	4.00	2.25	5.50	3.09	2.67
Basalt	94.67	2.50	4.85	11.48	3.20	7.57	9.53
Alluvium	363.85	6.23	3.45	78.20	2.05	46.47	62.34
Sandstone	414.70	9.50	19.80	780.05	12.20	480.64	630.34
Net Change in Groundwater Storage							**704.88**

The computed change in groundwater storage point to this very fact that, the potential aquifer like sandstone is subjected to highest level of change (~ 16 m) attributed to increase in groundwater demand due to on-going industrialization in the study area.

Putting together all inflow and out-flow parameters in water balance equation (Table 6.9), the water balance in the study area stand negative i.e. -1676.00 MCM.

Table 6.9 Estimated Water Balance Parameters

Net Study Area (A)= 1668 sq km and Average Annual Rainfall (R) = 0.440 m			
Sr. No.	**Parameter**	**Inflow (MCM)**	**Outflow (MCM)**
1	Rainfall (R x A)	734.31	----
2	Recharge from Rainfall (*Rr*)	89.44	----
3	Recharge from Canal Seepage *(Re)*	2.96	----
4	Recharge from Return Irrigation Seepage *(Ri)*	101.39	----
5	Recharge from Surface Storage (*Si*)	14.14	----
6	Surface Runoff (*O*)	----	423.40
7	Evapo-transpiration (*Et*)	----	1204.65
8	Groundwater Draft (*Dp*)	----	285.33
9	Change in Groundwater Storage *(ΔS)*	----	704.88
Total		**942.2**	**2618.30**
Balance: (Inflow – Outflow) = (942.2 -2618.30) = -1676.00 Say (1676 MCM)			

This derived negative groundwater balance scenario invite a very well defined framework of actions to explore and implement techniques for replenishing the dwindling groundwater resource on sustainable basis.

A framework of action and groundwater resource management plan is discussed in proceeding chapter.

Chapter - VII

CHEMICAL HYDROGEOLOGY

CHEMICAL HYDROGEOLOGY

"Quality of Groundwater is as Important as its Quantity"

INTRODUCTION

A Hydro-geological system can be considered as an energy system in which hydro-geologists identify controls on the sources, sinks and transformation of energy in the water. This energy system consists of potential and kinetic energy of groundwater flow, thermal energy, and chemical energy (Back et al, 1993).

Chemical hydrogeology is the study of chemical energy of the hydrologic system and can be defined as a study of geologic and hydrologic controls on the chemical characteristics of groundwater. The groundwater quality is one of several aspects with in chemical hydrogeology.

The chemical content in groundwater is a function of numerable factors and can be explained through hydro-geochemical cycle (Fig. 7.1). Hydro-geochemical cycle exercise major control on movement of gases and solutes and also facilitates to evaluate influences of present and past climatic, geologic, hydrologic, biologic and anthropogenic factors that effect the chemistry of groundwater (Back et al, 1993). These factors include-

The chemistry of in-filtering water is governed by air, temperature, frequency amount and duration of precipitation, mineralogy, vegetation and soil cover and rate of soil gas generation. Other important factors are mineralogy and thickness of geologic formation and potentiometric head distribution which is controlled by hydraulic characteristics of aquifer, topographic attributes and numerous chemical reactions (Back et al, 1993).

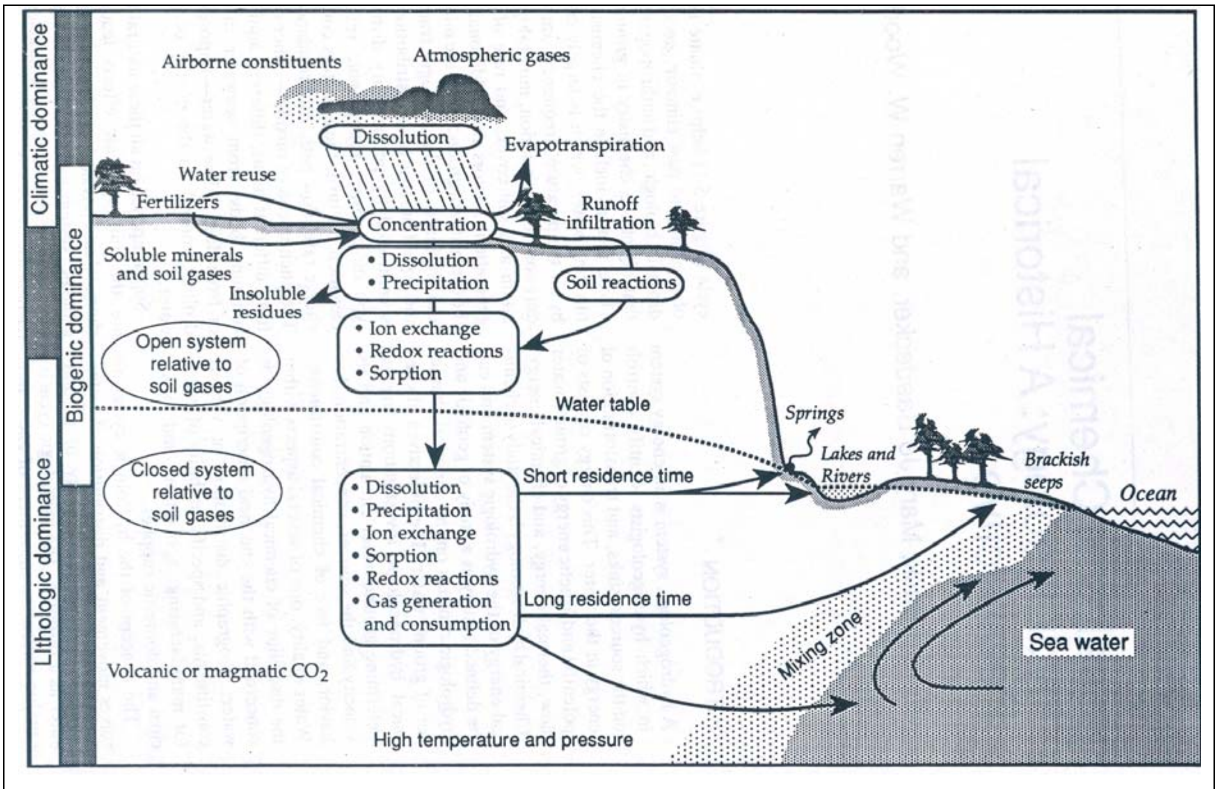


Fig. 7.1 Hydro-geochemical Cycle (After Back et al. 1993)

Further in an aquifer system, the vadose zone has a significant role in providing conducive environment for attenuation of natural and anthropogenic contaminants. Important active roles played by vadose zone are—

1. To weaken trace elements and other inorganic chemicals received through precipitation, sorption, cation exchange;
2. Sorption and biodegradation of organic compounds; and
3. Interception, sorption and delimination of pathogens (Hem, 1991 & Alley, 1993).

It has already been eluded that lithologically the study area is predominated by the sedimentary rocks and the igneous basaltic lava flows are just confined to central part of the area. Therefore, the chemical content in groundwater has more influence of sedimentary terrain. The occurrence of groundwater in basaltic lava flows is mainly associated with the weathered and fractured zones, and movement of groundwater is facilitated through hydro-fractures. Therefore, due to relative insolubility of the rock composition and flushing effect, the dissolved ionic content invariably moves to lower reaches of the study area which is characterized by sedimentary sequences. Hence, overall quality of groundwater in basaltic aquifers is excellent except the issue of fluoride as a natural contaminant.

SOURCES OF GROUNDWATER SALINITY

All groundwaters are characterized by dissolved salts. In natural groundwater, the reported salt content ranges from < 25 mg/l in quartzite spring to more than 3,00,000 mg/l in brines (Houlihan & Lucia, 1999). The type of salts and their concentration is the manifestation of prevailing environment, groundwater movement and its source. Higher concentration of salts in groundwater system is attributed to its exposure to soluble minerals in rock formations which are normally derived from solution of rock materials.

Also, the salinity in groundwater tends to vary with specific surface area of aquifer, solubility of minerals and contact duration; salinity values tend to be highest where movement of groundwater is least viz; alluvium. The salinity generally show increasing trend with depth. A common geochemical sequence in groundwater includes bicarbonate waters near ground surface varying to chloride waters in the deepest portions of aquifer (Todd & Mays, 2005).

A summary of the natural sources and concentrations of the principal chemical constitutes found in groundwater (Todd & Mays, 2005) is given in Table 7.1.

Table 7.1 Principal Chemical Constitutes in Groundwater- Their Sources and Concentrations (After Todd and Mays, 2005)

Constitutes	Major Natural Sources	Concentration in Natural Water
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, clay minerals	Generally less than 100 mg/l; brines may contain as much as 75,000 mg/l
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals	Generally less than 50 mg/l; ocean water contains more than 1,000 mg/l and brines may contain as much as 57,000 mg/l
Sodium (Na)	Felspars (albite), clay minerals, evaporates, such as halite (NaCl) and mirabilite (Na2SO4.10H2O), industrial wastes	Generally less than 200 mg/l; about 10,000 mg/l in sea water; about 25,000 mg/l in brines
Potassium (K)	Feldspars (orthoclase and microcline), felspathoids, some micas, clay minerals	Generally less than about 10 mg/l; as much as 100 mg/l in hot springs; as much as 25,000 mg/l in brines
Carbonate (CO_3)	Limestone, Dolomite	Commonly less than 10 mg/l in groundwater. Water high in sodium may contain as much as 50 mg/l of carbonate.
Bicarbonate (HCO_3)		Commonly less than 500 mg/l; may exceed 1,000 mg/l in water highly charged with carbon dioxide.
Sulfate (SO_4)	Oxidation of sulfide ores gypsum; anhydrite	Commonly less than 300 mg/l except in wells influenced by acid mine drainage. As much as 200,000 mg/l in some brine.
Chloride (Cl)	Chief source is sedimentary rock (evaporites); minor sources are igneous rocks	Commonly less than 10 mg/l in humid region but up to 1,000 mg/l in more arid regions. About 19,300 mg/l in sea water; as much as 200,000 mg/l in brines
Fluoride (F)	Amphiboles (hornblende), apatite, fluorite, mica	Concentration generally do not exceed 10 mg/l. concentrations may be as much as1,600 mg/l in brines.
Nitrate (NO_3)	Atmosphere; legumes, plant debris; animal excrement	Commonly less than 10 mg/l.

GROUNDWATER CHEMISTRY OF STUDY AREA

Study of groundwater chemistry is aimed to understand-

- Groundwater interactions with geological formations
- To workout spatial and temporal changes in chemical contents of groundwater
- To study mechanism of sea water intrusion and groundwater salinization as a result of over-exploitation, particularly in coastal region
- To classify the groundwater from the point of view of its suitability for drinking and irrigation uses and
- To envisage suitable strategy for groundwater quality remediation and resource management.

To study groundwater chemistry, 91 observation wells have been utilized (Fig. 7.2). Water samples have been collected seasonally from these observation wells and were analyzed for determining chemical content and other physical parameters by using standard techniques. Important hydro-chemical parameters determined are-

(A) Physical: pH, Total Dissolved Solids (TDS) and Total Hardness (TH).

(B) Chemical:

Cations- Calcium, Magnesium, Sodium

Anoins- Carbonate, Bi-carbonate, Chloride, Sulfate, Fluoride, Nitrate and Boron (only for coastal aquifers)

Groundwater chemistry has been evaluated from year 2008 to 2012. Location specific detailed chemical contents analyzed seasonally for watershed region and the core area are given in Annexures- 7.1 to 7.16. In order to assess long term impacts, the candidate has colleted secondary data (since 1995) from GWRDC (Annexure 7.17).

The candidate based on analyzed groundwater chemistry parameters has attempted to classify data, based on available aquifer systems in the study area by considering maximum and minimum values of an individual parameter. Summary of range of concentrations obtained for all these parameters is given in Table 7.2.

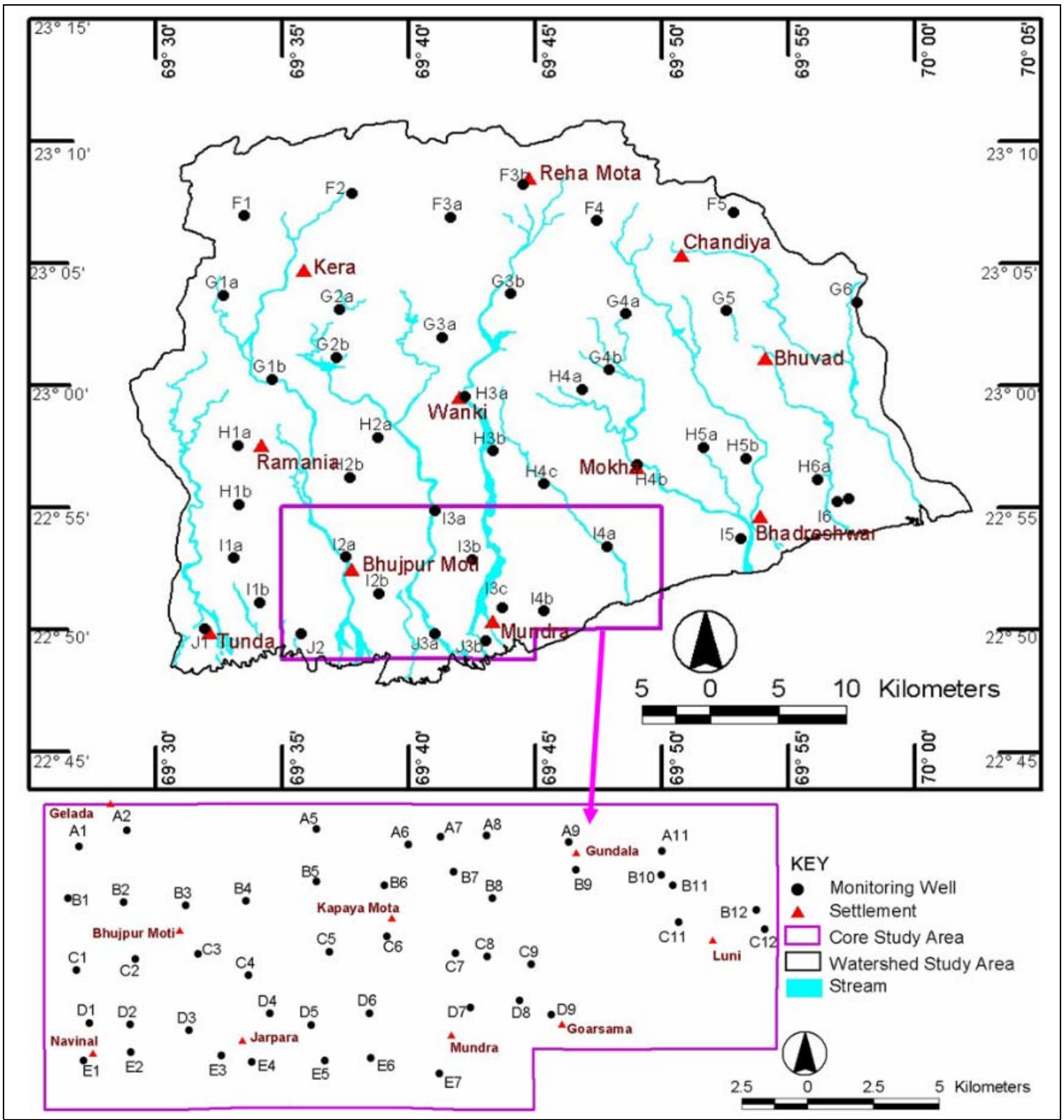


Fig. 7.2 Groundwater Sampling Locations of Observation Wells in the Study Area

Table 7.2 Aquifer wise Range of Hydro-Chemical Content in Groundwater

Aquifer	Cretaceous Sandstone		Deccan Trap Basalt		Laterite		Kankavati Sandstone	
Parameter	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
pH	6.9	7.9	6.9	8.0	7.0	7.3	6.8	8.1
EC µs/cm	561	4524	1030	4212	3900	5616	873	15600
TDS mg/l	360	2900	660	2700	2500	3600	560	10000
Ca^{2+} mg/l	28	92	16	52	40	76	08	696
Mg^{2+} mg/l	07	112	05	48	22	36	05	166
Na^{+} mg/l	74	722	200	851	742	1206	153	2628
CO_3^{-} mg/l	30	60	30	90	30	60	30	120
HCO_3^{-} mg/l	153	305	210	449	397	732	297	915
SO_4^{-} mg/l	154	750	192	528	336	739	86	1918
Cl^{-} mg/l	160	1050	230	900	630	1350	160	3243
F^{-} mg/l	01.5	01.6	----	01.5	----	01.5	----	01.5
Boron mg/l	----	----	----	----	----	----	0.2	3.2

A detailed account on various physical and chemical parameters is given as under-

HYDROGEN ION CONCENTRATION (PH)

pH is a measure of solvent power of water. It represents the overall balance of a series of equilibrium exists in solution (Hem, 1991). pH is controlled by chemical reaction and equilibrium between ions. Hydrolysis is most important reaction of ions affecting pH. In natural waters carbonate and bicarbonate salts predominates, due to this pH value rise above 7 (Ageno and Valla, 1911). pH scale is expressed in range from 1 to 14 where 7 value indicate neutral state between acid and basic. Acidic water has pH value lower than 7 while it is higher than 8 in basic water. Groundwater pH in study area ranges between 6.8 and 8.1 (Table 7.2).

ELECTRIC CONDUCTIVITY (EC)

Electric conductance of water indicates ability to conduct an electric current and expressed as µs/cm. Natural waters have specific conductance values much less than one mho (Hem, 1959). Chemically pure water has a very low conductance. It is an approximate indicator of concentration of dissolved solids and thus indicator of salinity. EC of groundwaters in the study area ranges between 560 and 15,600 µs/cm. Maximum EC value observed in inland aquifers of Bhuj sandstone, Deccan Trap basalt and laterite aquifers is around 5000 µs/cm. The EC is very high (15,600 µs/cm) in case of coastal aquifers. This exceptionally high EC value in coastal aquifers i.e. the Kankavati sandstone, points to severe salinity, which may be ascribed to seawater influence (Table 7.2).

TOTAL DISSOLVED SOLIDS

Electric conductance provides an amount of concentrated matter in water well-known as Total Dissolved Solids (TDS). It is the primary indicator of salinity and very basic tool for water quality analysis.

Aquifer wise the observed minimum and maximum range of TDS in the study area is in Table 7.2. Deep groundwater from Bhuj sandstone aquifers show range of TDS between 360 and 2900 mg/l. In Bhuj Sandstone which is characterized by intercalated layers of marine shales, may be the causative factor for giving high salinity. Coastal aquifers in Kankavati Sandstone, observed TDS values are ranging between 560 mg/l and >10,000 mg/l. This exceptionally high TDS value in groundwaters of coastal aquifers may be attributed to over exploitation leading to sea water intrusion. Groundwater quality in shallow aquifers is normally governed by local conditions. Aquifers in weathered basalt provide normally good groundwater but presence of chemically altered clays and amygdale minerals sometime deteriorates water quality. Groundwater from basaltic aquifers show TDS ranging between 660 and 2700 mg/l. Groundwater associated with laterite aquifer has high concentration of salts due to dissolution of salts associated with lithomarge clay.

Village wise seasonal behavioral pattern of TDS in groundwater has been presented for the last five years (Table 7.3). Looking to status of TDS in pre monsoon 2012, only 12 villages show TDS values within potable limits i.e. 1500 mg/l (WHO, 1993). As a general trend TDS content is increasing from post to pre monsoon season that may be attributed to high evaporative losses during summer, leading to enrichment of the salts in soils and latter become a part of groundwater system as rain water recharge.

TDS Hydrograph

Study through well hydrograph is considered to be the best technique to visualize the change in seasonal patterns of any hydro-geologic parameter. Therefore, the candidate by considering study areas' aquifer specific cases developed the TDS hydrographs (Fig.7.3). Based on analysis of relevant hydrographs, the aquifer specific findings are discussed as under-

- *<u>Bhuj Sandstone:</u>* The TDS hydrographs of Bhuj Sandstone shows inverse correlation with rainfall pattern; with an increase in rainfall, TDS values decreases. By and large area occupied by Bhuj Sandstone show this trend except the Sanosara village, a slight degradation in TDS is noticed (Fig 7.3 A).
- *<u>Weathered Basalt:</u>* The TDS hydrographs of weathered basalt aquifers also show good impact of rainfall input. TDS content show slight increase from year 2008 to 2010, but there has been a reduction in year 2012. Overall, the groundwater shows stable to slight improvement in water quality (Fig. 7.3 B).

- *Kankavati Sandstone:* TDS hydrographs for groundwater from Kankavati sandstone aquifer have been prepared for northern and southern coastal parts of the study area. As mentioned above, TDS values indicate improvement in quality with the amount of rainfall increased. Hydrographs for observation wells situated in northern part of the aquifer (Fig. 7.3 C) show slight decrease in TDS however, the western most Khakhar village shows increase in TDS concentration. Hydrographs of observation wells situated in coastal region (Fig. 7.3 D) show stable to slight decrease in TDS around Mundra, Sadau villages, whereas it show slight increase in western part around Zarpara village. Villages located in eastern part of the coastal aquifer i.e. Bhadreshwar, Kuvai show a marked increase in TDS over a period of 05 years.

Table 7.3 Seasonal Behavior of Total Dissolved Solids (mg/l) in the Study Area

OW Code	Village	Pre 2008	Post 2008	Pre 2009	Post 2009	Pre 2010	Post 2010	Pre 2011	Post 2011	Pre 2012
G3b	Bandra Nana	1623	1984	1530	1130	1010	1540	1220	1400	1650
I5	Bhadreshwar	3782	4800	3100	3400	2800	3570	4890	5200	4930
C1	Bhujpur Moti	3160	1390	1880	1920	1830	1240	2010	2030	2140
C3	Bhujpur Nani	4220	2080	2700	3200	2700	1280	1590	1010	1380
H2a	Bocha	3821	5798	3800	3800	3600	2490	2620	2130	2460
A1	Desalpar	2930	1350	1830	1810	1900	3270	2130	1490	2580
E5	Dhrab	4520	2530	2900	3000	2800	2930	2300	8190	2670
D9	Goyersama	3280	1520	2100	2300	1830	3070	1340	2490	1510
H6a	Hatadi	2342	4109	2500	2400	2900	2280	1980	1940	2250
G3a	Kanajra	966	1510	930	800	660	1140	1120	640	1050
C6	Kapaya Mota	2740	1090	1680	1740	1540	1890	1500	790	1420
I1a	Khakhar Moti	1997	2893	1720	1700	1290	1070	2700	2600	3860
H6b	Kuvai	2714	4147	2400	2700	2300	3500	2580	2620	4260
C11	Luni	4230	2700	4330	3100	3700	2530	3940	1910	3150
F1	Meghpar	3500	5837	3100	3300	2900	2570		760	950
E7	Mundra	4330	4493	2800	2900	3100	2270	2570	2320	2080
E2	Navinal	3290	1820	2100	2100	2100	3430	2230	3140	3900
C4	Pratappar	2810	1420	1780	1640	1600	1430	2750	2750	2120
B11	Ragha	5312	2920	5000	1770	4000	2680	3110	4340	3160
H1a	Ramaniya	1433	2637	1910	2900	2500	2440	3220	2510	1200
H4c	Ratadiya	2643	4627	3100	3200	2900	2170	2260	2150	2730
F3b	Reha nana	1818	2931	1760	1850	1680	1260	1020	1820	1480
C9	Sadau	2240	1070	1330	1380	1330	960	1370	1650	1420
F3a	Sanosara	493	725	450	450	360	720	750	930	590
J1	Tunda	2547	5581	3100	3000	2900	2300	4920	3050	2690
G4b	Vagura	2022	4467	2600	1280	1660	1160	1130	830	1240
H3a	Vanki	1491	2208	2500	850	1800	1700	1860	1630	950
F5	Wada	1984	1600	1600	1090	1550	1490	1560	920	1130
D3	Zarpara	4630	2360	3400	3400	3000	2930	3750	3830	3390

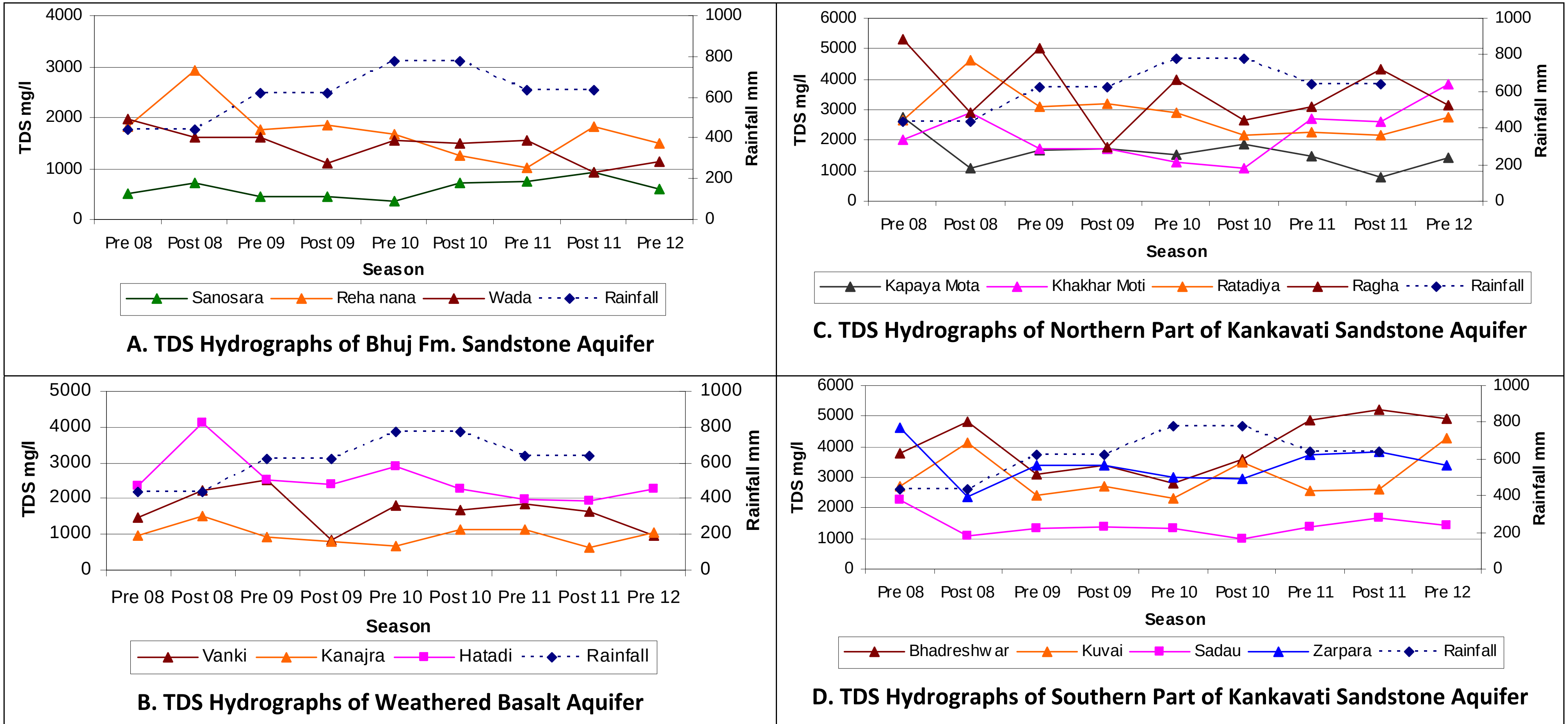


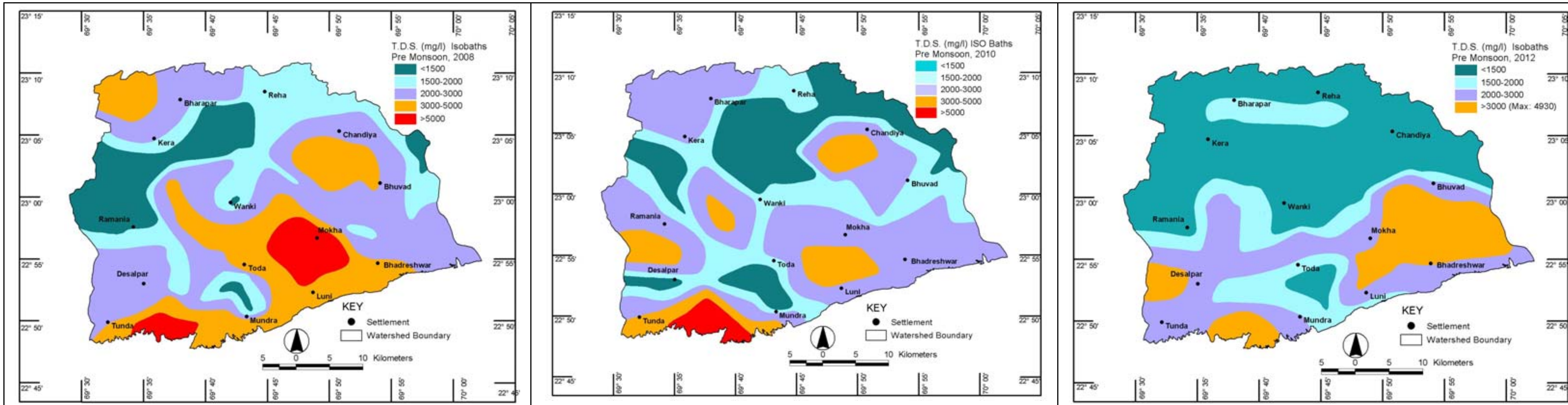
Fig. 7.3 Hydrographs Showing Aquifer Specific Temporal Behavior of TDS

TDS Isobaths

Isobath map considered to be the most illustrative way to represent spatial changes over a large area. TDS Isobath maps for the study area have been prepared for pre monsoon seasons for the years 2008, 2010 and 2012 (Fig. 7.4 A, B, C). TDS hydro-isobaths show drastic seasonal fluctuation in TDS range in coastal regions of the study area. Based on groundwater uses and the relevant quality standards, i.e. drinking water and irrigation; the candidate has attempted to categorize TDS range classes and the respective spatial coverage (Table 7.4). Spatial categorization of TDS isobaths does not provide any significant trend except categories 1 & 5 showing improvement in overall TDS content. This may be attributed to last 05 years rainfall which was above normal i.e. >600 mm/year and implementation of rainwater recharge schemes at large scale in study area leading to high order of recharge to aquifers thereby an overall dilution.

Table 7.4 TDS Based Spatial Categorization of Study Area

Sr. No.	TDS mg/l	Category	Covered Area (Sq.km.)		
			Pre Monsoon, 2008	Pre Monsoon, 2010	Pre Monsoon, 2012
1	<1500	Potable- Very Good	211.6	345.7	765.2
2	1500-2000	Permissible as per ICMR	340.0	393.6	291.9
3	2000-3000	Not potable, Can be used for Irrigation only to salt tolerant crops	625.1	712.2	363.1
4	3000-5000	Horticulture- only dates	394.9	179.7	248.7
5	>5000	Not usable, Highly saline	97.2	37.6	0.0
Total Area Sq.km.			**1669**	**1669**	**1669**



A B C

Fig. 7.4 Spatial Distribution Patterns of TDS (mg/l); (A) Pre Monsoon, 2008, (B) Pre Monsoon, 2010, (C) Pre Monsoon, 2012

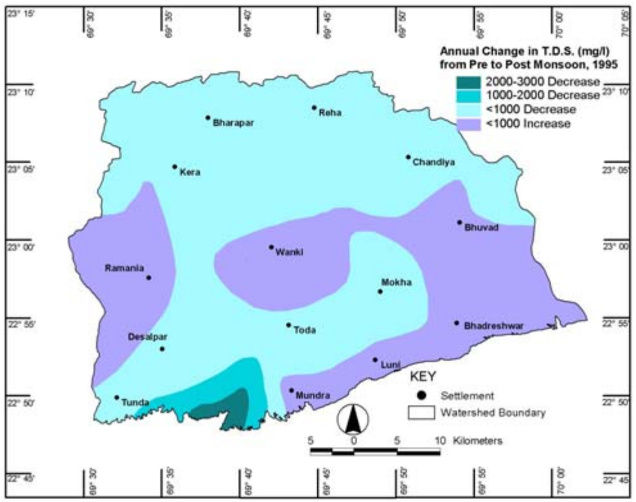
Annual Change in TDS

In order to assess annual changes in groundwater quality in terms of TDS, candidate has generated Iso TDS zonation maps considering pre monsoon to post monsoon seasons for the years 1995, 2008 and 2011 (Fig. 7.5 A, B, C). The change in TDS values after rainfall is normally attributed to dilution due to groundwater recharge. However, over exploitation may lead to increase in concentration of salts irrespective of recharge, particularly in coastal aquifers vulnerable to sea water intrusion. The annual change in TDS concentration in terms of increase leads to overall decrease in groundwater quality has been considered as negative (-) change; whereas decrease in TDS invariably improve the groundwater quality therefore considered as positive (+) change. Based on derived zonation categories (Fig.7.5 A, B, & C); the candidate has calculated the net are falling under the influence of such changes (Table 7.5).

The derived information suggests that during the year 1995, almost 65 % area (1071.5 km^2) show overall dilution in TDS and 35 % area (597.4 Km^2) the TDS enrichment. Comparing TDS change 1995 with 2008; the scenario has completely changed, wherein only 10 % area show dilution in TDS. Year 2008 onwards, annual rainfall being above normal (>600 mm), it has greatly impacted the TDS positively. The TDS isobath map for the year 2011 proves this fact as only 20 % area show increase in concentration of TDS up to 2000 mg/l.

Table 7.5 Spatial Annual Change in TDS Concentration from Pre Monsoon to Post Monsoon Seasons

TDS Category	Change (mg/l) (as range)	Spatial Coverage (Sq.km.)		
		Year 1995	Year 2008	Year 2011
Net Annual Decrease (+) (Concentration decreased from Pre to Post Monsoon)	(+) > 2000	16.7	3.4	40.6
	(+) 1000 – 2000	47.3	34.5	176.6
	(+) 0 – 1000	1007.5	126.3	1132.7
Net Annual Increase (-) (Concentration increased from Pre to Post Monsoon)	(-) 0 – 1000	597.4	559.0	278.9
	(-) 1000 – 2000	0.0	700.7	40.0
	(-) 2000 – 3000	0.0	177.4	0.0
	(-) > 3000	0.0	67.7	0.0
Total Area		**1669**	**1669**	**1669**



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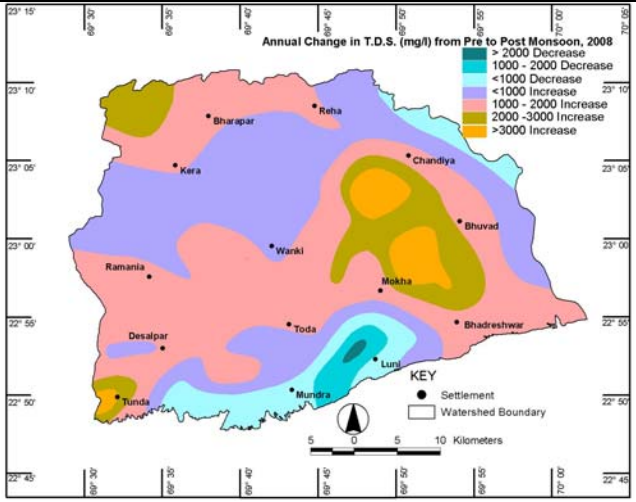

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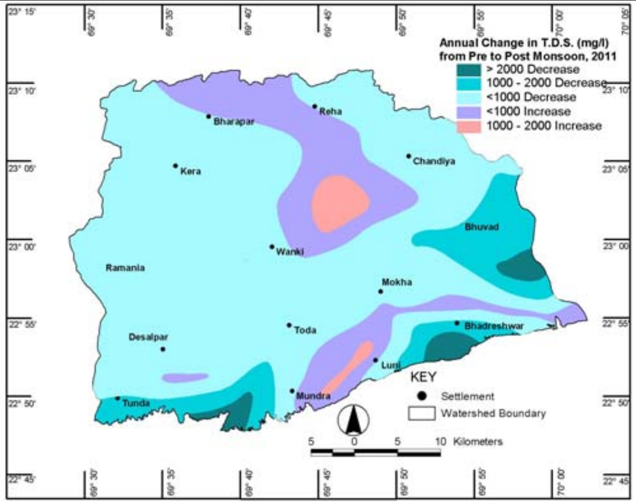


C

Fig. 7.5 Annual Change in TDS Concentration (mg/l) from Pre to Post Monsoon Season; (A) Year 1995, (B) Year 2008 (C) Year, 2011

Secular Change in TDS

TDS profiles have been prepared for selected observation wells of each aquifer system to observe long term (year 1995-2012) changes in TDS along N-S and E-W azimuths (Fig. 7.6 A-D). Seeing the long term trends in TDS change, the following inference can be drawn.

The secular change along TDS profiles on N-S transect divulged that in its western part (Fig. 7.6 A), there has been a rise in TDS >1500 mg/l between Tunda and Ramania villages characterized by Kankavati sandstone and laterite aquifers. Whereas, in the eastern part transect (Fig. 7.6 B), the rise in TDS concentration is very much high >3000 mg/l (Kankavati sandstone) except Bhuvad village comprising basaltic aquifer from year 1995 to 2012.

On the E-W transect the secular change in TDS in the northern part of the study area (Fig. 7.6 C), there has been a significant improvement in TDS concentration i.e. >1500 mg/l decrease from 1995-2012. Similarly, the southern part profile (Fig. 7.6 D) shows drastic increase in TDS concentration i.e. >3000 mg/l between Khakhar and Kapaya Mota villages falling within the domain of Kankavati sandstone and as a matter of fact the SEZ region.

These plotted secular profiles on TDS change particularly, in case of coastal Kankavati sandstone aquifer region (Fig. 7.6 B & D) show drastic increase in TDS concentration that may be attributed to over-exploitation due to increase in industrial water demand as well as the sea water ingress.

HARDNESS

Mostly calcium and magnesium cations contribute to water hardness (Hem, 1991). Here hardness in groundwater has been computed as calcium carbonate ($CaCO_3$). The observed range of water hardness in study area is 40 to 4300 mg/l. Bhuj sandstone aquifers show hardness ranging between 60 and 1000 mg/l. Hardness of groundwater from basalt aquifers sporadically show higher values (2300 mg/l) due to compositional variation in lava flows. In coastal Kankavati sandstone aquifer, groundwater hardness ranges between 40 and 4300 mg/l.

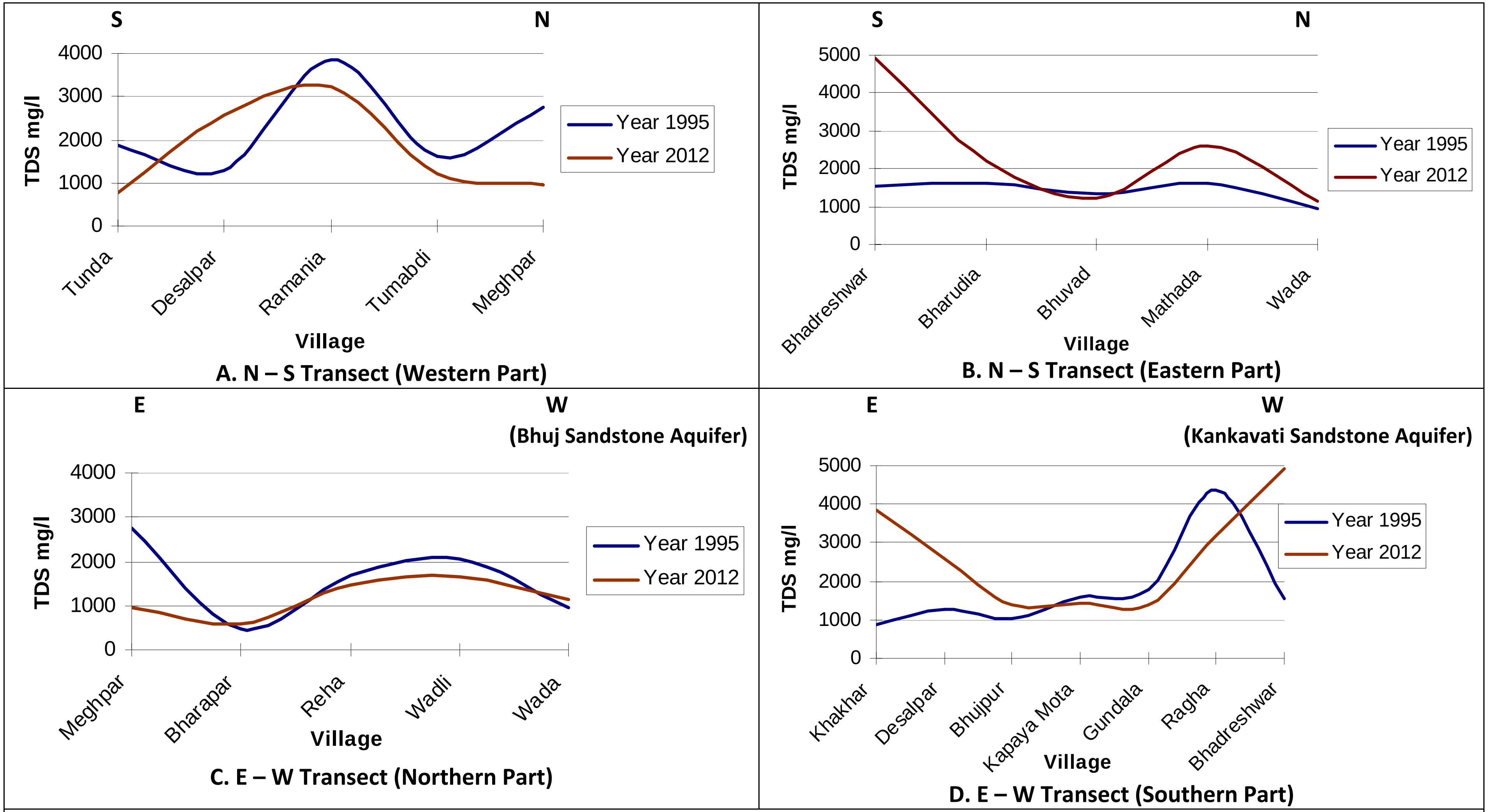


Fig. 7.6 Long Term (Secular) Behavior of TDS Concentration in Groundwaters of Study Area (Year 1995-2012)

ALKALINITY

Alkalinity is a property of water which has ability to neutralize the acids and is reported in terms of carbonate and bicarbonate or hydroxide ions. Anions present in water contribute to alkalinity which forms acids (Hem, 1991). Chloride, sulfate and nitrate ions do not affect alkalinity. Groundwater in the study area shows alkalinity ranging between 100 and 650 mg/l. Alkalinity in groundwater is comparatively higher in Kankavati sandstone aquifer than other aquifers.

IONIC CONCENTRATION

Ionic concentration in groundwater has been analyzed for major cations and anions. Cations include calcium, magnesium and sodium while carbonate, bi-carbonate, chloride, sulfate, fluoride, nitrate and boron as anions. Fluoride, nitrate and boron ions are rare and low in concentration in natural groundwaters, therefore concentration has been measured for pre monsoon season samples only.

Calcium (Ca^{2+})

Calcium is an alkaline earth metal. It is easily soluble and occurs as dominant cation in natural waters. It is an abundant constituent in sedimentary rocks and soil (Table 7.1). In sandstone, calcium carbonate usually found as cementing material. Low concentration of calcium than magnesium indicates base exchange of calcium by sodium (Hem, 1991). Calcium along with magnesium contributes hardness in groundwater. In study area, calcium concentration range between 8 and 696 mg/l. The higher content of calcium is observed in Kankavati sandstone aquifers. Other aquifers show Ca content between 16 and 92 mg/l that fall in potable range of water (Table 7.9).

Magnesium (Mg^{2+})

It is another alkaline earth metal and occurs as a major cation in groundwater. Major source of magnesium is carbonate rocks such as limestone, dolomite and ferro-magnesium and ultra basic rocks (Hem, 1991). In sea water, magnesium is major cation next to sodium. Observed concentration of magnesium in study areas' groundwater is ranging between 5 and 166 mg/l. it is maximum up to 580 mg/l observed in Kankavati sandstone aquifers.

Sodium (Na^+)

It is an alkali metal and occurs as dominant/major cation in natural waters. Sodium salts are highly soluble and tends to remain in solution. Due to this, more highly mineralized waters are characterized by high concentration of sodium. It is a major constitute in evaporate sediment and sea water (Hem, 1991). Igneous rocks are composed of 60 percent of feldspars which is a major source of sodium (Clarke, 1924b). Further, aquifer influenced by sea water intrusion can lead to excessive concentration of sodium due to base exchange with calcium and magnesium. In the study area, sodium content in groundwater ranges between 74 and 2,628 mg/l. Sodium up to 1000 mg/l is observed in Bhuj sandstone and basalt aquifers while it is more than 2600 mg/l in Kankavati sandstone aquifer. This high sodium concentration in coastal aquifers may be attributed to sea water intrusion.

Carbonates

Carbonates constitute major part of groundwater and referred as carbonate and bi-carbonate ions. It is widely distributed in sedimentary rocks. In presence of carbon dioxide, bicarbonate form and hydrogen ion remain separate (Hem, 1991). When pH value is less than 4.3, it exists as H_2CO_3, while pH value greater than 8.5 it exists as HCO_3^-. In the study area Carbonate (CO_3^-) concentration ranges between 30 and 120 mg/l while Bi-carbonate (HCO_3^-) ranges between 153 and 915 mg/l. The higher carbonate concentration has been observed in groundwater from Kankavati sandstone aquifers.

Sulfate (SO_4^-)

Sulfate is the oxidized form of sulfur available in water. Weathering of sulfide bearing rocks and evaporate deposits are important source of sulfate. Some shales also contain considerable amount of sulfur. High concentration of sulfate indicates arid climatic condition too (Hem, 1959). In arid areas, soil is gypsiferous having high sulfate content.

Further, rainfall in arid regions may carry significant amount of sulfate where air dust from burning of coal and industrial processes get diluted in rain water and ultimately releases sulfate ions (Hem, 1959). As the study area is characterized by arid to semi arid climate, sulfate content in groundwater is higher and ranges between 154 and 1918 mg/l. The Kankavati sandstone aquifers are characteristics of higher sulfate content.

Chloride (Cl^-)

Chloride is one of the major parameters of water chemistry and important measure for investigating sea water ingress. Chloride is an abundant anion in sea water. Chloride also occurs in sedimentary rocks and evaporates. Chloride concentration in natural waters in coastal areas is influenced by solid matters carried out by air to inland from sea coast (Hem, 1991). High concentration of chloride in freshwater aquifers indicate sea water salinity where sodium also remains high in concentration along with it.

Further, chloride is considered as an important source of salinity in groundwater in coastal regions as airborne salts, origination from air-water interface over the sea (Erissson, 1959). Further, salts are deposited on land both by precipitation and by dry fallout. Chloride deposition in coastal areas has been calculated to range from 4-20 kg. Cl/ha (Loewengart, 1961). The chloride deposition decreases inland and varying exponentially with distance from sea.

In study area, chloride concentration in groundwater occurs in range between 160 and 3243 mg/l. Concerning to drinking water standards of WHO (1993), permissible limit for chloride is 600 mg/l. Chloride concentration in groundwater from Bhuj Fm. sandstone aquifers show a wide range between 160 and 1050 mg/l, whereas in basalt aquifers it ranges between 230 and 900 mg/l. Groundwater samples from coastal aquifers shows comparatively very high concentration of chloride than the other aquifers of study area. In coastal villages, normal observed concentration of chloride is around 1000 mg/l. However in some pockets, good quality groundwater occurs, where chloride concentration is within the permissible limit as drinking water use. Chloride concentration more than 3000 mg/l signifying highly degraded groundwaters occur around Dhrab, Jharpara villages.

To derive an overall appraisal about the study area; village wise seasonal concentrations of chloride in terms of pre and post monsoonal changes for the last 05 years have been compiled (Table 7.6). The pre monsoon 2012 data suggests that in all 12 villages the chloride content in groundwater is within permissible limits. These villages represent potential groundwater pockets belonging to three major aquifers viz;. Kanjhara and Wanki villages on basalt aquifers; Sanosara, Reha and Wada villages on Bhuj Sandstone aquifers; and Magra, Bhorara, Kapaya, Sadau and Mundra villages on Kankavati sandstone aquifers study suggest that there has been a significant increase in chloride concentration from 2008 – 2012 particularly in aquifers around Bhadreshwar (1418 to 2800 mg/l), Kuvai (869 to 2240 mg/l) and Navinal village (1262 to 2000 mg/l). These villages are situated in the proximity of coast and rise in chloride concentration may be ascribed to over exploitation of groundwater leading to sea water intrusion.

Distribution of chloride and bicarbonate content in groundwater has been analyzed with respect to depth to water table for different aquifers viz. Bhuj Fm. sandstone, Deccan Trap basalt and Kankavati Fm. sandstone (Fig. 7.7). The graph clearly shows that as the depth of water table increases, value of chloride concentration increases in Kankavati Fm. sandstone. This again point to sea water influence at deeper levels in coastal aquifer. However, the distribution of chloride and bicarbonate do not show high concentration in Bhuj Fm. sandstone and Deccan Trap basalt.

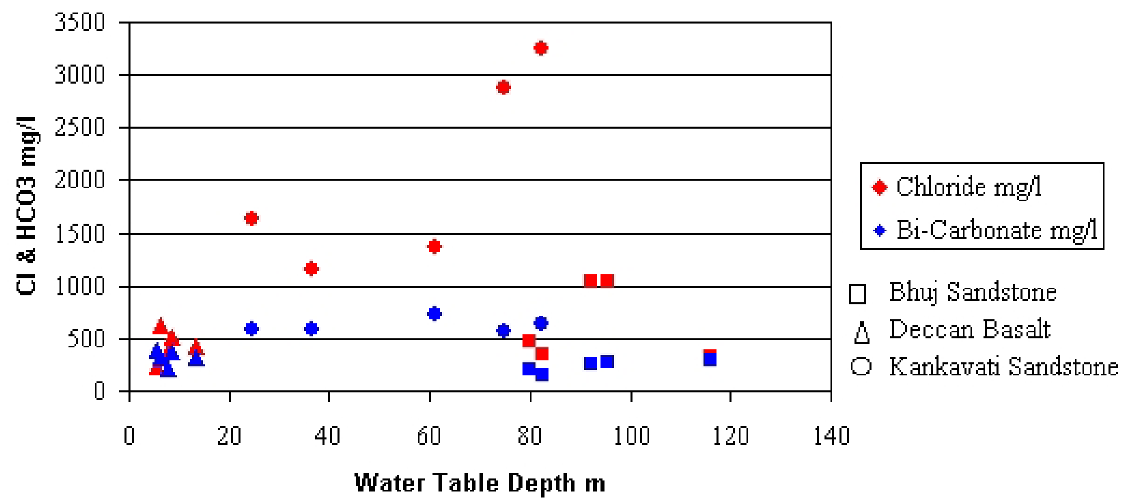


Fig. 7.7 Distribution Pattern of Chloride and Bicarbonate with Water Table Depth

Table 7.6 Seasonal Behavior of Chloride Ion in Groundwater of the Study Area

OW Code	Village	Pre 2008	Post 2008	Pre 2009	Post 2009	Pre 2010	Post 2010	Pre 2011	Post 2011	Pre 2012
G3b	Bandra Nana	301	443	350	201	266	440	608	680	744
I5	Bhadreshwar	1418	1617	1241	837	1200	1920	2760	2848	2800
C1	Bhujpur Moti	549	456	598	479	372	200	656	760	680
C3	Bhujpur Nani	1010	828	1050	943	730	400	504	392	464
H2a	Bocha	1276	1223	1329	479	1350	960	1136	952	976
A1	Desalpar	691	410	639	266	372	440	480	296	1360
E5	Dhrab	1081		1205	1052	1096	640	1176	4320	1400
D9	Goyersama	1285	646	939	567	730	320	304	640	400
H6a	Hatadi	510	1151	744	230	744	560	408	480	640
G3a	Kanajra		266	244	195	230	208	320	144	272
C6	Kapaya Mota	443	425	479	520	408	424	184	400	496
I1a	Khakhar Moti	425	479	425	230	408	392	520	784	920
H6b	Kuvai	869	1115	762	319	709	1440	1240	1064	2240
C11	Luni	957	1189	2140	956	532	880	1560	744	1512
F1	Meghpar	1106	1783	1023	723	1050	440		280	424
E7	Mundra	1593	1599	975	762	1150	784	1120	1072	1064
E2	Navinal	1262	720	656	674	620	1640	800	1600	2000
C4	Pratappar	319	450	585	443	443	216	1264	1160	1080
B11	Ragha	2534	773	2345	230	1860	600	800	1680	1320
H1a	Ramaniya	301	479	662	337	630	680	1008	496	304
H4c	Ratadiya	886	1275	970	714	1120	880	1104	864	1320
F3b	Reha nana	532	532	532	266	480	504	440	688	480
C9	Sadau	372	372	532	390	496	184	360	384	400
F3a	Sanosara	177	230	124	106	160	160	176	280	208
J1	Tunda	939	1947	1241	709	833	368	1288	1160	840
G4b	Vagura	602	833	869	355	514	248	240	112	192
H3a	Vanki	502	372	744	195	425	536	400	520	328
F5	Wada	511	372	337	266	355	400	544	312	480
D3	Zarpara	1188	1080	1258	1090	890	640	1952	1920	1720

Chloride Hydrograph: Chloride hydrographs have been prepared to observe seasonal variations during last five years (Fig 7.8). The derived inferences on chloride hydrographs are as under-

- *Bhuj Sandstone:* The chloride hydrographs of Bhuj Sandstone aquifers (Fig. 7.8 A) show stable to slight improvement in chloride content over 05 years period. Similar to TDS fluctuations, chloride concentrations are also decreases with rainfall increase.
- *Deccan Trap Basalt:* The chloride hydrographs of weathered basaltic aquifers point to an overall decrease in chloride concentrations over the period due to increase

in rainfall input. However, few wells show marked fluctuation in chloride concentration. Observation well at Vaghura village show drastic reduction in chloride concentration (Fig. 7.8 B).

- *Kankavati Sandstone:* Chloride hydrographs (E-W) for Kankavati sandstone aquifers have been plotted for inland and coastal aquifers covered by alluvium. Chloride hydrographs for inland observation wells (Fig. 7.8 C) show stable to slight increase in concentration of chloride. Observation well on western side (Khakhar village) show significant increase in chloride content. Hydrographs plotted for coastal villages (Fig. 7.8 D) show stability or slight decrease in chloride concentration around Mundra, and Sadau villages as well as along the bank areas of Bhukhi River which is considered to be one of the good groundwater pockets in coastal parts of the study area.

Chloride Isobaths: Chloride concentration in groundwater in study area has been presented through isobath maps for pre monsoon season of year 2008, 2010 and 2012 (Fig. 7.9 A, B, C). Observed chloride concentration has been categorized in 06 categories considering drinking water potablility and spatial coverage (Table 7.7). Chloride isobath analysis suggests that total area having more than 1000 mg/l concentration is increased from year 2008 (375 sqkm) to year 2012 (443 sqkm). However, change in chloride concentration <1000 mg/l show fluctuating trend which may be attributed to increase in rainfall input leading to dilution.

Table 7.7 Chloride Based Spatial Categorization of Study Area

Sr. No.	Chloride mg/l	Category	Spatial Coverage (Sq.km.)		
			Pre Monsoon, 2008	Pre Monsoon, 2010	Pre Monsoon, 2012
1	<600	Very Good	675.8	526.2	774.5
2	600-1000	Permissible as per ICMR	618.6	834.5	450.9
3	1000-2000	Not Potable, saline water, Sea water salinity	301.7	250.5	373.0
4	2000-3000		68.0	26.1	70.5
5	3000-5000		4.8	19.4	0.0
6	>5000		0.0	12.3	0.0
Total Area Sq. km.			**1669**	**1669**	**1669**

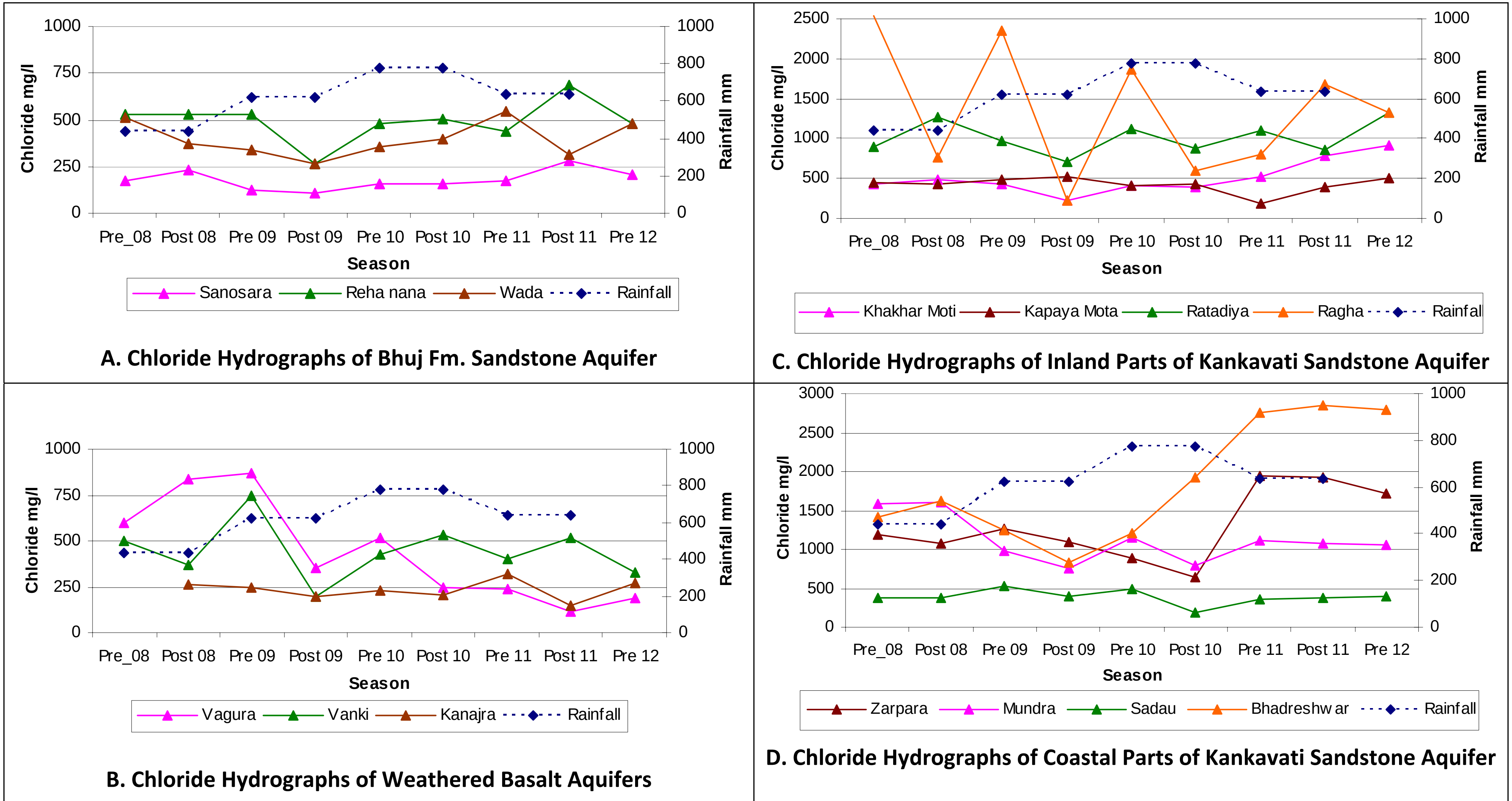
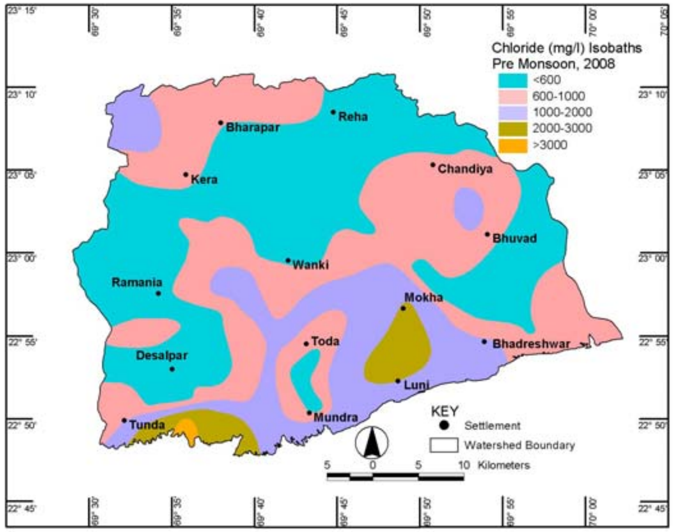
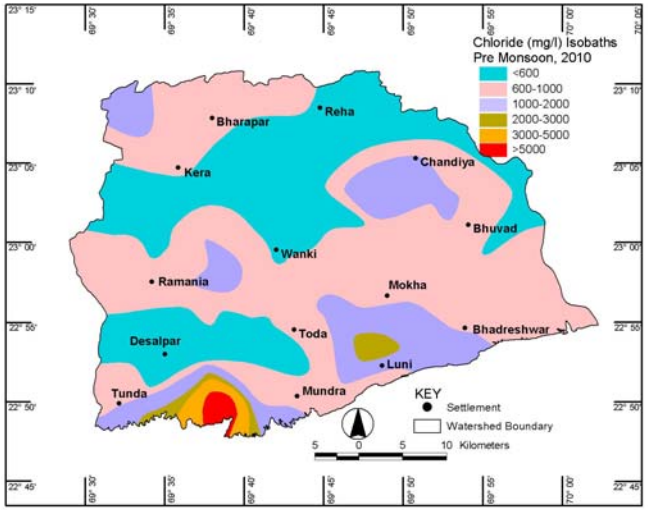


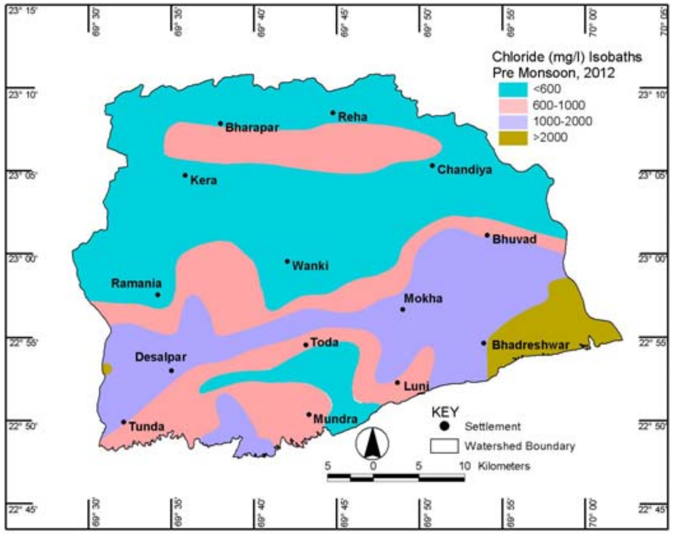
Fig. 7.8 Hydrographs Showing Aquifer Specific Temporal Behavior of Chloride



A



B



C

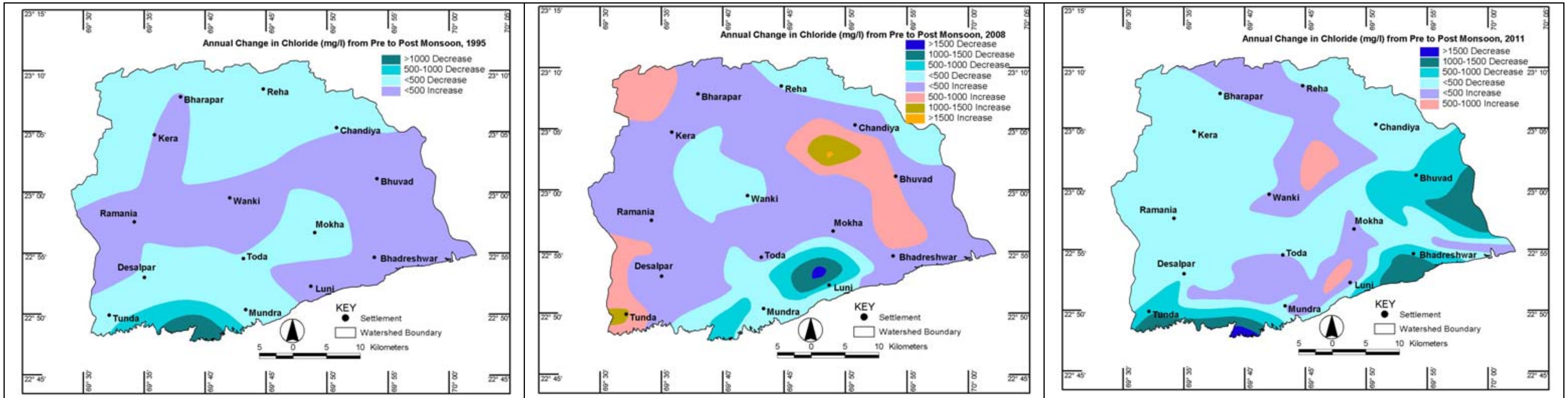
Fig. 7.9 Spatial Distribution Pattern of Chloride mg/l; (A) Pre Monsoon, 2008, (B) Pre Monsoon, 2010, (C) Pre Monsoon, 2012

Annual Change in Chloride Content: In order to delineate annual change in chloride concentration in groundwaters, chloride isobath maps have been generated considering pre monsoon and post monsoon seasons for the years 1995, 2008 and 2011 (Fig. 7.10 A, B, & C). Fluctuation in chloride content is depicted as decrease and increase in chloride concentration from pre monsoon to post monsoon seasons and is marked as decrease (+) change and increase as (-) change from the point of view groundwater quality deterioration. The overall spatial change (+/-) in terms of chloride concentration for the entire study area is given in Table 7.8.

In year 1995, more than 50 % area show dilution in chloride concentration (positive change) after monsoon in the northern and southern parts of study area (Fig. 7.10 A), while remaining area indicate increase in chloride content (negative change) particularly in basalt aquifers and in the eastern part of study area. Maximum reduction in chloride content has been observed in coastal regions. In year 2008, only 25 % area show reduction in concentration while 75 % area indicate increase in concentration of chloride (Fig 7.10 B). The scenario has reversed in year 2011 (Fig. 7.10 C) where 75 % area shows dilution in chloride concentration due to groundwater recharge. In general although the coastal part show significant decrease in chloride concentration, the dissolved chloride concentration still remain above the permissible limit i.e. >600 mg/l.

Table 7.8 Spatial Annual Change in Chloride Concentration from Pre Monsoon to Post Monsoon Seasons

Category	Change mg/l (as range)	Spatial Coverage (sq.km.)		
		1995	2008	2011
Net Annual Decrease (+) (Concentration decreased from Pre to Post Monsoon)	(+) >1500	0.0	2.8	4.1
	(+) 1000-1500	21.2	23.2	85.9
	(+) 500-1000	42.5	59.9	183.8
	(+) <500	829.9	357.2	990.9
Net Annual Increase (-) (Concentration increased from Pre to Post Monsoon)	(-) <500	775.3	961.3	368.0
	(-) 500-1000	0	235.3	36.2
	(-) 1000-1500	0	28.5	0.0
	(-) >1500	0	0.6	0.0
Total Area		**1669**	**1669**	**1669**



A B C

Fig. 7.10 Annual Change in Chloride Concentration (mg/l) from Pre to Post Monsoon Season; (A) Year 1995, (B) Year 2008 (C) Year, 2011

Secular Change in Chloride Content

In order to quantify long term change in chloride concentration in groundwater, the candidate has developed 04 numbers of profiles, considering observation wells falling along E-W and N-S transects of the study area (Fig. 7.11 A to D).

Chloride profiles follow more or less similar trends as that of TDS profiles. The chloride profiles of Bhuj sandstone aquifer indicate that concentration has decreased or remain stable in western and central parts viz. Meghpar village; while there has been an increase in chloride content in eastern part viz. Wada and Mathada villages of the study area (Fig. 7.11 A, B & C). Basalt aquifers viz. Tumbadi and Bhuvad villages depict dilution or stability in chloride concentration over the period. However chloride content has increased in coastal aquifers developed within the Kankavati sandstone viz. Bhadreshwar and Bharudia villages (Fig. 7.11 A & B). This chloride concentration increase (2012) in coastal aquifer viz; around villages Khakhar, Deshalpar, Gundala, and Bhadreshwar villages may be attributed to over exploitation of groundwater resource (Fig. 7.11 D).

Nitrate (NO_3^-)

Nitrate is an oxidized form of nitrogen element which is available in abundance in atmosphere. It gets oxidized and precipitate with rainfall. It is also generated by plants where plants convert air nitrogen to nitrate in soil (Hem, 1991). Nitrate is also added to water by organic pollutants and leaching from chemically fertilized soils. Therefore, it is strongly related with activities of plants and animals. The nitrate content in groundwater has been analyzed for core study area only comprising Kankavati sandstone aquifers. In coastal area groundwaters, nitrate content is ranges from 0.56 to 10.75 mg/l which is within the permissible limits of WHO (2005) and B.S. (1999).

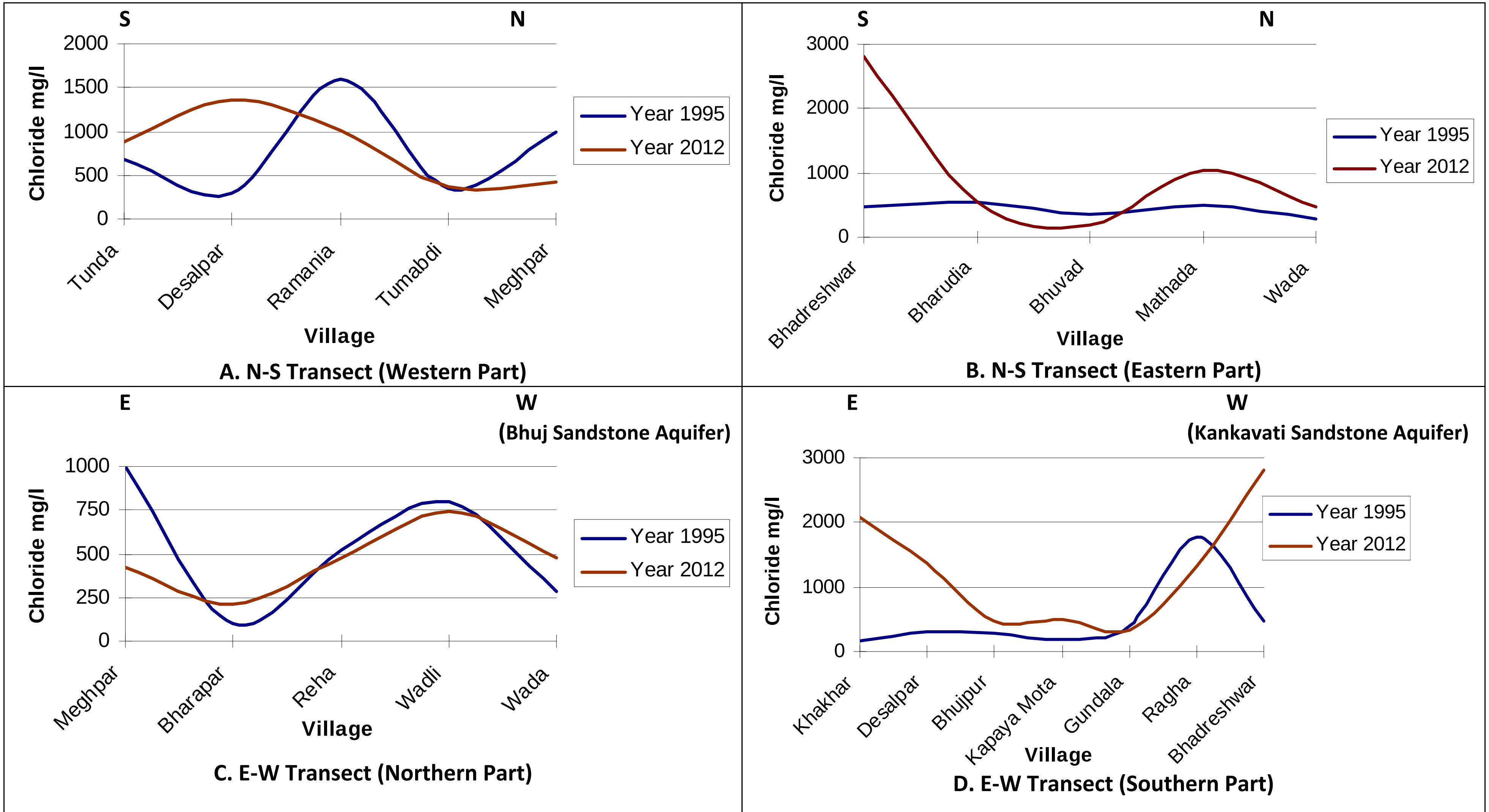


Fig. 7.11 Long Term (Secular) Behavior of Chloride Concentration in Groundwaters of Study Area (Year 1995-2012)

Fluoride (F^-)

Fluoride concentration in natural waters is normally very low. It is analyzed especially in drinking water context. When fluoride concentration exceeds the desirable limits, it causes dental defects and fluorosis disease (WHO, 2005). The main source of fluoride is fluoride bearing minerals commonly associated with igneous rocks. In study area, fluoride content remains within the limits of potability which is 1.5 mg/l. However, some deep groundwater sources viz; Bhuj Fm. and Kankavati sandstone aquifers show bit high values i.e. 1.6 mg/l concentration.

Boron (B^-)

It is a very minor constitute of rocks and natural waters. In sea water, average boron concentration is about 4.6 mg/l (Hem, 1993). Its' little high concentration in groundwater supports sea water ingress in coastal aquifers. Considering this significance, boron has been analyzed in groundwater samples for coastal part only. Boron concentration in drinking water standards suggests 0.50 mg/l as desirable limit (WHO, 2005). Plants are also sensitive to boron therefore classification for irrigation water (Wilcox, 1948) is also based on boron concentration. The candidate has utilized boron as parameter to classify groundwater of study for irrigation needs. In coastal area, boron content ranges between 0 and 4.6 mg/l. The detail account on spatial distribution of boron in coastal region is given as a part of core area appraisal.

WATER QUALITY INDICES

Water is being used by human being for various purposes such as drinking, domestic and occupational. Drinking water for human and cattle needs stand as foremost priority. Occupational water can be divided as agriculture and industrial needs. There has been a leap rise in industrial water demand as the study area is fast growing industrial hub. There exists national and international quality standards for water uses in various sections. The candidate, based on obtained chemical contents for aquifer specific groundwaters has made an attempt to classify the groundwaters for its suitability as drinking and irrigation needs.

DRINKING WATER QUALITY

Adequate and good quality drinking water is a prime need for every life. Groundwater being a main source, its quality needs to be examined on acceptable standards as permissible and desired limits of specified parameters.

Drinking water standards have been set by various authorities in terms of permissible and desirable limits for all the major, secondary, minor and trace constitutes present in groundwater. Any constitutes showing lower or higher concentration than the defined limits may cause deletherious effects on users' health. Table 7.9 shows drinking water quality standards set by World Health Organization (WHO), Indian Council of Medical Research (ICMR) and Indian Standards Institute (ISI). However, standards prescribed by WHO (2005) have been considered as base for comparing drinking water potability for this presented study.

Candidate has also attempted to analyze groundwater potability according to major aquifer systems in the study area (Table 7.9). Although chemical analysis of groundwater samples has provided wide range of values, only major constitutes have been presented as minimum and maximum obtained values. Minimum value of each parameter is in permissible limits as prescribed by WHO standards, whereas maximum values crosses the prescribed desirable limits. In general maximum value of each parameter is very high than the permissible limits. Very few parameters like pH, Nitrate and Fluoride are within potable limits irrespective of the aquifer system. Calcium and magnesium contents in groundwater from Cretaceous sandstone and Deccan Trap basalt are within potable limits but the same are beyond the limits in coastal aquifers of Kankavati sandstone. The TDS and chloride contents in groundwater irrespective of aquifer type are invariably high.

Table 7.9 Drinking Water Quality Standards and Comparison with Chemical Characters of Groundwater in the Study Area

Parameter	**Water Quality Standards**			**Aquifer Systems**					
	ICMR (1975)	**ISI (1983)**	**WHO (2005)**	**Cretaceous Bhuj Sandstone**		**Deccan Trap Basalt**		**Tertiary Kankavati Sandstone**	
				Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
TDS (mg/l)	500 (1500)	2000	500 (1500)	360 – 2900	450 – 3500	660 – 2700	740 – 3200	560 – 10,000	670 – 7700
pH	7-8.5 (6.5-9.2)	6.5-8.5	7-8 (6.5-9.2)	6.9 – 7.9	6.4 – 7.8	6.9 – 8.0	6.8 – 8.3	6.8 – 8.1	6.5 – 8.6
TH (mg/l)	300 (600)	300	300 (600)	60 – 1000	210 – 1090	150 – 490	140 – 490	40 – 4300	30 – 3020
Calcium (mg/l)	75 (200)	75	75 (200)	28 – 92	40 – 136	16 – 52	20 – 148	8 – 696	16 – 568
Magnesium (mg/l)	50 (100)	30	50 (150)	7 – 112	0 – 91	5 – 48	0 – 34	5 – 166	0 – 580
Chloride (mg/l)	200 (1000)	250	200 (600)	160 – 1050	106 – 810	230 – 900	195 – 554	160 – 3243	213 – 2261
Sulfates (mg/l)	200 (400)	150	200 (400)	154 – 750	234 – 950	192 – 528	180 – 979	86 – 1918	134 – 1171
Nitrate (mg/l)	20 (50)	45	-- (50)	----	----	----	----	0.56 - 10.75	0.0 – 8.35
Fluoride (mg/l)	1.0 (1.5)	0.6 (1.2)	-- (1.5)	1.5 – 1.6	----	1.5	----	1.5	----

Note: Figures in parenthesis (-) indicate maximum permissible limit of the parameter.

IRRIGATION WATER QUALITY

Agriculture is a major traditional occupation for study area. Although for irrigation, both surface water and groundwater are utilized, but groundwater use in irrigation is much higher than surface water. Surface water mainly comes from rainwater harvesting structures and therefore it has normally better quality than groundwater. As explained in previous sections, groundwater quality largely depends on aquifer characteristics, climate, recharge – discharge rates etc. Irrigation water supply provide necessary nutrients to soil and crop while excessive of salt may cause soil salinity, reduce growth and yield. The assessment become more important as the core study area falls within the limit of coastal region and having a threat of sea water contamination due to lowering down of water table as a result of over exploitation. The irrigation water quality assessment also helps to maintain the soil productivity such as use of low quality irrigation waters on heavy, clayey soils, is hazardous whereas, the same water can give sufficient produce on sandy and/or permeable soils (Ayers & Westcot, 1985).

Irrigation water quality evaluation has been done through following parameters.

- Sodium Adsorption Ration (SAR)
- Residual Sodium Carbonate (RSC)
- U.S. Salinity diagram

Sodium Adsorption Ration (SAR)

Sodium concentration in groundwater reacts with soil to reduce its permeability. Soil containing high concentration of sodium with carbonate as predominant anion is termed alkali soils and soil with chloride and sulfate as the predominant anion is saline soil (Todd & Mays, 2005). The SAR value suggests adsorption of sodium by soil from water added which results into sodicity hazards to soil (Richard, 1954). The SAR value is very significant parameter for irrigation water quality purpose. The SAR value has been calculated by following equation.

$$SAR = Na^{+} / \{(Ca^{2+} + Mg^{2+})/2)\}^{½}$$

Where, ionic concentrations are in mille-equivalent per liter.

SAR has been computed for groundwater available from each major aquifer system of the study area and characterized based on classification given by Richard, 1954 (Table 7.10). Looking to the SAR scenario over the period, safe to moderately safe groundwater is decreasing from year 2008 (82 %) to 2010 (37 %). This drastic change is due to over exploitation of groundwater leading to deterioration in water quality mainly in Kankavati sandstone aquifer (40.5 to 4.9 %).

Table 7.10 Irrigation Water Quality Characterization Based on SAR Values for Study Area as (%) of Total Monitoring Wells (After Richard, 1954)

Aquifer		Pre Monsoon (2008)	Post Monsoon (2008)	Pre Monsoon (2009)	Post Monsoon (2009)	Pre Monsoon (2010)
Watershed Region						
1. Bhuj Sandstone						
<10	Safe	11.9 (5)	4.7 (2)	14.0 (6)	11.9 (5)	7.3 (3)
10-18	Moderately safe	11.9 (5)	7.0 (3)	9.3 (4)	11.9 (5)	17.1 (7)
18-26	Moderately unsafe	0.0 (0)	7.0 (3)	0.0 (0)	2.4 (1)	2.4 (1)
> 26	Unsafe	0.0 (0)	7.0 (3)	0.0 (0)	0.0 (0)	0.0 (0)
2. Deccan Trap Basalt						
<10	Safe	7.1 (3)	0.0 (0)	4.7 (2)	7.1 (3)	2.4 (1)
10-18	Moderately safe	9.5 (4)	7.0 (3)	11.6 (5)	11.9 (5)	4.9 (2)
18-26	Moderately unsafe	2.4 (1)	4.7 (2)	7.0 (3)	2.4 (1)	9.8 (4)
> 26	Unsafe	2.4 (1)	9.3 (4)	0.0 (0)	2.4 (1)	4.9 (2)
3. Kankavati Sandstone						
<10	Safe	14.3 (6)	0.0 (0)	25.6 (11)	0.0 (0)	0.0 (0)
10-18	Moderately safe	26.2 (11)	4.7 (2)	14.0 (6)	9.5 (4)	4.9 (2)
18-26	Moderately unsafe	7.1 (3)	9.3 (4)	7.0 (3)	9.5 (4)	14.6 (6)
> 26	Unsafe	7.1 (3)	39.5 (17)	7.0 (3)	31.0 (13)	31.7 (13)
In Totality						
<10	Safe	33 (14)	4 (2)	44 (19)	19 (8)	10 (4)
10-18	Moderately safe	48 (20)	19 (8)	35 (15)	33 (14)	27 (11)
18-26	Moderately unsafe	10 (4)	21 (9)	14 (6)	14 (6)	27 (11)
> 26	Unsafe	9 (4)	56 (24)	7 (3)	34 (14)	36 (15)
Total		100 (42)	100 (43)	100 (43)	100 (42)	100 (41)
Core Area (Kankavati Sandstone)						
<10	Safe	45 (21)	31 (14)	30 (13)	9 (04)	7 (03)
10-18	Moderately safe	21 (10)	42 (19)	33 (14)	27 (12)	9 (4)
18-26	Moderately unsafe	19 (9)	16 (7)	16 (7)	29 (13)	28 (12)
> 26	Unsafe	15 (7)	11 (5)	21 (9)	35 (16)	56 (24)
Total (%)		**100 (47)**	**100 (45)**	**100 (43)**	**100 (45)**	**100 (43)**

Note: Figure in bracket indicates number of wells

The SAR values of groundwater from Bhuj Sandstone aquifer show almost stable situation over the seasons, while groundwater quality indicates slight deterioration in basalt aquifers. The groundwater from coastal aquifers of Kankavati sandstone shows drastic change in irrigation water quality, where proportion of safe and unsafe water has almost reversed from year 2008 to 2010. Out of 23 monitoring wells based on Kankavati sandstone, SAR values of 17 (74 %) sources indicate safe water in pre monsoon 2008 which has decreased up to 2 (9 %) in pre monsoon 2010. This clearly indicates water quality deterioration in coastal aquifers. SAR analysis of monitoring wells situated in core area also point to drastic reduction in percentage of safe to moderately safe water from 76 % to 26 %.

Residual Sodium Carbonate (RSC)

RSC is a significant tool to analyze sodicity hazards especially water rich in carbonate and bicarbonate ions (Richard, 1954). The RSC values for groundwater for each aquifer have been calculated by using following equation.

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Where, ionic concentrations are in mille-equivalent per liter.

RSC value is calculated for each monitoring well of watershed and core area and summarized here in accordance with aquifer system (Table 7.11).

According to RSC status in watershed region, proportion of safe water is decreasing from year 2008 (57 %) to 2010 (24 %). Looking to aquifer wise status, groundwater from Bhuj sandstone aquifers indicates stability, while groundwater from Basalt aquifers show slight degradation trend. Groundwater from Kankavati sandstone clearly indicates water quality degradation for irrigation use. Percentage of safe water has decreased from 21 % (year 2008) to 2 % (year, 2010) in Kankavati sandstone aquifer. This also reflects in RSC analysis of core area where percentage of safe water stands at 74 % in year 2008 which has decreased up to 9 % in year 2010. In general, groundwater quality of coastal aquifers is deteriorating and indicates predominance of carbonate rich groundwater. Findings from RSC analysis for irrigation water quality is comparable to SAR distribution pattern in the study area.

Table 7.11 RSC Based Irrigation Water Quality Characterization in (%) of Total Monitoring Wells (After Richard, 1954)

Aquifer		Pre Monsoon (2008)	Post Monsoon (2008)	Pre Monsoon (2009)	Post Monsoon (2009)	Pre Monsoon (2010)
Watershed Region						
1. Bhuj Sandstone						
< 1.25	Safe	21 (9)	12 (5)	24 (10)	17 (7)	17 (7)
1.25 - 2.5	Moderate	0 (0)	5 (2)	0 (0)	7 (3)	2 (1)
> 2.5	Unsafe	2 (1)	9 (4)	0 (0)	2 (1)	7 (3)
2. Deccan Trap Basalt						
< 1.25	Safe	14 (6)	7 (3)	17 (7)	10 (4)	5 (2)
1.25 - 2.5	Moderate	2 (1)	2 (1)	2 (1)	0 (0)	2 (1)
> 2.5	Unsafe	5 (2)	12 (5)	5 (2)	12 (5)	15 (6)
3. Kankavati Sandstone						
< 1.25	Safe	21 (9)	9 (4)	24 (10)	2 (1)	2 (1)
1.25 - 2.5	Moderate	2 (1)	2 (1)	2 (1)	0 (0)	2 (1)
> 2.5	Unsafe	31 (13)	42 (18)	26 (11)	49 (20)	46 (19)
In Totality						
< 1.25	Safe	57 (24)	28 (12)	64 (27)	29 (12)	24 (10)
1.25 - 2.5	Moderate	5 (2)	9 (4)	5 (2)	7 (3)	7 (3)
> 2.5	Unsafe	38 (16)	63 (27)	31 (13)	63 (26)	68 (28)
Core Area (Kankavati Sandstone)						
< 1.25	Safe	74 (35)	27 (12)	47 (20)	13 (6)	9 (4)
1.25 - 2.5	Moderate	0 (0)	24 (11)	16 (7)	7 (3)	7 (3)
> 2.5	Unsafe	26 (12)	49 (22)	37 (16)	80 (36)	84 (36)

Note: Figure in bracket indicates number of wells

U.S. Salinity Chart

The U.S. Salinity diagram (1954) is another important tool to identify probable sodium alkalinity (SAR) and salinity hazards (EC/TDS) to soils due to irrigation by groundwater. The U.S. Salinity Chart is divided into 04 salinity classes as C_1 to C_4 and 04 sodium classes as S_1 to S_4 as per severity of hazards (Table 7.12). The salinity classes C_1 to C_4 are based on specific conductance (EC) and alkalinity classes S_1 to S_4 are based on Sodium Adsorption Ratio (SAR). To generate a respective class plot, specific conductance value is plotted on X axis, while SAR value on Y axis.

The obtained values of SAR and EC for an individual observation well have been plotted on U.S. Salinity chart for the watershed region and core area for pre monsoon seasons for the years 2008, 2010 and 2012 (Fig. 7.12, 7.13, 7.14 A & B). The alkalinity and salinity plots of most of the wells of watershed and core area fall in Bad Water class.

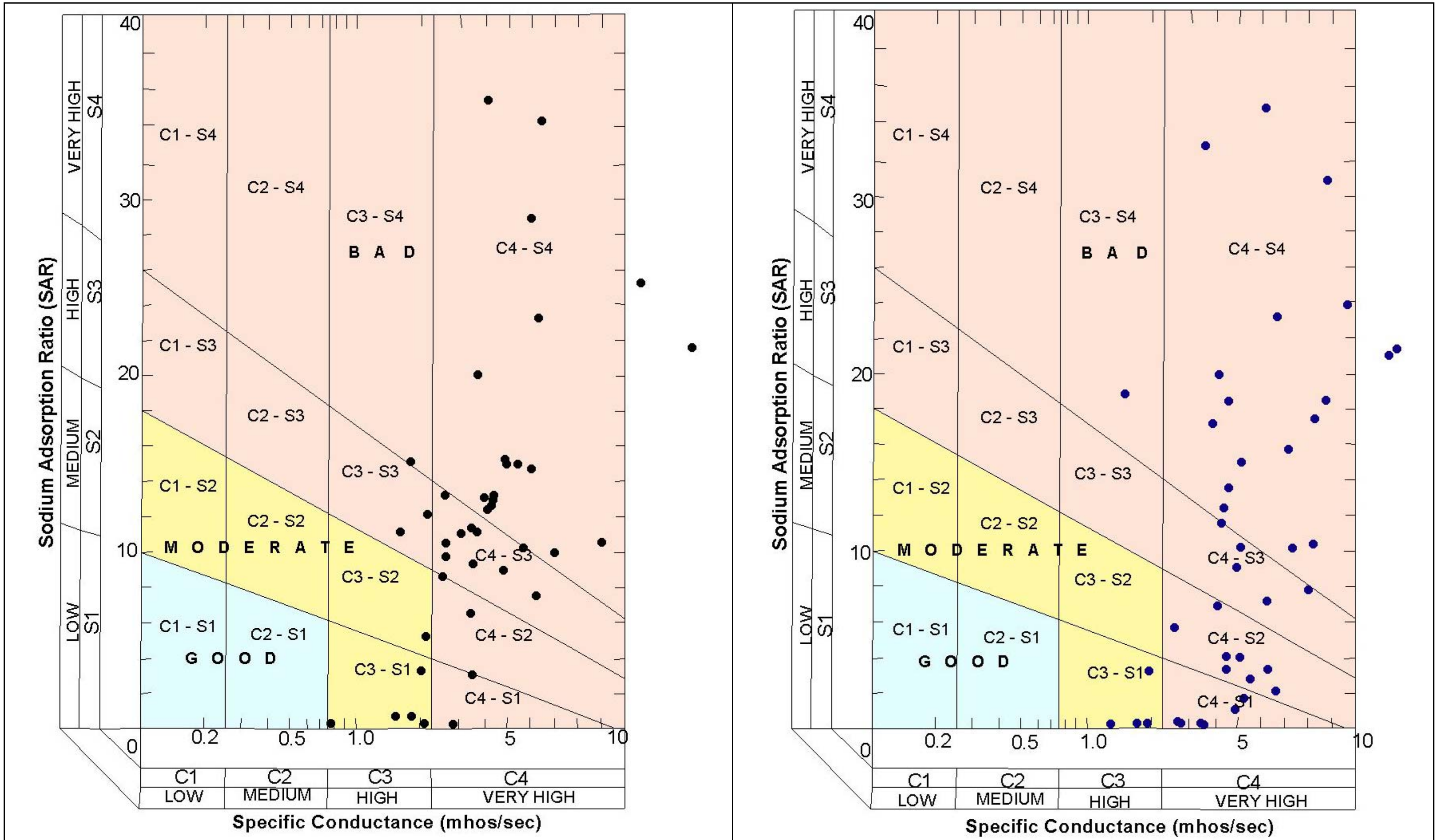
Table 7.12 EC and SAR Based Salinity Classification

Hazard Level	Salinity (EC)		Alkalinity (SAR)	
	Class	Characteristics	Class	Characteristics
Low	C_1	Low Salinity Water: Suitable for most crops on most soils with some leaching	S_1	Low Sodium Water: Suitable for almost all soils with less danger
Medium	C_2	Medium Salinity Water: Suitable for most crops with moderate leaching	S_2	Medium Sodium Water: Normally suitable for permeable coarse textured soils, may create sodium hazards in fine textured soil with poor leaching condition
High	C_3	High Salinity Water: Suitable for sodium resistant plans with adequate drainage	S_3	High Sodium Water: Needs special management practices such as soil management, good drainage, high leaching and addition of organic matter
Very High	C_4	Very high Salinity Water: Normally unsuitable for irrigation, but may occasionally be used under special conditions.	S_4	Very high Sodium Water: Normally unsuitable for irrigation. Special reclamations are to be adopted for use of this water.

(Source: USGS, 1954 & Charu & Datt, 1982)

The U.S. Salinity plots for the years 2008 and 2010 show only 6 sources (out of 42) fall within Good to Moderate groundwater classes (C_3 & S_1-S_2) in watershed region, while in core region only 4 sources (out of 43) fall within good to moderate water classes. All other groundwater falls within the Bad water categories, characterized by Very High Salinity Hazards (C_4 class) and Very High Sodium Hazards (S_4 class). Although there has been a slight improvement in groundwater quality during 2012 (Fig. 7.14) which may be ascribed to enhancement in groundwater recharge due to above normal rainfall received by the study area.

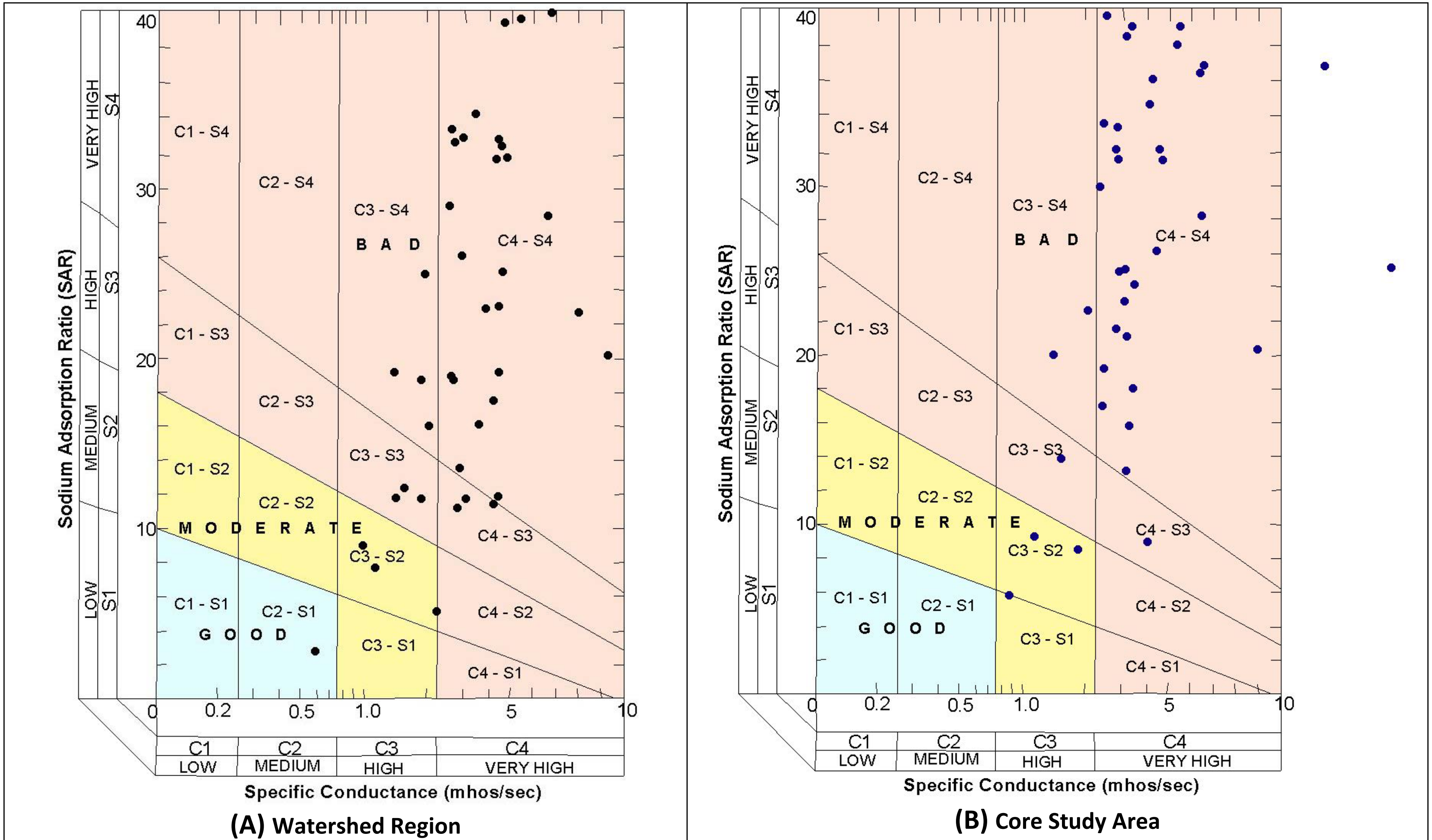
The villages of watershed region representing suitable groundwater are Sanosara, Varli, Wada, Bharapar villages situated on Cretaceous sandstone aquifer; Chunadi, Tumbadi, Kanjara, Lifra, Wanki, Patri villages situated on Deccan Trap basalt. While in costal track, sources near to river bank viz; Mundra, Magara, Bhorara, Kapaya Mota villages are providing moderate category groundwater (Classes C_1-S_2, C_2-S_2, C_3-S_3, & C_3-S_1) belonging to Kankavati Sandstone.



(A) Watershed Region

(B) Core Study Area

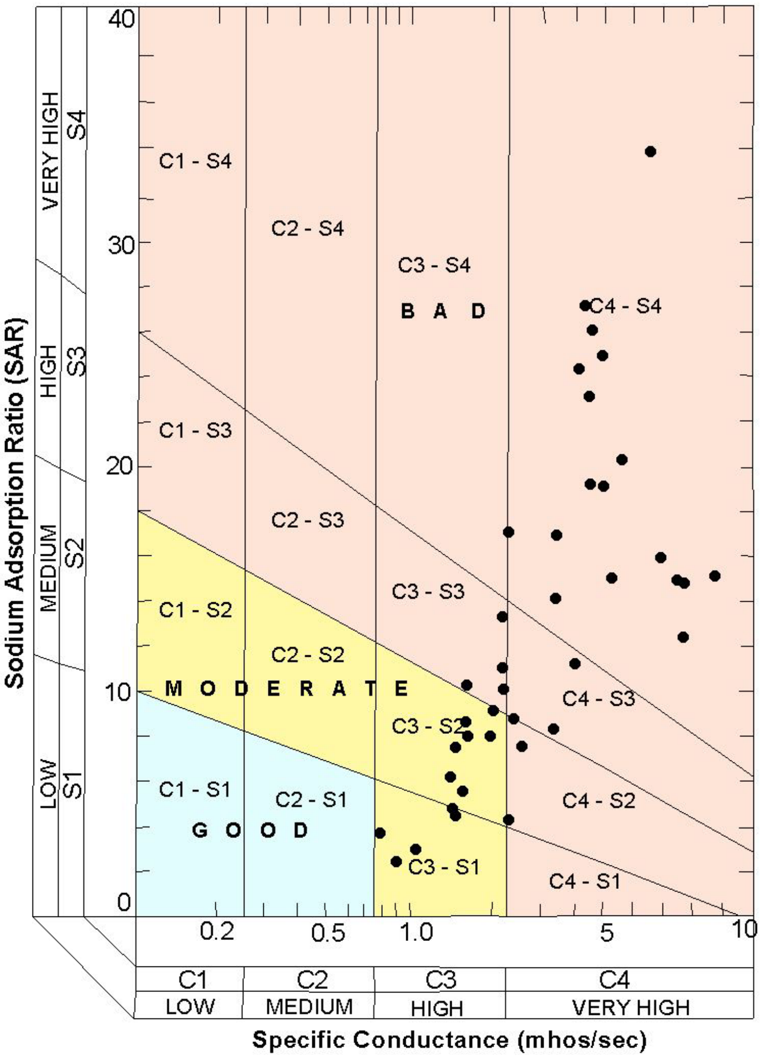
Fig. 7.12 U S Salinity Diagram - Irrigation Water Classification of Groundwater, Pre Monsoon (Year 2008)



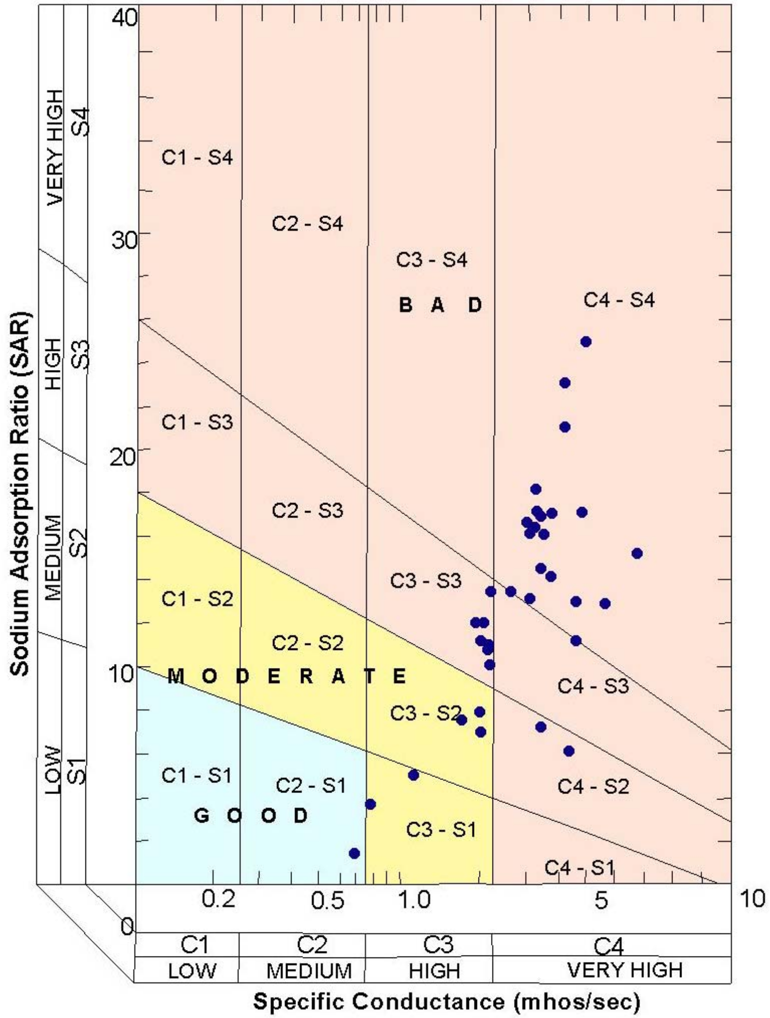
(A) Watershed Region

(B) Core Study Area

Fig. 7.13 U S Salinity Diagram - Irrigation Water Classification of Groundwater, Pre Monsoon (Year 2010)



(A) Watershed Region



(B) Core Study Area

Fig. 7.14 U S Salinity Diagram - Irrigation Water Classification of Groundwater, Pre Monsoon (Year 2012)

GENETIC CLASSIFICATION OF GROUNDWATER

Water being a part of active hydrological cycle and little residence time have active interaction through numerous chemical reactions with atmospheric and geological environments. Therefore, the genetic attributes of groundwater has direct relevance with its major ionic contents. In order to determine genetic relationship of study areas' groundwaters and to understand groundwater facies; the candidate has evaluated the chemical contents using Piper Trilinear and Gibbs approach.

PIPER TRILINEAR DIAGRAM

This diagram (Piper, 1953) is a tool to interpret genetic character of groundwater. It is one of the important tools for drinking water potablity analysis. Another advantage, this diagram can take 'n' numbers of data from similar or varied geological environments and provide clues about the predominance of particular ions, physico-chemical conditions etc. through various fields. The diagram consists of two small triangles on lower side and one diamond shape polygon in middle. The two triangles represent cationic and anionic contents. Percentage of ion concentration of total cations/anoins plotted on lower triangles and parallel lines are drawn upward in middle diamond shaped polygon where lines of cation and anion cross each other (Fig. 7.15). The intercept points give the total chemical content (major ions only) of particular sample. The relative positions of plotted points in a central diamond is then interpreted in accordance with its different sub fields and their characteristics. Information pertaining to various fields and their salient significance is given here under-

1. Alkaline earths exceed alkalies
2. Alkalies exceed alkaline earths
3. Weak acids exceeds strong acids
4. Strong acids exceeds weak acids
5. Carbonate hardness (Secondary alkalinity) exceeds 50 % i.e. chemical properties of groundwater are dominated by alkaline earths and weak acids
6. Non carbonate hardness (Secondary salinity) exceeds 50 %.

7. Non carbonate alkali (Primary salinity) exceeds 50 % i.e. chemical properties are dominated by alkalies and strong acids, ocean water and many brine plot in this area, near its right hand vertex.
8. Carbonate alkali (Primary alkalinity) exceeds 50 % - here plot the groundwater which are inordinately soft in proportion to their content of dissolved solids.
9. No one cation – anion pair exceeds 50 %.

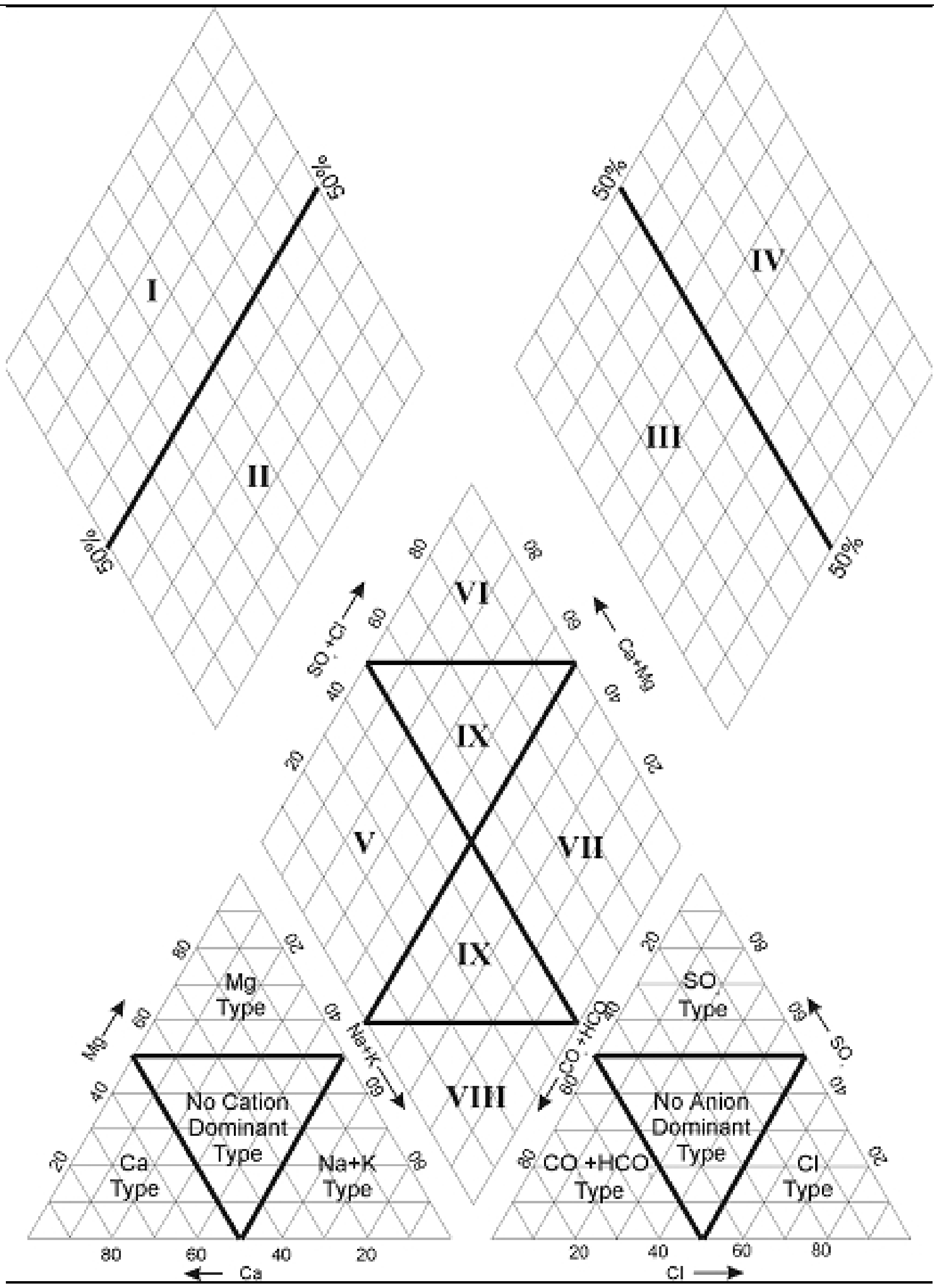


Fig. 7.15 Genetic Interpretation of Piper Trilinear Fields (Source: Piper, 1953)

For the presented study, ionic concentrations of major cations and anions have been plotted on the Piper Trilinear diagram for the years and seasons as pre monsoon 2008 & 2011; post monsoon 2008 & 2011 (7.16 & 7.17). The derived inferences on Piper plots are as under-

- Pre monsoon plots for year 2008 and 2011 fall in Field-7 suggesting alkalies exceeds alkaline earth and strong acid exceeds weak acids. Sodium and chloride are dominant ions. In pre monsoon, most of the samples (75 %) indicate primary salinity, means non carbonate alkali. Only 20 % samples fall in potable water field i.e. Fields 8 & 9.
- Piper plots for post monsoon 2008 and 2011 also suggest more or less similar trend i.e. alkalies and strong acids exceed alkaline and weak acids. Sodium remains as dominant cation, while chlorides along with carbonates are dominated anion. The plots indicate primary salinity in groundwater. Only 5 to 18 % groundwater samples are of potable nature i.e. Field 8 & 9.

Therefore, overall genetic characteristics of study areas' groundwater have described as-

- Groundwater has dominance of alkalies and strong acids over alkaline earth and weak acid respectively in all the aquifers.
- In general sodium and chloride are dominant ions. In watershed region, chloride is emerged as more dominant ion. Concentration of sodium and chloride is higher in coastal area aquifers than the inland aquifers therefore, pointing to influence of sea water salinity.
- Groundwater of the study area indicates primary salinity means non carbonate salinity where alkalies and strong acids are dominant.
- Very few water samples fall in potable field in pre monsoon season while in post monsoon also majority of the water samples fall in non potable category. This may be due to dilution of salt enriched soils during rains and their sub sequent enrichment in groundwater regime.

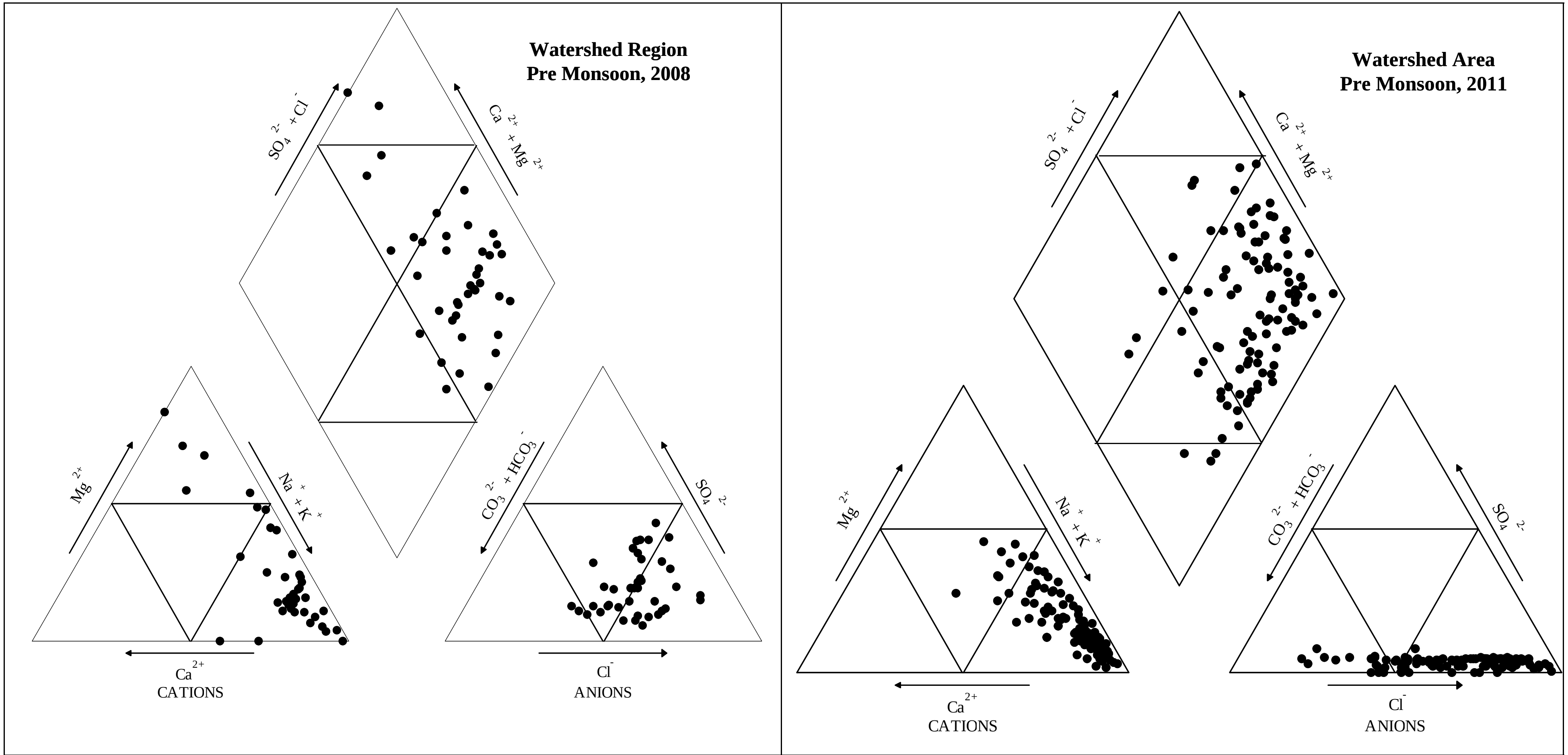


Fig. 7.16 Piper Trilinear Diagram of Pre Monsoon Season of Year 2008 and 2011 (After Piper, 1953)

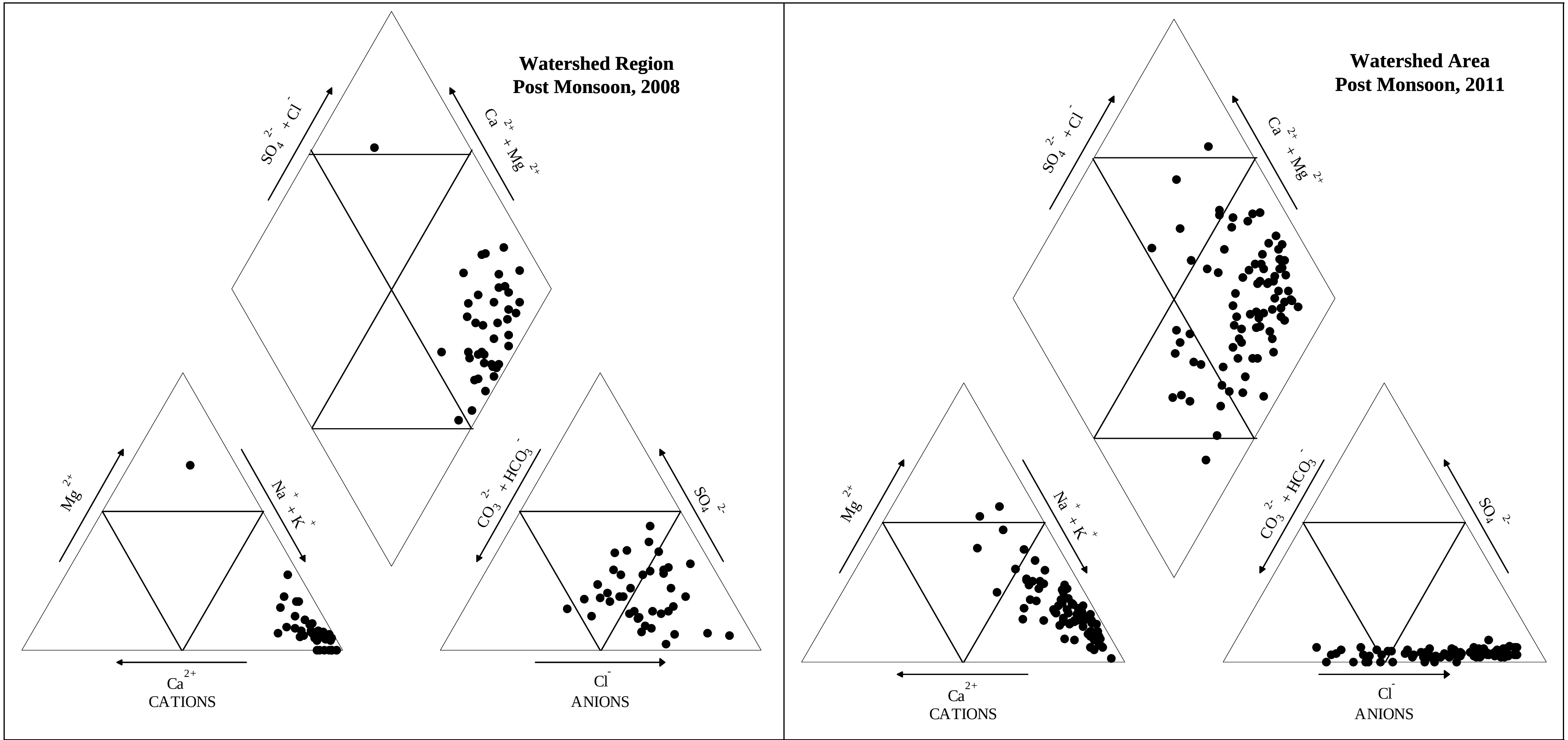


Fig. 7.17 Piper Trilinier Diagram of Post Monsoon Season of Year 2008 and 2011 (After Piper, 1953)

Water is considered to be the most chemically reactive and being part of hydrologic cycle has numerous interactions viz: ocean, atmosphere (precipitation), ground surface (a soil), and rock formations. Under different states it react with available dissolved constitutes therefore its chemical content goes on modifying (Gabriel and Donatus, 2011). Study area being a part of semi arid- arid domains, evaporation process further enriches the chemistry of groundwater. Even, groundwater occurrence at shallow depths and deeper levels tend to vary in its chemical content due to its reactions with aquifer minerals (Subrami et al, 2010)

Therefore in order to establish true genetic relationship of study areas' groundwater, the candidate has evaluated the chemical content using Gibbs (1970) plots.

GIBBS PLOTS

Gibbs (1970) has suggested a method to interpret genetic relationship of groundwater by relating TDS with anions and cations present in groundwater. Gibbs plots identifies three domains viz; (01) Evaporation Dominance; (02) Rock Dominance and (03) Precipitation Dominance. In Gibbs plot TDS content is plotted on Y axis while ration of cations ($Na^+ + K^+$) to ($Na^+ + K^+ + Ca^{+2}$) plotted on X axis. Same way in another diagram, along with TDS value on Y axis, ration of Cl^- to ($Cl^- + HCO_3^-$) of anions are plotted on X axis.

Thus, derived Gibbs plots (Fig. 7.18) for the study area are suggestive of rock dominance with very few waters belongs to evaporation domain. This corroborates to prevailing chemical contents in study areas' groundwater, predominantly attributed to the dissolution of rock minerals constituting aquifers at large. Water sample showing evaporation dominance are definitely relevant to semi arid to arid climatic domain of the study area.

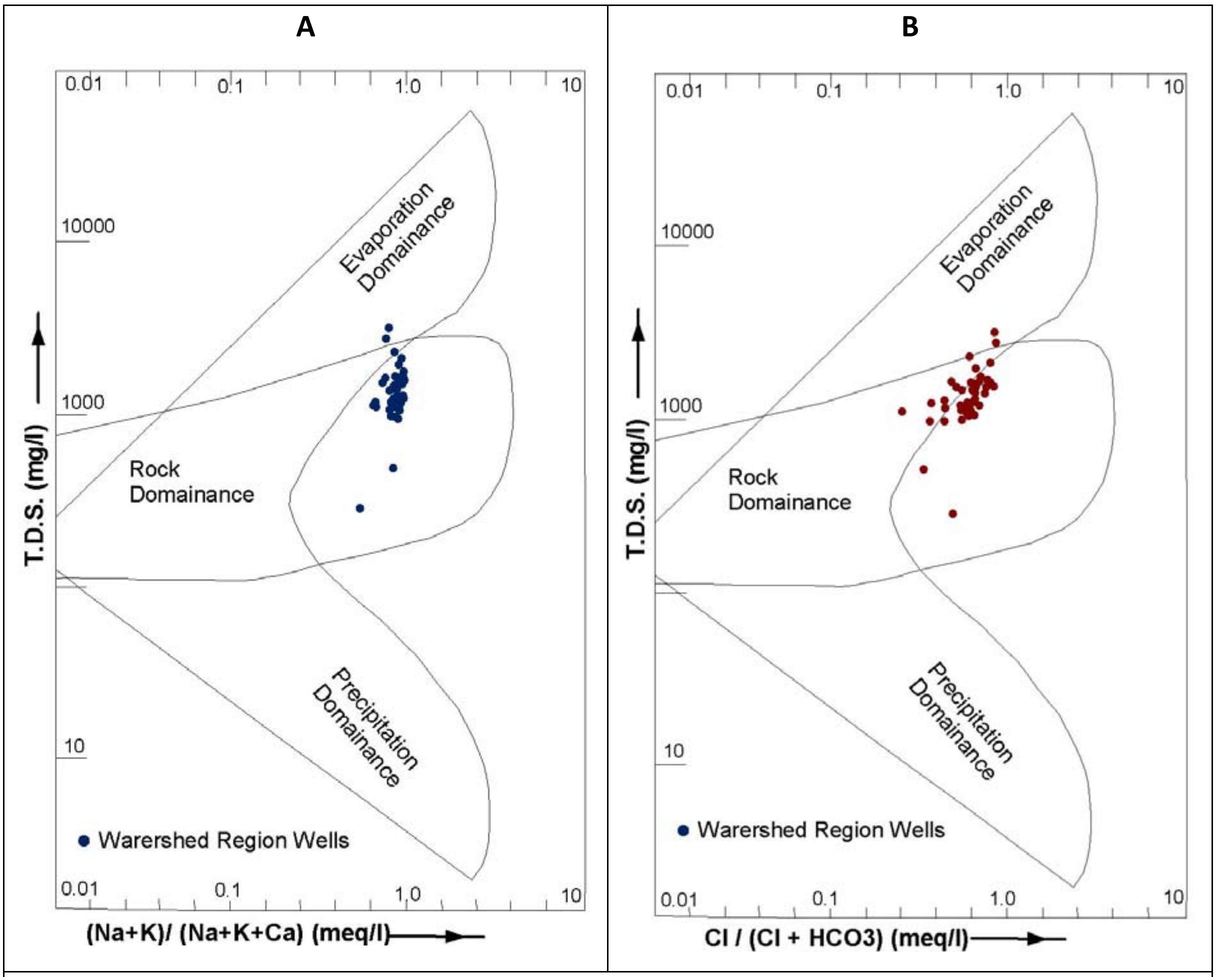


Fig. 7.18 Gibbs Plots for Interpretation of Groundwater Chemistry in Watershed Region (After Gibbs, 1970)

STIFF PATTERN DIAGRAM

There exists large number of graphical techniques to represent chemical content in groundwater. The Stiff Pattern diagram (Stiff, 1951) is one of them ideal to identify rock specific polygon shapes signifying rock - water interaction. Stiff's Patterns are useful in making comparison of waters from highly mineralized to low. (Hem, 1959)

As the study area is characterized by varied lithological domains, the candidate has made an attempt to construct the polygon patterns using aquifer specific groundwater quality data. Pattern diagrams have been prepared by using cationic and anionic contents of groundwater samples. The diagram has four parallel axes and one middle zero line. Cations are plotted on left side of vertical axis and anions on right side of the axis by selecting appropriate scale. The study area is characterized by 03 rock specific aquifers viz; Bhuj Fm (Sandstone), Deccan Trap (Basalt) and Kankavati Fm (Sndstoen); the candidate has constructed the stiff patterns for these aquifers using pre monsoon (2010) data (Fig. 7.19).

The obtained pattern shows a definite diversity in terms of their aquifer composition. In general, Stiff pattern diagram of Kankavati Fm. sandstone indicate highly mineralized water followed by groundwater from Bhuj Fm. sandstone and then basalt.

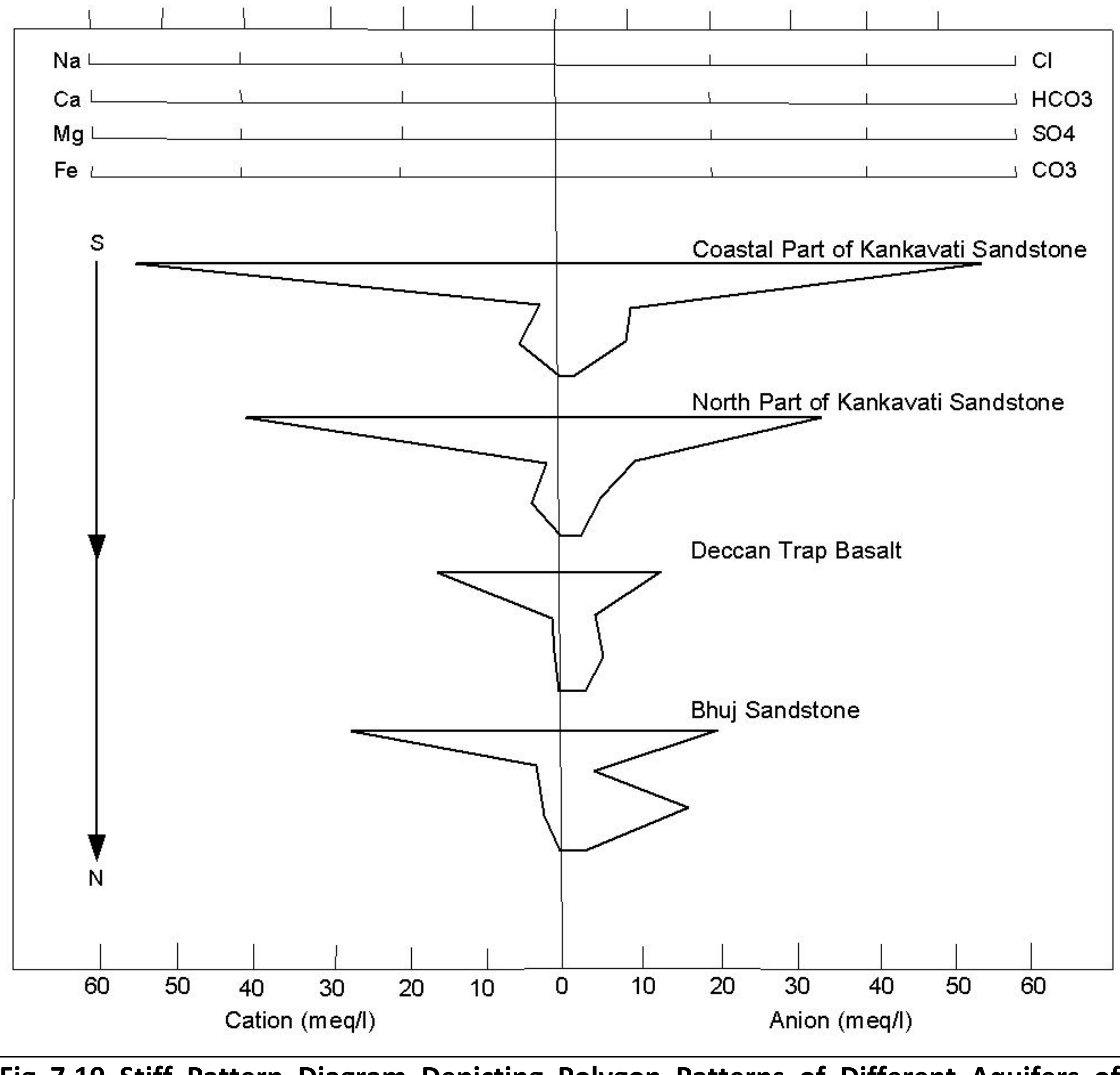


Fig 7.19 Stiff Pattern Diagram Depicting Polygon Patterns of Different Aquifers of Study Area **(After Hem, 1991)**

GROUNDWATER FACIES

Hydro-chemical facies of groundwater has been used to diagnose chemical character of water solution in hydrologic system. (Seaber, 1962) The facies reflects the effect of chemical processes occurring between lithologic framework and groundwater. (William, 1966) Chemical composition of groundwater also depends on rate of precipitation, climate, anthropogenic activities etc. In presented study, hydro-chemical facies has been studied to assess dominance of ion in groundwater and changes in it over the period. Change in chemical composition may be caused of ion exchange, base exchange, chemical precipitation etc.

Proportion of cation and anion has been studied for the last five years and based on ionic dominance, aquifer specific facies have been constructed (Table 7.13). Groundwater from Bhuj Fm. sandstone is mainly sodium-chloride type of water where concentration of bi-carbonate and sulfate exceed each other in some areas. In Basalt aquifers, dominance and order of cations gives one type viz, sodium type water, but in anion bi-carbonate and chloride are dominant anions. Kankavati Fm. sandstone aquifer, groundwater has single type of hydro-chemical facies, which is sodium-chloride type. In general, groundwater has sodium-chloride type of facies except some areas of basalt. This suggest lower most hydrodynamic zone which is referred as stagnant in which rocks are unleached and water is highly mineralized. (Kamensky, 1958) Sodium-chloride dominance further indicates sea water influence in groundwater and base exchange reaction where sodium has replaced calcium and magnesium.

Table 7.13 Hydro-Chemical Facies of Groundwater in the Study Area

Aquifer	Facies
Bhuj Fm. Sandstone	$Na^+ – Ca^{2+} – Mg^{2+} – K^+ : Cl^- – SO_4^- – HCO_3^-$ Type
	$Na^+ – Ca^{2+} – Mg^{2+} – K^+ : Cl^- – HCO_3^- – SO_4^-$ Type
Deccan Trap Basalt	$Na^+ – Ca^{2+} – Mg^{2+} – K^+ : HCO_3^- – Cl^- – SO_4^-$ Type
	$Na^+ – Ca^{2+} – Mg^{2+} – K^+ : Cl^- – SO_4^- – HCO_3^-$ Type
Kankavati Fm. Sandstone	$Na^+ – Mg^{2+} – Ca^{2+} – K^+ : Cl^- – HCO_3^- – SO_4^- – CO_3^{2-}$ Type

Chapter - VIII

SALINITY HAZARDS AND ZONATION

CHAPTER – VIII

SALINITY HAZARDS AND ZONATION

INTRODUCTION

Groundwater quality is as important as the quantity. Groundwater consists of many types of dissolved salts which are basic indices of water quality. Groundwater salinity can be defined simply as high concentration of dissolved salts in water more than permissible limit for drinking and irrigation water use. Salinity is a very critical problem of groundwater quality worldwide as it makes adverse impact on human health, plant growth, livelihoods and ecosystem. Once groundwater get saline, it is very difficult to remediate as it needs very scientific program with enough time and finance. There are various causes for groundwater salinization. Rock deposited in marine environment has inherent salt particles preserved at the time of deposition. Therefore, groundwater from marine deposited formation has little high concentration of salts due to inherent salinity. Sea water encroachment in deeper aquifer takes place due to over exploitation of groundwater. Sea water salinity in groundwater is very critical issue in coastal area where sea water is a major source of salinity.

The groundwater salinity in the study area has both the characters i.e. coastal salinity and inherent salinity. Along with this, the region is characterized as arid to semi arid region where evaporation salinity also exists. Further in the light of on-going rapid pace of industrialization causing more stress over ground water regime, it has become more pertinent to study the problem of groundwater salinization. Groundwater salinity aspects have been studied for seasonal and long term duration based on primary and historic groundwater quality data. The present status and level of seasonal variation in groundwater quality have already been presented in previous Chapter- 8.

The present chapter deals with long term change in groundwater quality, causes and its impact. Author has also made an attempt to map salinity zonation for its vulnerability assessment.

SALINITY CHARACTERISTICS

Groundwater salinity includes various types of ions in dissolved form wherein groundwaters in study area are characterized by dominant ions as chloride and sodium. In present case Total Dissolved Solids (TDS), chloride and boron have been considered as indices to map groundwater salinity hazards in the study area. TDS is a very basic norm which determines level of dissolved salt concentration in groundwater, while chloride is a very important indicator of sea water influence in groundwater. As the core part of the study area is along the sea coast, chloride analysis is very essential to diagnose sea water salinity. Major source of chloride is sea water (Eriksson, 1959; Hem, 1991). Salinity trend in groundwater has been analyzed based on self monitored (Annexure 7.1 to 7.16) and historic data collected from GWRDC (Annexure 7.17). Secular change and present status of TDS and chloride in the study area is given in Table 8.1.

Table 8.1 Aquifer wise Long Term Secular Change in Groundwater Quality

Aquifer	Secular Change (From 1995 to 2010)		Existing Status (2010)		Locality
	TDS (mg/l) Range	Cl (mg/l) Range	TDS (mg/l) Range	Cl (mg/l) Range	
Kankavati Sandstone (Coastal)	500 -3000	200 - 3000	900 - 11000	200 - 5600	Core Area includes- Bhadreshwar to Mundra, Jharpara, Tunda villages
Laterite	300 – 500	50 - 100	2500 - 3500	500 – 1200	Ramaniya, Bocha villages
Deccan Trap Basalt	300 – 1400	100 – 700	600 - 3500	250 - 2000	Babia, Wanki, Bagada, Vaghura villages
Bhuj Sandstone	800 – 1500	100 - 600	400 - 2900	300 - 1200	Meghpar, Bharapar, Reha, Mathada villages

TOTAL DISSOLVED SOLIDS

Secular change in TDS has been analyzed through isobath map, influenced area calculation and hydrographs. For TDS evaluation groundwater quality data have been utilized from GWRDC for years 1995, 2000, 2005; and self monitoring data for year 2010 (Table 8.2). The data provides scenario of TDS values at interval of 5 year from year 1995 to 2010. Based on the data, hydrographs have been plotted for each aquifer system (Fig 8.1. A, B, C). Secular change in TDS of 15 years is presented as isobath map (Fig 8.2) and calculated area under influence in Table 8.3.

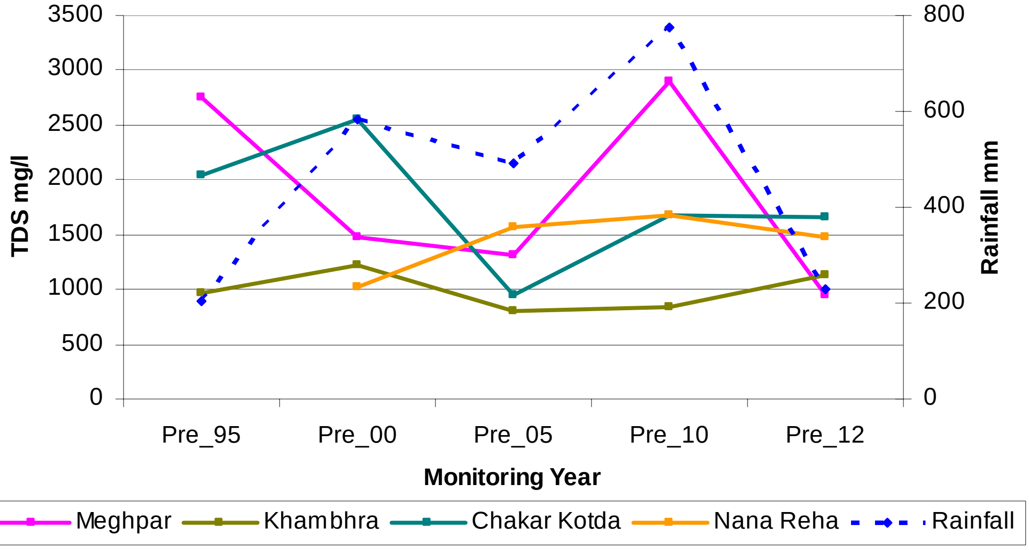
TDS Hydrograph

- TDS-well Hydrographs for Bhuj Fm. Sandstone aquifer (Fig. 8.1 A) indicate stable to slight increase in TDS over a period of 17 years. Well hydrograph of Meghpar village shows high fluctuation in TDS with over all decreasing trend. Observation wells in central part at Reha and Chakar villages, TDS concentration show marginal increase ~ 500 mg/l after year 2005 but later there has been a bit decrease due to continual good rainfall in the study area after year 2008.
- Well hydrographs of basalt aquifers (Fig 8.1 B) indicate high fluctuation in TDS content but overall it is stable.
- Well Hydrographs of Kankavati Fm. Sandstone aquifers (Fig. 8.1 C) show overall increasing trends. In western part, the observation wells at Tunda, Desalpar and Khakhar villages show gradual increase while in eastern part TDS content show stable to slight decrease whereas TDS concentration trend in well hydrograph at Mundra town shows initially stable but later show increase after 2005.

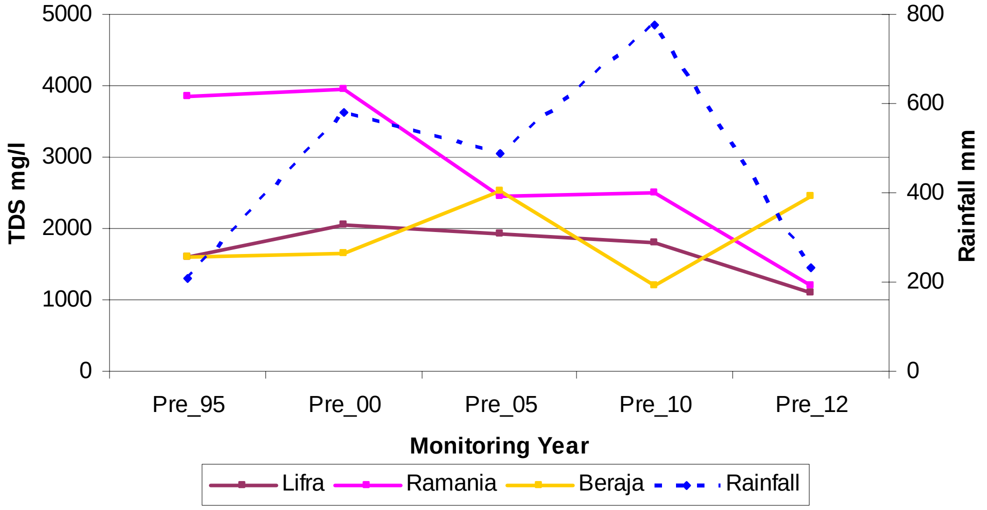
Table 8.2 TDS Concentrations in Groundwaters in the Study Area (Year 1995 to 2010)

GWRDC Well Code	Village	Aquifer	TDS Concentration (mg/l) in Pre Monsoon Season			
			Year 1995*	Year 2000*	Year 2005*	Year 2010
NCCA-254	Luni	Kankavati Sandstone	----	----	1820	4000
NCCA-255	Mundra	Kankavati Sandstone	----	----	490	960
NCCA-256	Navinal	Kankavati Sandstone	----	----	2360	5600
KC-40	Bhujpur (m)	Kankavati Sandstone	1020	1160	1470	2500
KC-41	Tunda	Kankavati Sandstone	1860	1540	2440	2900
KC-46	Nani Khakhar	Kankavati Sandstone	880	1400	1480	1290
KCT-12	Deshalpar	Kankavati Sandstone	1600	2120	2420	1900
KCT-11	Meghpar	Bhuj Sandstone	2760		1320	2900
KC-24	Vira	Kankavati Sandstone	4480	3460	3400	2300
KC-25	Chandroda	Basalt	1340	3460	3800	1660
KC-26	Khambhra	Bhuj Sandstone	960	1220	800	830
KC-33	Bharapar	Bhuj Sandstone	480	760	700	2300
KC-34	Chakar Kotda	Bhuj Sandstone	2040	2560	940	1680
KC-35	Lifra	Basalt	1600	2040	1930	1800
KC-36	Patri	Basalt	1340	3260	5060	3400
KC-37	Bhadreshwar	Kankavati Sandstone	1540	2500	2550	2800
KC-39	Mundra	Kankavati Sandstone	2940	2120	1080	3100
KC-42	Ramania	Laterite	3840	3960	2460	2500
KC-43	Beraja	Basalt	1600	1660	2530	1200
SHP/200	Nana reha	Bhuj Sandstone	.----.	1020	1570	1680
SHP/202	Bhadreshwar	Kankavati Sandstone	.----.	4120	6000	2700
SHP/203	Lakhapar	Kankavati Sandstone	.----.	2480	3400	2900
Shp/II/28	Bhujpur (m)	Kankavati Sandstone	.----.	1300	1540	1620
Shp/II/29	Nani khakhar	Kankavati Sandstone	.----.	1240	1580	1290
KC22	Vidi	Bhuj Sandstone	1220	2120	2690	1290
HLT-052	Vadala	Kankavati Sandstone	2040	2440	3760	.---.
HLT-070	Pragpar	Kankavati Sandstone	1660	1920	1340	2200
HLT-072	Jharpara	Kankavati Sandstone	6600	8320	3010	8000

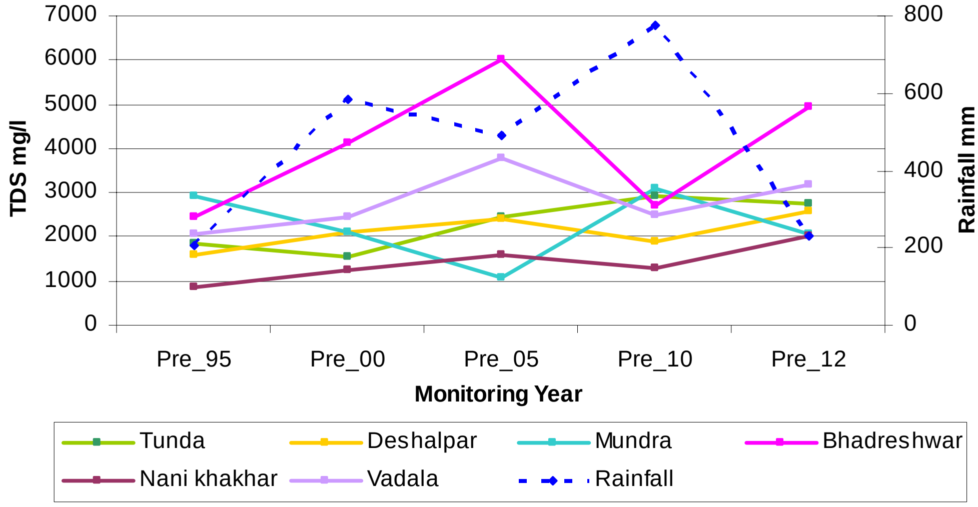
*** Data source: GWRDC (2005)**



A. Hydrographs of Secular Change in TDS - Bhuj Sandstone Aquifer



B. Hydrographs of Secular Change in TDS - Basalt Aquifer



C. Hydrographs of Secular Change in TDS - Kankavati Sandstone Aquifer

Fig. 8.1 Aquifer Specific Well Hydrographs of Secular Change in TDS Concentration

Overall secular spatial change in TDS (Table 8.2) from year 1995 to 2010 show almost 60% study area has suffered from groundwater quality deterioration, where in the TDS has risen between 1000 mg/l and >5000 mg/l. This simply points to over exploitation of groundwater resource. Detail spatial scenario on secular change in TDS has been depicted through TDS isobaths.

TDS Isobaths:

In order to make an assessment on spatial change in TDS from pre-monsoon (1995) period to pre-monsoon (2010), the candidate has generated TDS – isobaths maps (Fig. 8.2 A & B). Based on derived isobath patterns, TDS categorization and their specific aerial coverage have been computed (Table 8.3). The obtained information clearly points to a marked deterioration in groundwater quality due to increased TDS wherein TDS categories 3, 4 and 5 show significant increase in aerial coverage.

Table 8.3 TDS Categories and Spatial Distribution (Year 1995 and 2010)

Sr. No.	TDS Category (mg/l)	Pre Monsoon, 1995		Pre Monsoon, 2010		Overall Trend
		Sq. km.	% of Total	Sq. km.	% of Total	
1	<1500	456.3	27.3	345.7	20.7	Fall
2	1500-2000	772.2	46.3	393.6	23.6	Fall
3	2000-3000	309.6	18.5	712.2	42.7	Rise
4	3000-5000	113.1	6.8	179.7	10.8	Rise
5	>5000	17.7	1.1	37.6	2.3	Rise
Total Area		**1669**	**100**	**1669**	**100**	**-----**

TDS Isobath map (Fig 8.3) on 15 years secular change (1995-2010) shows that there has been a considerable increase in TDS (3000 mg/l) in the western coastal part of the study area viz. around Luni, Jharpara and Bhujpar villages. TDS content is also increased around Chakar, Kotada village based on Bhuj sandstone aquifer. However, there has been a marked improvement around Mundra town, Bhadreshwar and Reha villages situated in eastern part of the study area. The candidate has made spatial area calculation for each category depicted in isobath map (Table 8.4).

The spatial distribution pattern of TDS (Fig 8.2) based on TDS change from year 1995 to year 2010 show a marked dilution i.e. groundwater quality improvement has been observed in about 516 sq.km area (31% of total area); whereas TDS level has increased in about 1153 sq.km area (69 % of total area). In totality there has been a gradual deterioration in groundwater quality particularly in the coastal aquifers.

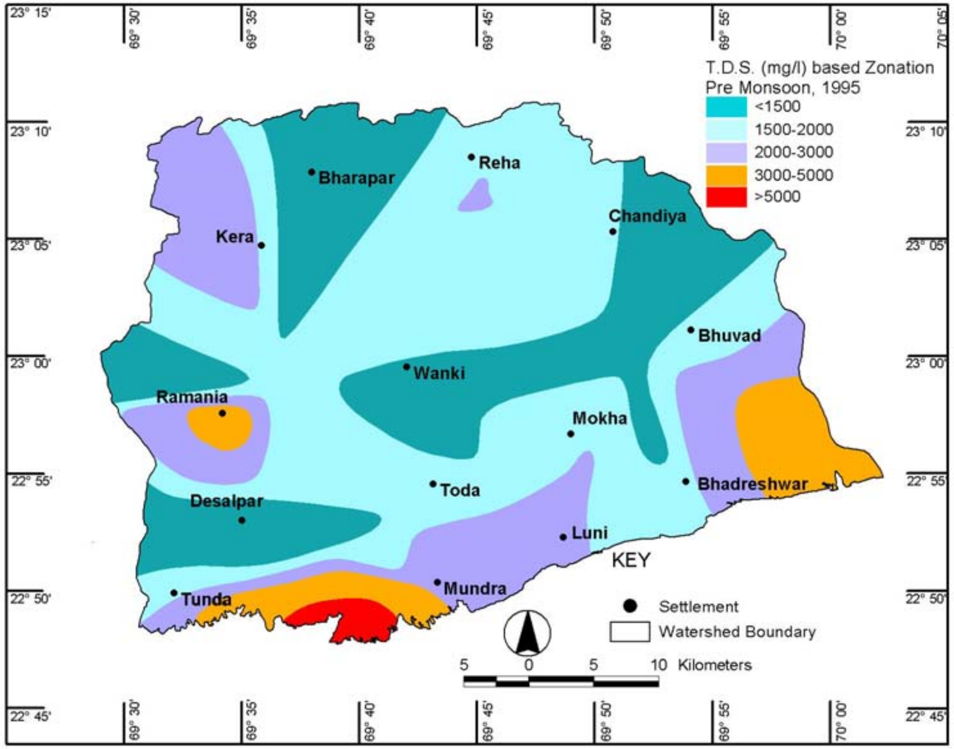


Fig. 8.2 A TDS Isobath Map (Pre Monsoon, Year 1995)

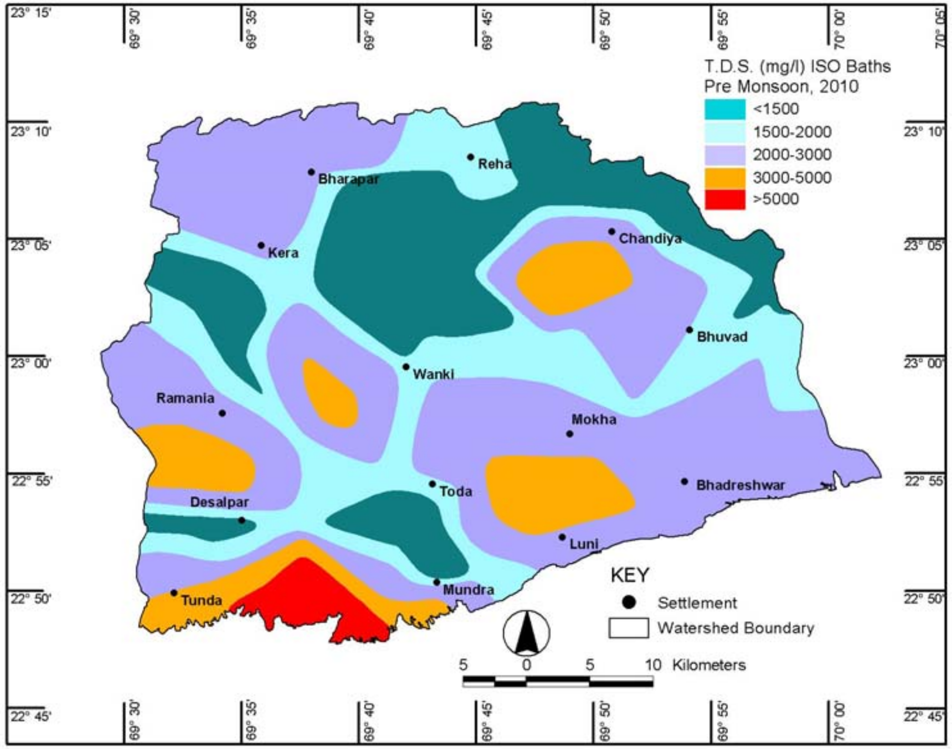


Fig. 8.2 B TDS Isobath Map (Pre Monsoon, Year 2010)

Table 8.4 Spatial Characterization of Secular Change in TDS Content (Year 1995-2010)

Category	Change in (mg/l)	Influenced Area (Sq. km.)	% of Total Area	Important localities
Reduction (Concentration decreased from 1995 to 2010)	>1000	63.3	3.8	Vira, Waladiya, South to Dhrab village
	500-1000	55.2	3.3	Bhadreshwar, Kapaya, Dhrab
	<500	397.5	23.8	Meghpar, Chunadi, Reha, Bandra, Chakar, Bhadreshwar, Mundra, Samagogha
Increase (Concentration increased from 1995 to 2010)	<500	412.1	24.7	Kera, Tumbadi, Wanki, Bhuvad, Shekhadia, Pragpar, Ramania
	500-1000	448.5	26.9	Bharapar, Beraja, Depa, Gelada, Mokha, Khedoi, Chandroda
	1000-2000	262.3	15.7	Bhalot, Khakhar, Tunda, Desalpar, Bhujpur, Siracha, Luni
	2000-3000	25.1	1.5	Navinal, Jharpara
	>3000	4.8	0.3	Navinal, Bhujpur
Total Area		1668.9	100.0	
Net Area: Reduction in TDS Concentration		**516.0**	**30.9**	
Net Area: Increase in TDS Concentration		**1152.8**	**69.1**	

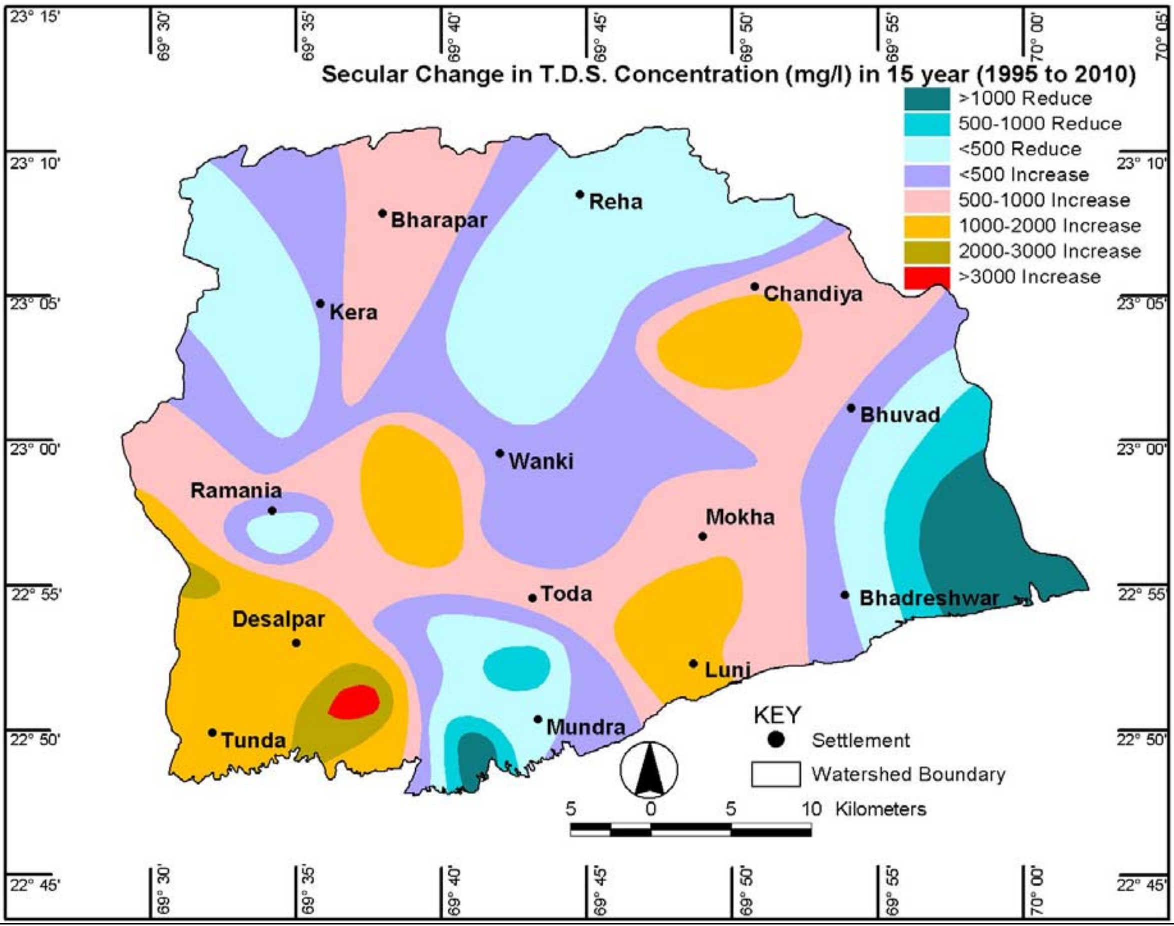


Fig. 8.3 Isobath Map on Secular Change in Total Dissolved Solids (Pre monsoon, 1995 to Pre Monsoon, 2010)

CHLORIDE CONCENTRATION

Chloride is one of the most important indices used for the assessment of groundwater salinity with specific reference to seawater influence in coastal aquifers. The secular change in chloride concentration has been analyzed through chloride isobath map, isobath area characterization and the well hydrographs; at an interval of 5 years period from year 1995 to 2010 (Table 8.5).

Chloride Hydrograph

The candidate has prepared aquifer specific chloride hydrographs (Fig 8.4 A, B, C) for evaluation of long term change in chloride. Salient characteristics of hydrographs are described as under-

- Chloride hydrographs of Bhuj sandstone aquifer (Fig. 8.4 A) show overall increasing trend in chloride concentration (300 – 500 mg/l) over the period after 2005.
- Chloride hydrographs of basalt aquifers (Fig 8.4 B) suggests more or less stable concentration in chloride content in groundwater.
- Chloride hydrographs of Kankavati sandstone aquifers (Fig. 8.3 C) show continual rising trend in chloride content i.e. >1000 mg/l in all the observation wells.

Chloride Isobath

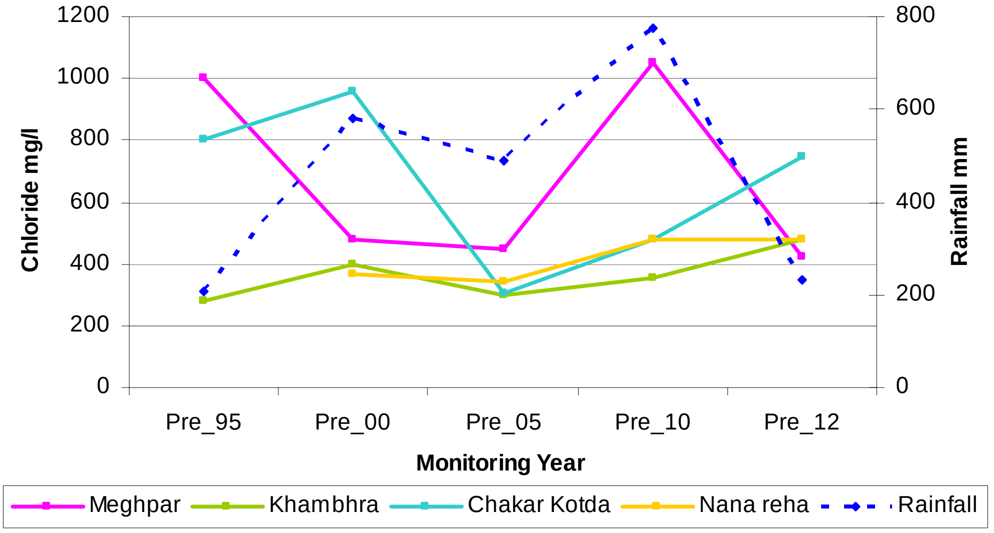
For the assessment on long term spatial changes in chloride concentration in the groundwaters, the candidate has utilized pre monsoon data for the years 1995 and 2010. Respective chloride isobath maps have been prepared (Fig 8.5 A & B) to evaluate and quantify spatial change in chloride concentration over a period of 15 years.

Chloride isobath comparison (Fig. 8.5 A &B) shows presence of maxima between Tunda and Mundra with a chloride concentration > 2000 mg/l (1995) and > 5000 mg/l (2010). Important villages fall with in this maxima domain are Jharpara and Bhujpar. There are pockets in isobath map (2010) showing marked increase (>2000 mg/l) in chloride concentration from 1995 viz around Luni and Bhadreshwar. The change perceived in chloride concentration is more in the coastal aquifers comprising Kankavati Fm. Sandstones.

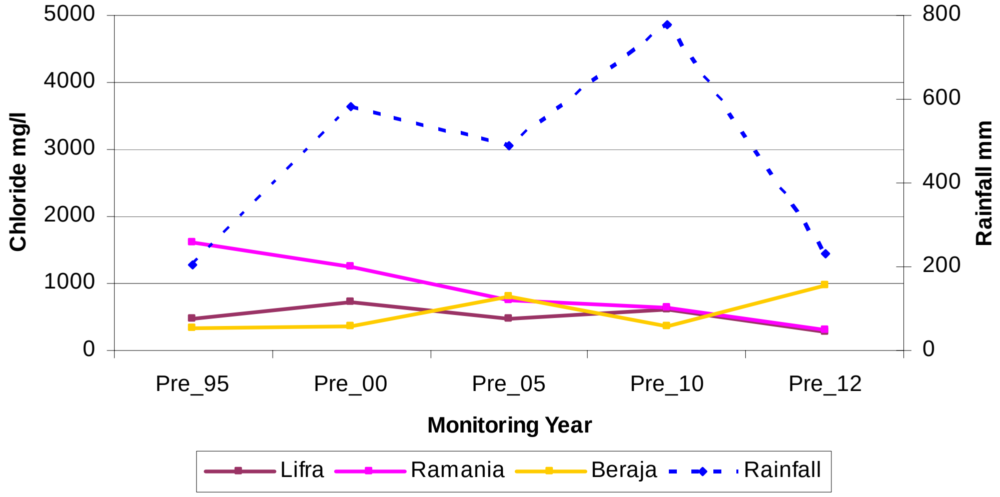
Table 8.5 Chloride Concentrations in Groundwaters in the Study Area (year 1995 – 2010)

GWRDC Well Code	Village	Aquifer	Chloride Concentration (mg/l) in Pre Monsoon Season			
			Year 1995*	Year 2000*	Year 2005*	Year 2010
NCCA-254	Luni	Kankavati Sandstone	.----.	.----.	920	2560
NCCA-255	Mundra	Kankavati Sandstone	.----.	.----.	120	160
NCCA-256	Navinal	Kankavati Sandstone	.----.	.----.	536	2450
KC-40	Bhujpur (m)	Kankavati Sandstone	280	360	520	674
KC-41	Tunda	Kankavati Sandstone	680	296	800	833
KC-46	Nani Khakhar	Kankavati Sandstone	160	416	400	408
KCT-12	Deshalpar	Kankavati Sandstone	344	600	920	939
KCT-11	Meghpar	Bhuj Sandstone	1000		450	1050
KC-24	Vira	Kankavati Sandstone	1840	1400	1400	709
KC-25	Chandroda	Basalt	360	1280	1720	514
KC-26	Khambhra	Bhuj Sandstone	280	400	296	355
KC-33	Bharapar	Bhuj Sandstone	104	136	160	750
KC-34	Chakar Kotda	Bhuj Sandstone	800	960	304	480
KC-35	Lifra	Basalt	472	720	480	620
KC-36	Patri	Basalt	416	1280	2000	1471
KC-37	Bhadreshwar	Kankavati Sandstone	472	740	880	1200
KC-39	Mundra	Kankavati Sandstone	1040	376	216	1050
KC-42	Ramania	Laterite	1600	1240	760	630
KC-43	Beraja	Basalt	344	368	800	372
SHP/200	Nana reha	Bhuj Sandstone	.----.	368	344	480
SHP/202	Bhadreshwar	Kankavati Sandstone	.----.	1960	3200	680
SHP/203	Lakhapar	Kankavati Sandstone	.----.	1120	1680	1120
Shp/II/28	Bhujpur (m)	Kankavati Sandstone	.----.	560	560	479
Shp/II/29	Nani khakhar	Kankavati Sandstone	.----.	544	760	408
KC22	Vidi	Bhuj Sandstone	400	144	1140	408
HLT-052	Vadala	Kankavati Sandstone	680	1000	1480	.---.
HLT-070	Pragpar	Kankavati Sandstone	320	200	200	479
HLT-072	Jhaarpara	Kankavati Sandstone	3000	3880	1080	4573

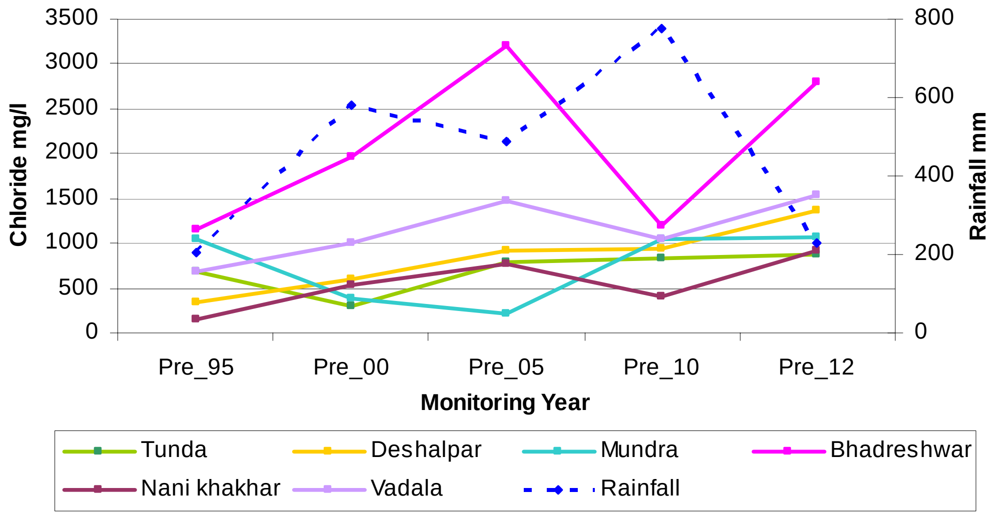
*** Data source: GWRDC (2005)**



A. Hydrograph of Secular Change in Chloride in Bhuj Sandstone Aquifer

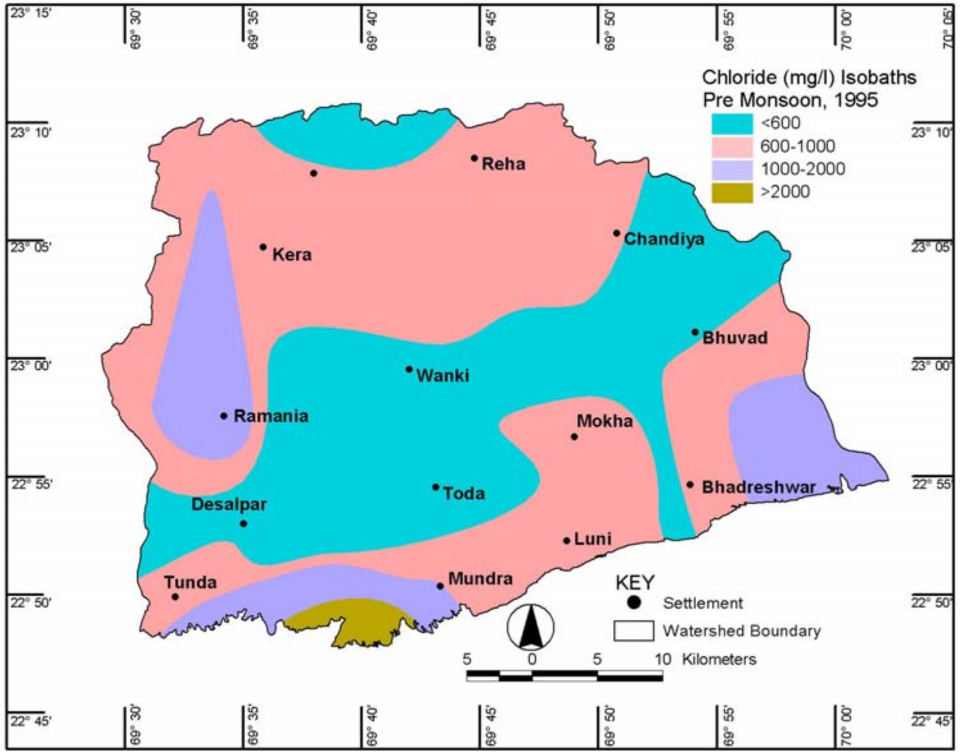


B. Hydrograph of Secular Change in Chloride in Basalt Aquifer



C. Hydrograph of Secular Change in Chloride in Kankavati Sandstone Aquifer

Fig. 8.4 Aquifer Specific Hydrographs of Secular Change in Chloride Concentration in Study Area



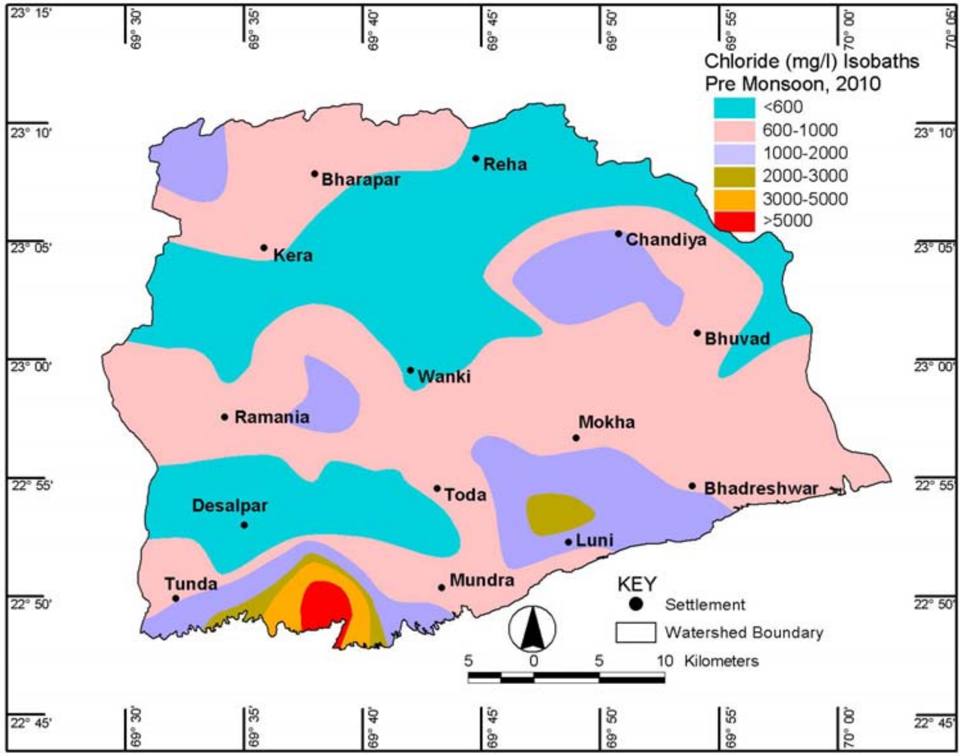


Fig. 8.5 A. Chloride Isobath Map (Pre Monsoon, 1995)	**Fig. 8.5 B. Chloride Isobath Map (Pre Monsoon, 2010)**

The candidate considering these two chloride isobath scenarios computed the aerial coverage in accordance with the derived chloride concentration categories (Table 8.6). The derived outcome clearly establishes an overall deterioration in groundwater quality due to increase in chloride content particularly the categories 3 to 6 (>1000 mg/l – 5000 mg/l). This rise in chloride concentration in groundwater of coastal aquifers is attributed to over-exploitation of aquifers showing lowering of groundwater levels more than 50 m.

Table 8.6 Chloride Categories and Spatial Distribution (Year 1995 and 2010)

Sr. No.	Chloride Category (mg/l)	Pre Monsoon, 1995		Pre Monsoon, 2010		Overall Trend
		Area sqkm.	% of Total	Area sqkm.	% of Total	
1	<600	593.7	35.6	526.2	31.5	Fall
2	600-1000	834.0	50.0	834.5	50.0	No Change
3	1000-2000	220.0	13.2	250.5	15.0	Rise
4	2000-3000	21.2	1.3	26.1	1.6	Rise
5	3000-5000	0.0	0.0	19.4	1.2	Rise
6	>5000	0.0	0.0	12.3	0.7	Rise
Total		**1669**	**100**	**1669**	**100**	**----**

Chloride isobaths for depicting secular change of last 15 years (Fig 8.6) point to a marked increase in chloride concentration in Kankavati sandstone aquifer. The increase in chloride content is >3000 mg/l observed around Jharpara and Bhujpur villages. Another maxima up to 2000 mg/l rise in chloride concentration is around Luni- Mokha villages. The candidate based on secular isobath map has categorized the study area in terms of rise and fall in chloride concentration. The outcome of categorization is given in Table 8.7. Almost more than 5 % of the area predominantly coastal aquifers shows enhancement in chloride content > 1000 mg/l over a period of last 15 years.

Table 8.7 Spatial Characterization of Secular Change in Chloride Content (Year 1995-2010)

Category	Change in mg/l	Influenced Area Sq. km.	Influenced % of Total Area	Influenced Area around Villages
Reduction (Concentration decreased from 1995 to 2010)	>1000	4.3	0.3	Ramania
	500-1000	84.6	5.1	Chunadi, Tumbadi, Gajaod
	<500	429.5	25.7	Sanosara, Reha, Kanjra, Depa, Mindiyana, Vira, Hatdi,Valadiya
Increase (Concentration increased from 1995 to 2010)	<500	715.8	42.9	Meghpar, Kera, Wanki, Bhuvad, Chakar, Bhadreshwar, Desalpar, Kapaya, Toda, Mundra, Dhrab
	500-1000	333.9	20.0	Mathada, Mokha, Wadala, Bhujpur, Bocha
	1000-2000	76.2	4.6	Luni, Ragha, Bhalot, Navinal, Pratapar
	2000-3000	12.7	0.8	Navinal, Jharpara
	>3000	11.9	0.7	Jharpara
Total Area		**1668.9**	**100.0**	
Net Area: Reduction in Cl^- Concentration		**518.4**	**31.1**	
Net Area: Increase in Cl^- Concentration		**1150.5**	**68.9**	

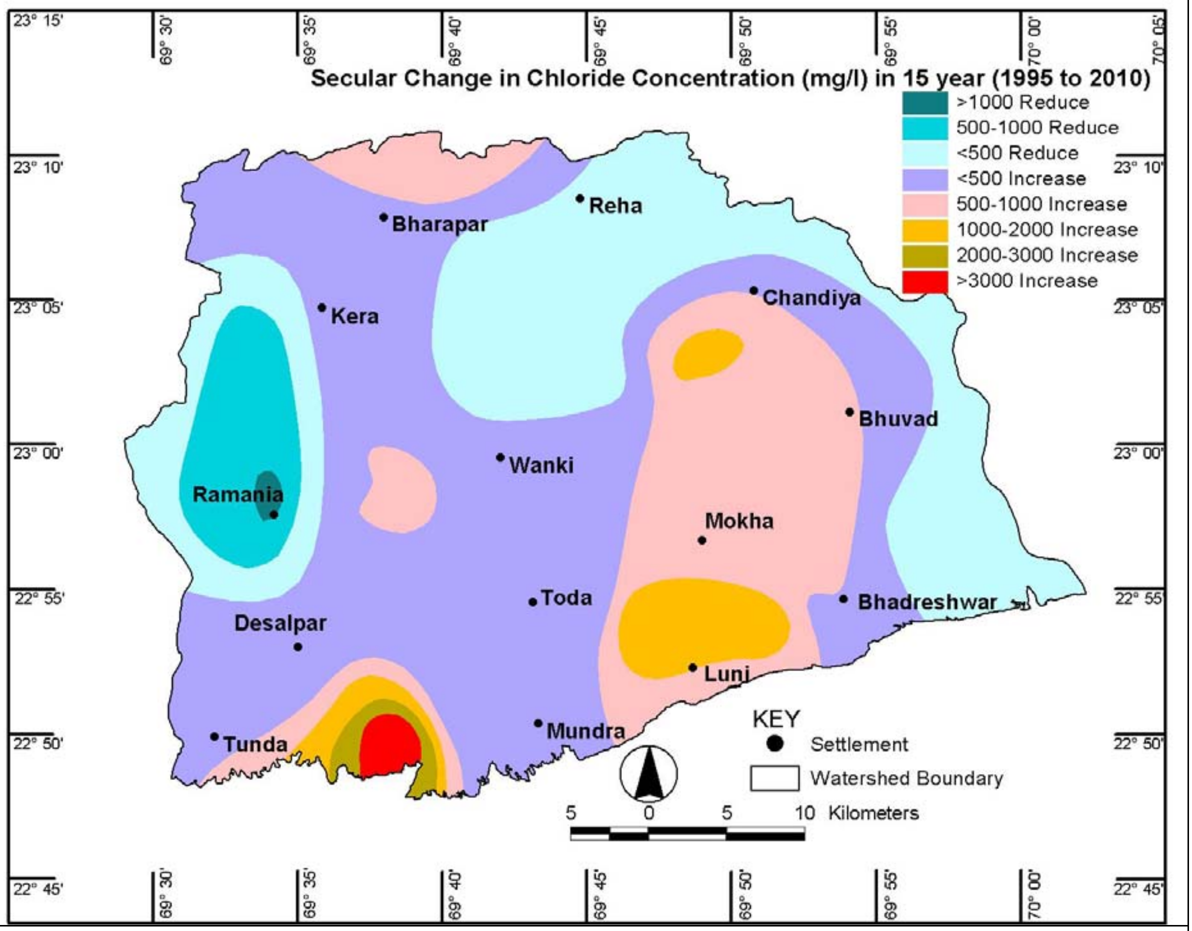


Fig. 8.6 Secular Change in Chloride (Pre Monsoon, 1995 to Pre Monsoon, 2010)

DISSOLVED BORON

Boron concentration in groundwater is normally derived from leaching of rocks and soils that contain borate and boro-silicate minerals (SWRCB, 2010). It can also be derived from municipal waste, industrial effluent and thermal power. The majority of the Earth's boron occurs in the oceans, having average concentration of 4.5 mg/liter (Weast et al., 1985; Hem, 1993). Therefore, boron is considered as on of the indicators of sea water influence in coastal aquifer. In study area, boron has been analyzed for coastal aquifers only. The range of boron in coastal groundwater varies from 0.2 to 3.2 mg/l. According to Indian Drinking Water Standards, the desirable limit of boron is up to 1.0 mg/l (BS, 1999) whereas WHO (2005) prescribed 0.5 mg/l. Taking the permissible limit (1.0 mg/l) as base, boron isobaths have been prepared for core area only (Fig. 8.7). Groundwater in permissible limit of boron (<1 mg/l) occurs in about 167.15 sq.km. area (51 % of total) encompassing western sides of Bhujpar and central-eastern parts of the study area. While 160.85 sq.km. (49 %) area has boron above permissible limits (>1 mg/l). The area around Jharpara, Tunda, Bhujpar, Gelada and north of Luni villages are characteristics of high boron concentration. The boron concentration shows increasing trend towards sea i.e. area around Tunda- Navinal and Jharpara villages. The boron distribution pattern is almost of similar kind of as that of TDS and Chloride; therefore further strengthen the possibility of seawater intrusion in the coastal part of the study area.

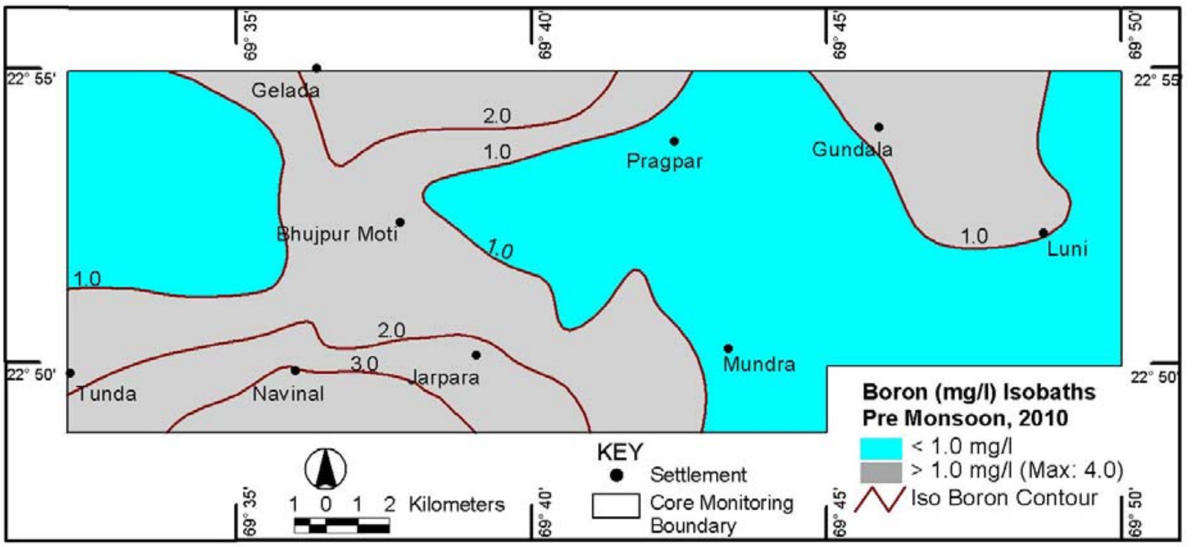


Fig. 8.7 Boron Isobath in Core Study Area

GROUNDWATER SALINIZATION AND CAUSES

Groundwater salinity has various types of origin. Groundwater at shallow depth and active in hydrological cycle is normally good in quality i.e. fresh water. A large part of saline groundwater on earth is present in more or less stagnant condition at greater depths for more than many thousands or million of years (IGRAC, 2009).

The term 'Saline Groundwater' refers to any groundwater containing more than 1000 mg/l total dissolved solids (Carroll, 1962). The classification of saline groundwater based on TDS suggests following categories-

Water Type	**TDS (Salinity) Range (mg/l)**
Fresh	0 – 1,000
Brackish	1,000 -10,000
Saline	10,000 – 100,000
Brine	> 100,000

Genetically, the salinity in groundwater recognizes 04 types of occurrences viz. (01) Connate (Brine) water, (02) Intruded Sea water, (03) Water salinized by contact with soluble salts in the formation, and (04) Water in regions with shallow water table conditions where evapo-transpiration concentrates the salts in soluble (Todd and Mays, 2005).

Further, salinity in aquifers may be ascribed to numerous other sources (TCSWI, 1969) viz.

1. Encroachment of sea water in coastal aquifers
2. Sea water that entered aquifers during past geologic time
3. Salt in salt domes, thin beds or disseminated in geologic formations
4. Water concentrated by evaporation in tidal lagoons, playas and other enclosed areas like Rann
5. Return flows to streams from irrigated land, and
6. Human saline wastes

The study area has very limited shallow depth groundwater restricted to basaltic aquifers. Other parts of the study area are characterized by deep groundwater conditions. In coastal part, alluvium is a shallow aquifer but it has dried up due to lowering of water table.

Regionally, Kachchh district has been identified by three types of groundwater salinity; (01) inherent salinity; (02) sea water intrusion and (03) evaporation (Jadeja, 2005).

INHERENT SALINITY

During deposition of sediments in marine environment, salts are deposited in rock matrix and stored in voids. These salt latter mix with in-filtering fresh water and enhance the salinity in groundwater. Both Bhuj Fm. and Kankavati Fm. sandstones represent mixed fluvio-marine type of depositional environments comprising sandstone with intercalations of clays (Biswas, 1993). Continuous recharge and discharge of groundwater to and from aquifers has reduced salt concentration thereby improved groundwater quality. Same way aquifers developed with laterite, litho-merge clay inhibiting salts make groundwater quality saline.

SEAWATER INTRUSION

This phenomenon is most common in coastal zone where sea water and groundwater in coastal aquifer are in hydraulic dynamics. In this dynamic equilibrium, it results in natural landward thinning ‘saltwater wedge’ overlain by fresh water discharging into sea (Bear et al. 1999). Sea water intrusion can be categorized as lateral ingress on surface and vertically in aquifer.

Intensive groundwater utilization against limited recharge results in lowering down of water table. Lowering down of water table reverse groundwater gradient and allow sea water to move inside the fresh groundwater zone. Perhaps groundwater salinity in coastal aquifers of the study area is attributed to this factor. Agriculture being a major source of livelihood, farmers use more and more groundwater for better production and to secure their crops. Industries in study area also pump groundwater intensively to subsist their industrial and domestic demands. The study area indicates drastic increase in population from year 2011, necessitating more exploitation of groundwater resource. All these factors make aquifer under pressure of over exploitation. During last 15 years, water table has gone down more than 80 meters in Bhuj Fm. sandstone around Reha and Chakar villages; and in Kankavati Fm. sandstone aquifer around Bhujpar village (Fig 5.21). Analysis of seasonal fluctuation in water table indicates gradual depletion in water table in coastal aquifer. Increased concentration of chloride & TDS and boron in entire coastal part of the study area point to sea water intrusion in coastal aquifer; therefore can be considered as prime factor in overall deterioration in groundwater quality.

Saline water encroachment in coastal aquifers occurs as a result of over pumping of fresh water that previously has discharged from a coastal aquifer. The study area is a fit case to explain contamination of freshwater aquifers by sea water. Salt water intrusion can be categorized as active and passive types (Fetter, 1973).

Passive Seawater Intrusion results when in-spite of pumping of fresh water from the aquifer, the hydraulic gradient in the aquifer remains sloping towards the sea water – freshwater interface (Fig. 8.8 A). In the passive encroachment the interface would gradually shift in land until it reaches an equilibrium positions.

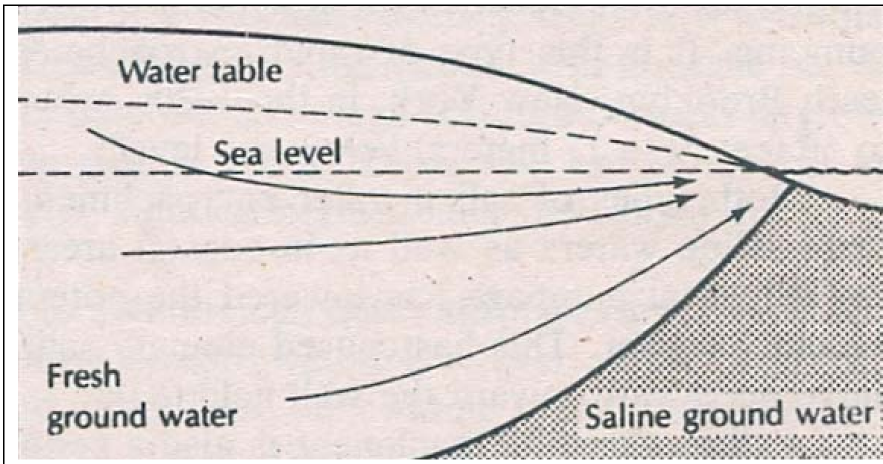


Fig. 8.8 A Passive Seawater Intrusion in an Unconfined Aquifer
(Source: Fatter, 1973)

In case of **active seawater intrusion**, the natural hydraulic gradient has been reversed and the movement of freshwater is away from sea water –fresh water interface (Fig. 8.8 B). Active encroachment is mainly attributed to continual and concentrated withdrawal of groundwater causing a deep cone of depression. The interface boundary in this case will move rapidly inland until it has reached the center of pumping.

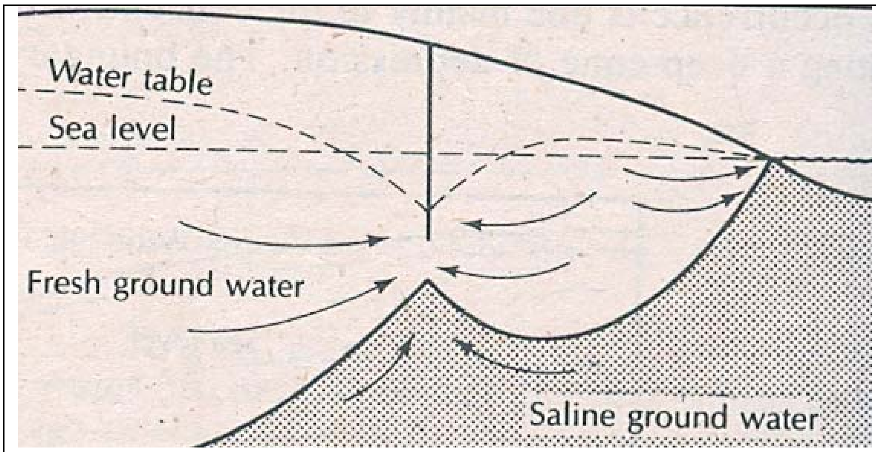


Fig. 8.8 B Active Seawater Intrusion in an Unconfined Aquifer (Source: Fatter, 1973)

In the study area, the coastal segment between Tunda and Mundra is one such region wherein the aquifer is witnessing sea water encroachment of active nature. The conclusion on active type of sea water encroachment in coastal aquifer is based on following facts-

1. Excessive lowering of water table (>80 m) due to over pumping has caused reversal in hydraulic gradient (Fig.5.21 & 5.26);
2. TDS and chloride concentration has increased over a period of time and are reported the highest values (Fig. 8.3 & 8.6);
3. The dissolved chloride content in coastal aquifer tend to increase with the increase in the depth of water table (Fig.8.7). This further corroborates its affinity and source to sea water;
4. Boron concentration in coastal aquifer is more than 4 mg/l (Fig. 8.7). This implies and points to having its source to sea water that has made encroachment into the coastal freshwater aquifer.

Lateral ingress of sea water travels through river channel and make land saline. This phenomenon has been observed along the entire coast from Navinal to Bhadreshwar in river mouths and surrounding low lying flat areas (the mudflats). The tidal ingress has been observed for a long distance along Phot River. Due to excessive sand mining in Phot River, river bed level has gone down and tidal waters impounded in sand pits ultimately finds it way to aquifer and contaminate water with added salinity. Massive destruction of mangrove forest in ongoing industrial belt has also facilitated the tidal waters to have more lateral spread and contaminate the groundwater through slow percolations.

EVAPORATION

The study area is climatically fall under arid region where rate of evaporation is normally high. In evaporation, water is lost in atmosphere as vapor and leaving behind the salt particles with soil. This makes soil enriched with salts (Carroll, 1967). During precipitation, salt preserved in soil get diluted and becomes a part of groundwater system through in-filtration. Further, coastal area has number of salt pans manufacturing thousands of tons of salt annually. Strong wind form sea side obviously lift dry salt from these salt pans and spread in inland regions, it latter become a part of soil and groundwater system. Therefore, study area makes salinity contribution to groundwater through the process of evaporation too.

IRRIGATION

Crop intake necessary water from supplied water and transfer to atmosphere as water vapor during evapo-transpiration process. In this process, salt remains with soil and concentrate in it. Irrigation with poor quality water adds more salt in soil. This leads to soil salinity hazards. These salts are added to surface water body or groundwater by dilution during precipitation. This may increase progressive salinity in groundwater. However, it is assumed that the groundwater salinization because of irrigation is restricted to first to ten meters below ground level only (IGRAC, 2009).

SALINITY HAZARDS ZONATION

Based on spatial and temporal behavior of salinity indices, the candidate has made an attempt to classify the study area in salinity hazard zones.

So far salinity hazard zonation is concern, no significant information is available except the work carried out by Shrivastava et.al. (1997). Their adopted methodology for salinity hazard zoning based on areas' satellite image (FCC), vegetation indices and growth along with chloride contours. The overlay model has been based on combining various thematic layers by assigning a score to each attributes using GIS software modules.

In the present case, the candidate has adopted TDS and Chloride isobath maps to derive salinity hazard zones. For this the candidate has overlaid the 02 thematic layers using Idrisi and Carta-Links softwares. Although the generated information (salinity zones) are very much similar to that of TDS isobaths, but still hold good on assigning ratings to various categories based on Drinking and Irrigation Water Quality Standards.

METHODOLOGY

Based on groundwater quality data viz. TDS and chloride isobaths, TDS and chloride concentration have been categorized in four categories representing range of values of parameters and water use standards i.e. drinking water and irrigation water (Table 8.8). Both the layers have been synthesized and given final rating to each category by summing the scores of TDS & Chloride (Table 8.9). The synthesized layer has categorized in four Salinity Hazard Zones as per use i.e. Low - indicate potable water and excellent for irrigation; Moderate - indicate good to moderate for irrigation; High - indicate salt tolerance crop irrigation and very high indicate no utilization.

Table 8.8 Categorization of TDS and Chloride for Salinity Hazard Zonation

Category	Score	Assessment Parameter Concentration		Character as per utilization
		TDS mg/l	Chloride mg/l	
Low	1	<1500	<600	Potable, excellent for irrigation
Moderate	2	1500-2000	600-1000	Good to moderate for irrigation
High	3	2000-3000	1000-2000	Irrigation for salt tolerant crops
Very High	4	>3000	>2000	Prefer for no utilization

Table 8.9 Ranking of Salinity Hazard Zonation

TDS	Chloride					Salinity Hazard Zonation	
	Class	Low	Moderate	High	Very High		
Class	Score	1	2	3	4	Score	Category
Low	1	2	3	4	5	2	Low
Moderate	2	3	4	5	6	3-4	Moderate
High	3	4	5	6	7	5-6	High
Very High	4	5	6	7	8	7-8	Very High

Salinity hazard zonation has been carried out by using candidate's own monitoring data of year 2010 and GWRDC monitoring data of year 2012 (Fig. 8.9 & 8.10). The quantitative assessment of various salinity zones in terms of aerial coverage (Table 8.10) suggests, in the Low Salinity Zone the spatial coverage was 322 sq.km. in year 2010, which has increased to 699 sq.km. in year 2012. This zone represents major part of Bhuj Fm. sandstone and Deccan Trap basalt aquifers. In Moderate Salinity Zone Category, the aerial coverage was 447 sq.km. in year 2010 and it has increased to 356 sq.km. in year 2012. This salinity zone is widely distributed covering part of Bhuj Fm. sandstone, Deccan Trap basalt and the Kankavati Fm. sandstone aquifers. High Salinity Zone sprawling in 721 sq.km. area during year 2010, which has reduced to 352 sq. km. in year 2012. In Very High Salinity Zone, about 179 sq. km. area was influenced in year 2010 that has increased to 263 sq.km. during 2012. High to Very High Salinity Zones are mostly falling in coastal region of the study area encompassing major industrial establishments.

Table 8.10 Salinity Hazards Zonation Vis – a – Vis Spatial Coverage

Category		Year 2010		Year 2012	
		Area Sq. km.	% of Total Area	Area Sq. km.	% of Total Area
1	Low	322	19.3	699	41.9
2	Moderate	447	26.8	356	21.3
3	High	721	43.2	351	21.0
4	Very High	179	10.7	263	15.8
Total		**1669**	**100**	**1669**	**100**

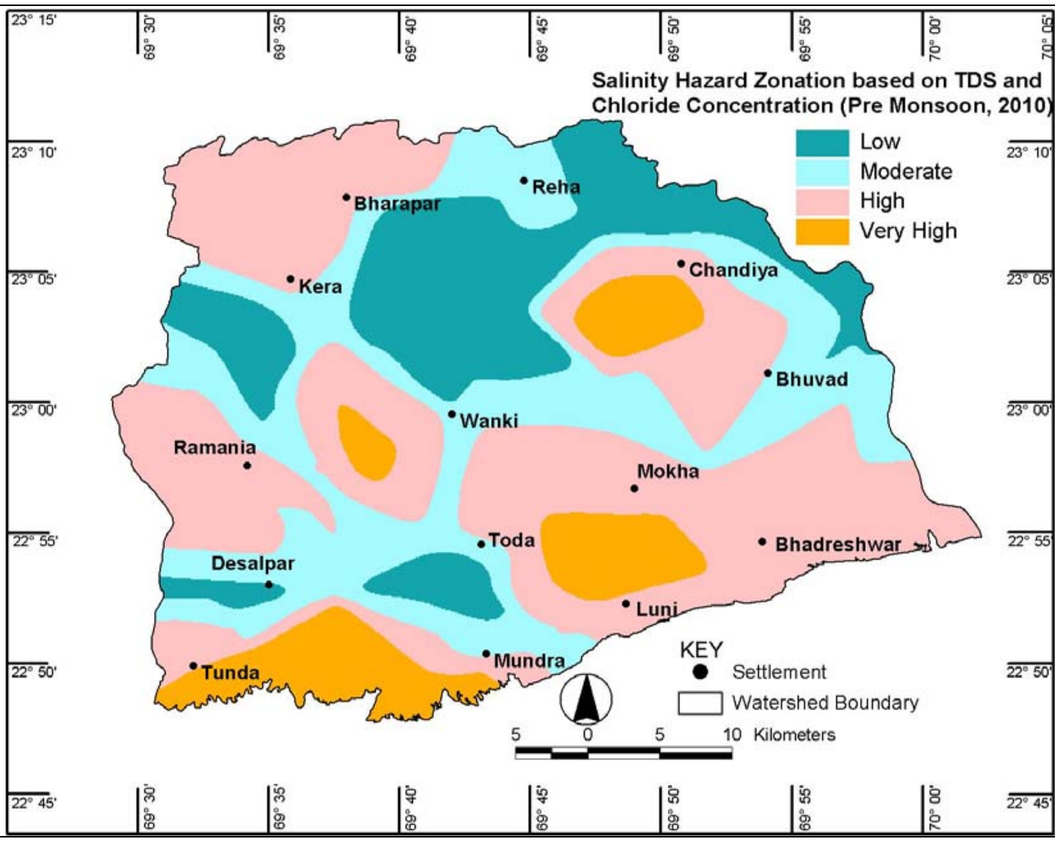


Fig. 8.9 Groundwater Salinity Hazard Zonation (Pre Monsoon, Year 2010)

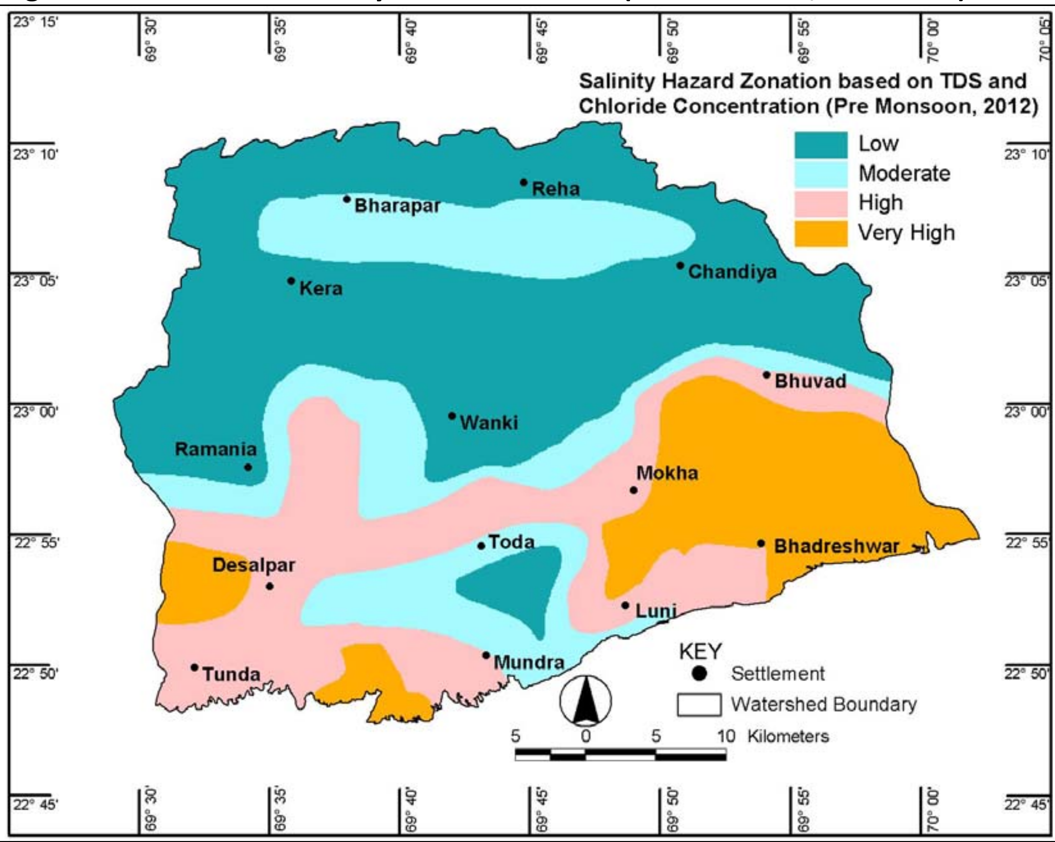


Fig. 8.10 Groundwater Salinity Hazard Zonation (Pre Monsoon, Year 2012)

IMPACT OF SALINITY

Water is very basic and principal resource on the earth being used for various purposes. For drinking water, water must be potable and according to standard norms. Agriculture also depends more on quantity and quality of supplied water. Quality of water impacts on human health, cattle health, soil health and crop production. Use of high salt concentrated water can damage and create hazards.

DRINKING WATER

Poor quality of drinking water cause many types of water-borne diseases. About 80 % of water-borne diseases in the world (WHO, 1984) and over one-third of the total deaths in the developing countries are caused by consumption of polluted water (Earth Summit, 1992). Continuous consumption of saline water may lead to hypertension in human life (Khan et. al. 2008). In Mundra area about 43 % population is affected by seven types of water-borne diseases (Table 2.5). In the study area, use of poor quality water for drinking has increased cases of kidney stone. Beside this, watering of livestock with high salt content may cause physiological upset or even death in livestock (Ayers and Westcot, 1985).

AGRICULTURE

Agriculture requires basic resources i.e. soil and water. Crop yield depends on soil health and quality and quantity of provided watering. If irrigation water is poor in quality or saline, plants have to use more energy to extract water from soil, this affect plant growth and in sequence crop production. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Thorne and Peterson, 1954). Using of saline water for irrigation make soil enriched with salt and make it hard. Hard soil restricts to percolate water or even penetrate roots of plants. Water having high content of sodium affects the basic soil structure, the crumbs. As a result, the soil tends to become deflocculated and relatively impermeable (N. Rao, 2005). High sodium concentration also disrupts the forces that bind soil particle together which lead clay particles expansion and soil dispersion (IGRAC, 2009). Soil dispersion causes clay particles to plug soil pores and reduce permeability and infiltration capacity (Rhoades et al. 1992). Soils in coastal region have been affected by the problems of sodicity and alkalinity due to use of poor quality water that render soil to be unfit for any agriculture practices. Increasing groundwater salinity has also affected the horticulture produce in coastal villages of the study area viz. Jharpara, Dhrab. The poor quality water has made adverse impact on field crops resulting reduction in crop production.

Chapter - IX

EIA OF CORE AREA

CHAPTER – IX

ENVIRONMENTAL IMPACT ASSESSMENT STUDY OF CORE AREA

INTRODUCTION

The core area constitutes an integral part of study area (Fig. 9.1). The core area has been marked based on the pace and scale of industrial development in coastal part of the taluka. The core area has been declared as Special Economic Zone (SEZ) by the Government of Gujarat under Government of India's Industrial Development Policy, 2005. The Mundra town which is taluka headquarter is also the central hub of the core area. Core area is situated about 40 km south of Bhuj, the district headquarter of Kachchh. To its east Gandhidham (Kandla) and Adipur are other industrial towns located at about 50 km distance. In west Mandvi town which is also important port and is located about 40 km distance from Mundra. Core area is very well connected with other parts of the district and state through a network of rail and roads.

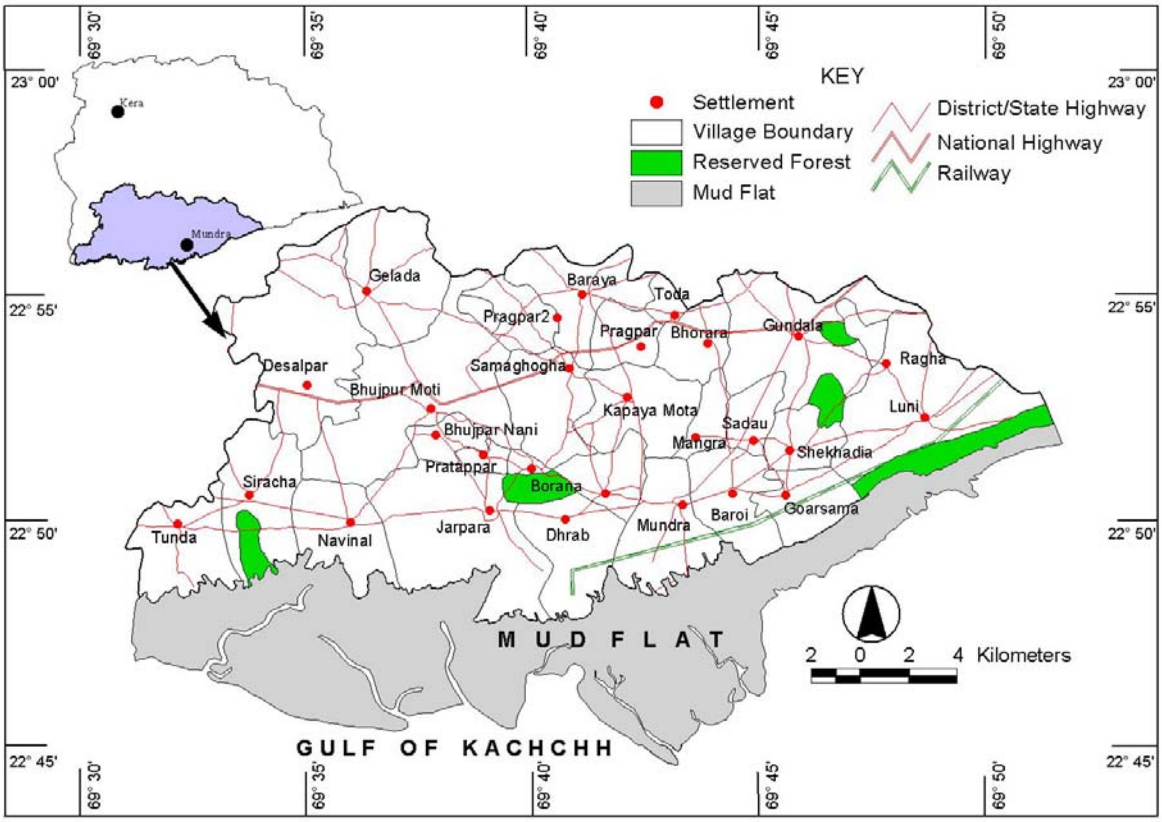


Fig 9.1 Location Map of Core Study Area

After the declaration of SEZ, the area now has a dedicated broad gauge rail line, an aerodrum and four lane highway whose work is in progress. The core area covers 29 villages where one village is un-habitated. These villages together cover about 353.7 sq.km. area, that also includes five reserved forests. Distance of villages from sea coast is in range between 2.5 km. Luni village and 13.6 km. Gelada village. Dominant livelihood of core area inhabitants is agriculture, animal husbandry and fisheries. Although, fisheries occupation is dominantly developed in eastern part of the core area, involving villages like Baroi, Goersama, Shekhadia, Luni and Bhadreshwar but contributes to major part of economy. In agriculture sector, there is dominance of small to marginal farmers. Very few farmers are socio-economically rich.

The EIA study of core area is aimed to have an insight at positive and negative changes that have taken place in various attributes of physical and biological environments, owing to industrial development. Current on-going industrial development is based on advanced technology which may not apt to local ecological conditions. Whereas, traditional livelihood practices follow principle of ecology with long term sustainability since generations. Further, the industrial development and industries also depend on local natural resources such as land, water, mineral and human resources. Therefore, it is bound to make positive/negative impacts in the area at large including socio-economic aspects of the region.

INDUSTRIAL DEVELOPMENT: SALIENT FEATURES

PRE INDUSTRIAL DEVELOPMENT SCENARIO

Economic scenario of any region depends on potential of natural resources. Although Mundra region fall within arid climatic domains, it is very rich in natural resources i.e. land, water and coastal resources. These resources have very well furnished traditional occupations i.e. agriculture, fisheries and animal husbandry which are locally termed as traditional industries. The region is known for having good quality deep groundwater supporting irrigated agriculture. Animal husbandry is considered to be one of the major occupations contributing to economy of the area based on milk production and animal trade. Even, rich and thriving mangrove forests along coast considered as a vital source of fodder during drought spells and have sustained the community against migration. The taluka has 72 km long coast line along the Gulf of Kutch and is dotted with large number of fishing jetties. Fish production of the area is enough high and contributing good economy to community and the region as well.

Today the definition of economic development has changed from traditional de-centralized industries to centralized one, induced with advance technology and machinery based. The present development seems to be beyond the carrying capacity of the region, whose stress symptoms have now start discerning in the core (SEZ) area.

INDUSTRIAL DEVELOPMENT SCENARIO

The present ongoing industrial development is concentrated in coastal areas around Mundra (Fig. 9.2). This includes about 32 industrial units, which range from small manufacturing units to large scale port (Table 9.1 & 9.2). Very first in year 1995, M/S Adani Port Limited had acquired an approval to set up a port near Mundra for facilitating general cargo, LPG and chemical storage terminal to be expanded in phased manner. Mundra port is a privately owned and developed largest port of India started functioning since year 1998 thereby placed the Mundra town among one of the largest port cities of the country (Plate 9.1). The Adani port covers southern to south-western parts of the core area, which is considered to be the only industrial component of the study area in last century. The last decade especially after Kutch earthquake of January 26, 2001; the state government has promoted industrial development for betterment of Kutch region by making concessions in its industrial policies. Comparing other parts of the district, potential of natural resource of Mundra has attracted the enterpreneures to set up industries and develop as industrial hub (Table 9.1). Various multi product units like coke processing, steel pipes, chemical, agro products, petro-chemical, engineering etc have been established. Later establishment of mega power plants has illuminated the core area at national level for its power generation. Ultra mega thermal power plants viz. Adani Power Ltd. and Coastal Gujarat Power Ltd (CGPL) owned by TATA have been set up on western coast of the region, while OPG Power Plant Ltd. on eastern coast near Bhadreshwar village. Gross power generation capacity of already functioned power plants and the proposed power plants is about 15,971 MW (Table 9.2). The Adani and CGPL power plants have also set up 16 km long conveyor belt from Adani's south port to transport coal which is imported from other countries.

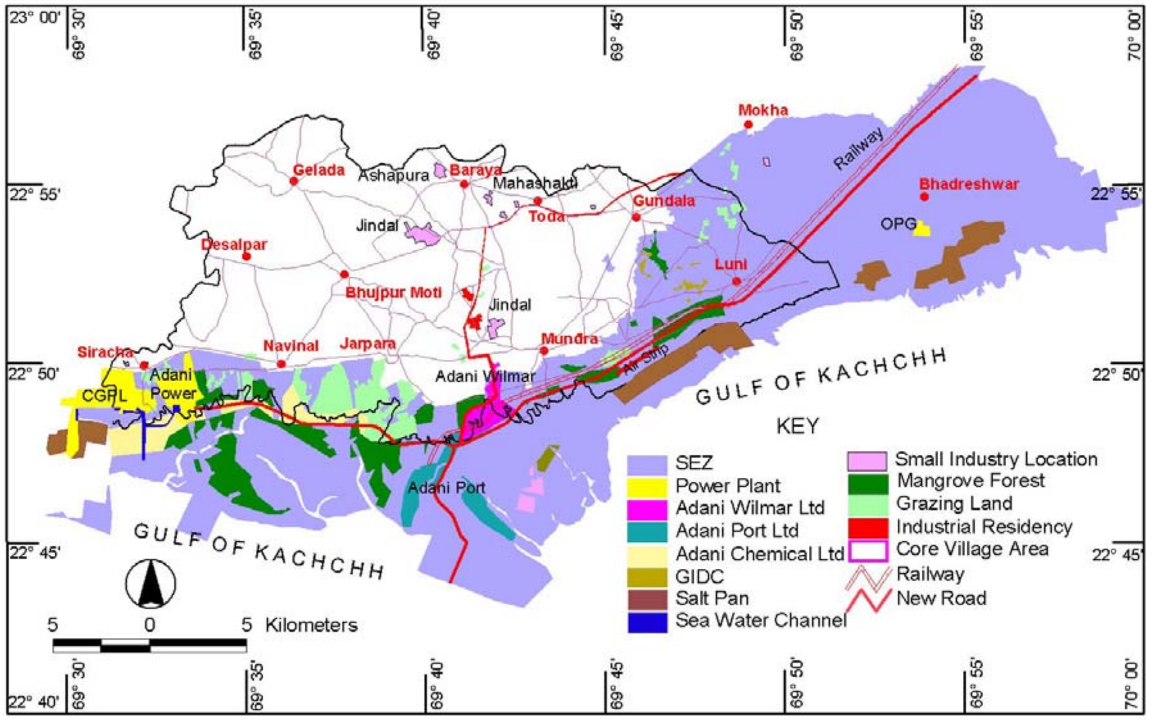


Fig. 9.2 Layout Map of Existing Industrial Set-up of Mundra Region

Table 9.1 Basic Information on Industrial Set-up in Mundra Region

Sr. No.	Name	Location	Type
1	Mundra Port and SEZ Ltd.	Coastal Track	Port, Industrial Park, Infrastructure Project
2	Gujarat Adani Port Ltd.	Mundra, Goersama	Petrochem and Refinery
3	Adani Wilmar Ltd.	Baroi, Pragpar	Fortune Oil
4	Adani Chemicals Ltd	Dhrab	Chemical
5	Indian Oil Corporation	Patri, Bhadreshwar	Oil Factory
6	Gujarat Energy Transmission Corporation Ltd	Siracha, Moti Bhujpar, Mokha	Energy Transmission
7	Jindal Saw Pipe Ltd	Samagogha, Pragpar, Moti Bhujpar	Metallurgical Industry, Steel Pipes
8	Jindal Coke Ltd	Toda	Coke Processing
9	Saw Pipe Ltd.	Nana Kapaya, Samagogha	Metallurgical Industry, Steel Pipes
10	Lakshmiwadi Mines & Minerals Pvt.Ltd.	Bhorara, Gundala	Mines and Minerals
11	Phillips Carbon Black Ltd.	Wadala, Mokha	Coke Processing
12	Mahashakti Coke Ltd.	Lakhapar	Metallurgical Industry
13	Shree Ashapura Minechem Ltd	Baraya	Bentonite processing
14	BLA Coke Pvt ltd.(Metcoke plant)	Baraya	Coke Processing
15	Nilkanth Concast Private Ltd.	Vadala	Boiler and steel manufacturing plant
16	Saurashtra Ferrous Pvt. Ltd	Baroi	Manufacturing of steel and iron
17	Maruti Suzuki India Ltd.	Mundra	Metallurgical Industry
18	Aadinath Polifils Private Ltd.	Dhrab	Chemical
19	Agro Crops Exime Ltd	Nana Kapaya	Agricultural Products
20	Ms. Kotak Agro Processing Pvt. Ltd	Baraya	Agricultural Products
21	L T C Agro Sals Ltd	Ratadiya	Agricultural Products
22	Ashok Alcho Chem Ltd.	Baraya	Chemical
23	Deast Industries Private Ltd.	Vovar	Chemical
24	Gujarat State Petronet Ltd.	Gundala	Industrial Oil
25	HPCL Mittal Pipeline Ltd.	Gundala	Infrastructure
26	Rishi Containar Fait Station Private Ltd.	Mota Kapaya	Infrastructure
27	Shree Amit Marketing Private Ltd	Patri	Infrastructure
28	Shree Sanghvi Movers Ltd.	Chhasara	Infrastructure

(Source: Taluka Panchayat, 2012; A.C.T., 2006)

Table 9.2 Details of Existing and Proposed Power Plants in Mundra Region

Sr. No.	Power Industry	Capacity (MW)	Location (Village)	Status	Fuel
1	Coastal Gujarat Power Limited (CGPL)- TATA	4000	Tunda	Operational and under expansion	Indian and imported coal
2	Adani Power Limited (ADANI)	4620	Siracha	Operational and under expansion	Imported coal
3	Kutch Power Generation Limited (KPGL)	3300	Bhadreshwar	Submitted for environmental clearance	Indian and imported coal
4	OPG Power Gujarat (OPG)	300	Bhadreshwar	Got environmental clearance and awaiting CRZ clearance	Indian and imported coal
5	OPG Power Gujarat (OPG)	2300	Bhadreshwar	Submitted for approval for project expansion	Indian and imported coal
6	Coastal Power Limited (CPL)	1400	Vira	TOR issued in 2007	Imported coal
7	Nilkanth Concast Pvt. Ltd	11	Mokha	Operational	Indian and imported coal
8	Philips Carbon Black Limited (PCBL)	20	Mokha	Operational	Indian and imported coal
9	Jindal Sow pipes	20	Samagogha	Operational	Indian and imported coal
Total		**15,971 MW**			

(Source: Ministry of Environment and Forest, GoI, 2007)

Plate 9.1 A Space View of Adani Port, Mundra (Google Earth, 2013)

Mundra Special Economic Zone (SEZ) is a mega industrial project promoted by Adani Group vides Government of India Notification, 2005. SEZ provide a space with required infrastructure to small scale multi product industrial units. Government of India has notified in all 6472.86 ha (64.72 sq km) land for SEZ as a part of Phase-I development, which attract tax holidays and SEZ benefits as per government policy. The Mundra port has identified additional 18,000 ha (180.00 sq km) land area as a part of its future development plan of 25 years that shall be acquired in different phases (REIA, 2006). This additional projected area covers 14 coastal villages from Tunda in west to Bhadreshwar in east. Extended SEZ is bounded between National Highway No. 8A in North, Khari River in West and Mithi River in East. Out of this, about 43.88 % area covers mudflats of Gulf of Kutch. The developmental activities in SEZ area has made drastic rise in population growth. Projected population growth in Phase-I is 2,20,000 which will attain about 6,60,000 by the time of its full development (REIA, 2006).

Besides mega industrial projects, the SEZ comprises many small to large scale industrial units of various types i.e. coke processing, minerals and mines, oil, chemical industries. The edible oil refinery i.e. Adani Wilmar Ltd. is the largest edible oil refinery of the country. Apart from SEZ, the Mundra has 02 additional industrial estates covering 189.91 ha area, developed by Gujarat Industrial Development Corporation (GIDB, 2004).

Plate 9.2 A View of CGPL (Tata) Power Plant at Tunda Village

Plate 9.3 A View of Nilkanth Concast Industry at Vadala Village

GROUNDWATER RESOURCE STATUS

Water is basic necessity for any developmental activities. When it comes to industrial development of mega scale, it requires huge volume of water on daily and sustainable basis. As its well known fact that, surface water resources are rainfall dependent and need reservoirs of sufficient capacities. In present case the core area has no such provision.

Therefore, major onus of meeting the industrial water plus domestic demand rests on groundwater resource. In the Mundra region industrial zone, the groundwater resource utilization to meet industrial demand has began since 1995 i.e. setting up of Mundra Port and SEZ Limited (Adani Port).

Further during a span of last 17 years large number of mega, major and small industrial units have started functioning having dependency solely on groundwater resources of the core area and its surrounding.

Also, industrial development coupled with increase in human resource (man power population) and needed civil infra-structures have increased the water demand manifold. Resultantly, the aquifers are under severe stress causing adverse impact of groundwater salinization.

Ensuing content on the state of groundwater resource in core area highlights the magnitude and extent of problem through systematic study on the status of hydro-geologic regime of the core area since, 1995.

The core area has potential groundwater occurrence in sandstone of Kankavati Fm. of Tertiary age. Kankavati sandstone is a deep aquifer having a cap of 5 to 10 m thick alluvium. Sandstone, being fluvio-marine in origin is characterized by clay intercalations (Fig 5.7 & 5.8). Water table depth in core area varies from shallow water table at 20 m in eastern part of core area around Luni. Whereas depth to water table ranges from 80 to 100 m around Bhujpur and Jharpara villages located in western parts of the core area.

ANNUAL CHANGE IN STATIC WATER LEVELS

As it has already been elucidated in preceding chapter, that the candidate through established network of observation wells has carried out the seasonal monitoring of water table (Annexure 9.1). In core area the water table and water quality have been monitored through 47 numbers of observation wells.

Based on seasonal monitoring data, the candidate has developed hydro-isobaths for year 2008 and 2011 (Fig. 9.3, 9.4). Accordingly, annual change in groundwater storage and the aerial coverage have been worked out (Table 9.3). The presented data analysis suggests that there has been a marked negative change in groundwater storage from year 2008 to 2011, even in water table rise categories up to 5-10 m. This is in spite of area received good rainfall. Only about 30 % area shows addition in groundwater storage which is < 5m. This clearly point to more groundwater draft than the recharge. The well hydrographs of OW-I2a (Moti Bhujpur) and OW- I1b (Siracha) too suggests groundwater depletion rate between 5 and 8 m/year (Fig. 5.12.). Thereby, an overall 65 % area has witnessed depletion in groundwater storage between 2008 and 2011 in spite of good rains received by the area during this period.

Table 9.3 Annual Change in Groundwater Storage

Category Rise (+) Fall (-)	Change in Storage (m)	Area under Change km^2	
		2008	**2011***
Rise	>20 m	12.1	0
Rise	10-20 m	91.6	0
Rise	5-10 m	68.0	0.0
Rise	<5 m	130.0	229.3
Fall	<5 m	24.7	91.7
Fall	> 5 m	2.2	7.6
Total		**328.6**	**328.6**

*** Source: GWRDC, 2011**

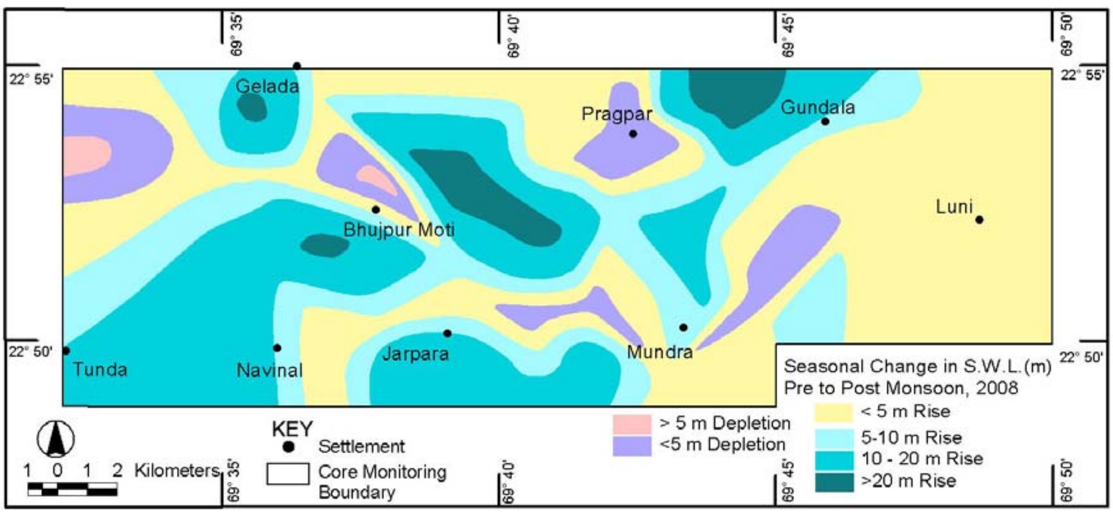


Fig. 9.3 Hydro-Isobaths of Annual Change in Groundwater Storage in Core Area (2008)

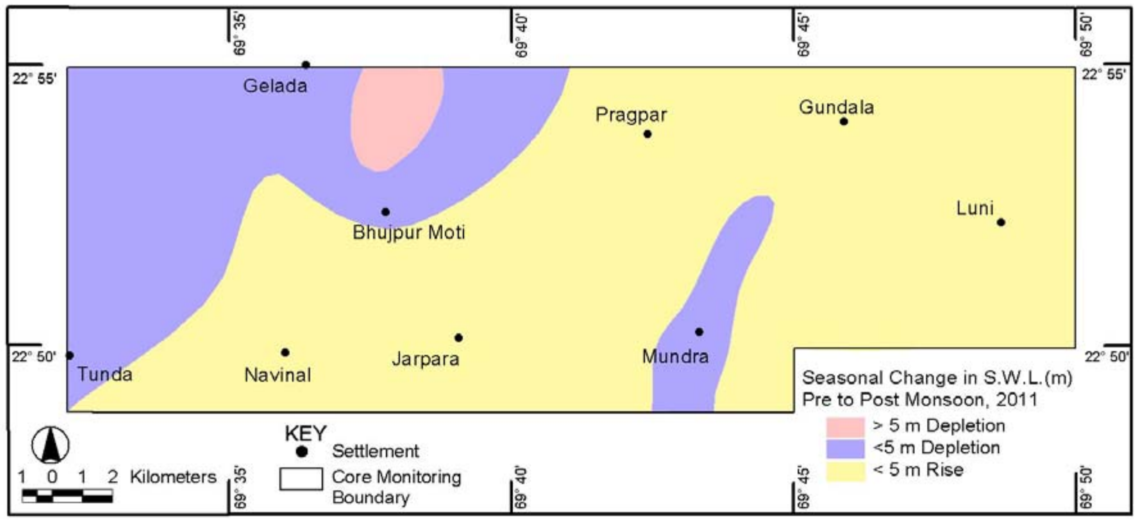


Fig. 9.4 Hydro-Isobaths of Annual Change in Groundwater Storage in Core Area (2011)

REDUCED WATER LEVELS (RWL)

To understand and delineate the geological control over groundwater regime, Reduced Water Levels (Annexure 9.2) contour patterns are pre requisite. RWL also provide area specific information on groundwater movement and gradient. RWL contours have been plotted for core area for pre monsoon and post monsoon seasons of year 2008 to 2010 (Fig 9.5 to 9.9). The RWL contours have revealed that groundwater flows from eastern and western parts i.e. towards west and east respectively thereby forming a linear depression. The groundwater flow is also landward side from the coast i.e. around Navinal village, is suggestive of reversible of groundwater gradient thereby indicating active type of sea water intrusion (Fetter, 1973); where in overall groundwater levels have gone 70 m below MSL i.e. maximum gradient of groundwater flow. The groundwater gradient in linear depression is quite steep i.e. 1:20 which is again suggestive of excessive pumping. A brief summary on groundwater behavior is given in Table 9.4.

Further, it is interesting to observe that there has been a progressive expansion in the aerial coverage of linear depression from year (2008) to year (2010). This further substantiates increase in groundwater draft with time.

Table 9.4 Groundwater Behavior in Core Area Based on RWL Contours

Sr. No.	Locality	Groundwater Movement Direction	Groundwater Gradient	Pattern Type
1	Eastern Part: Around Luni-Gundala- Mundra -Pragpar villages	Westerly	1:200	Linear
2	Western and North Western Part: Around Tunda and south west of Gelada villages	Easterly	1:200	Linear
3	North Central and South Central Part: Around Gelada- Bhujpar-Jharpara and Navinal Villages	Towards Centre	1: 20	Internal with linear depression trending NNW-SSE

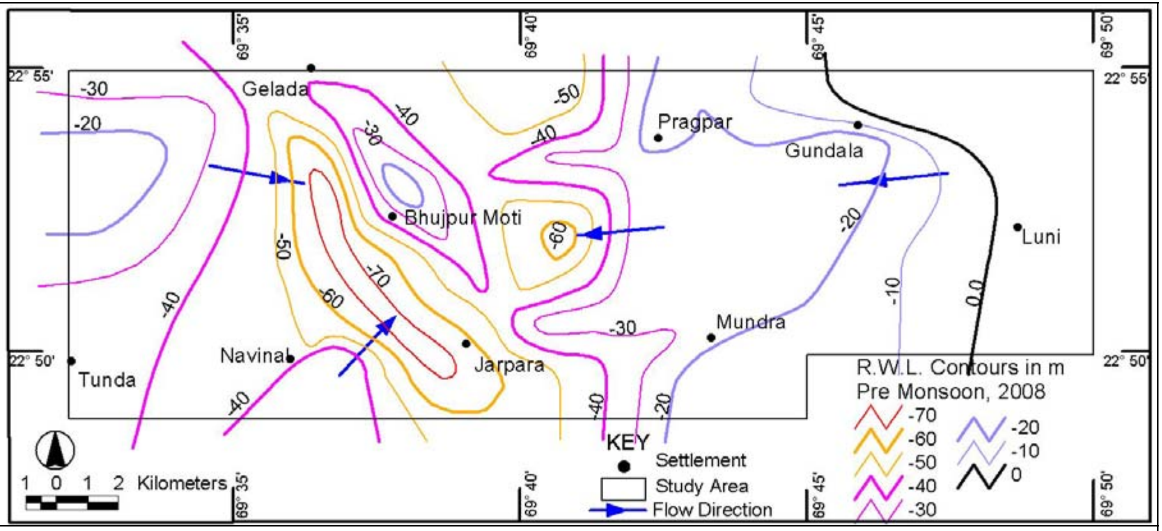


Fig. 9.5 Reduced Water Level Contours of Pre Monsoon, 2008

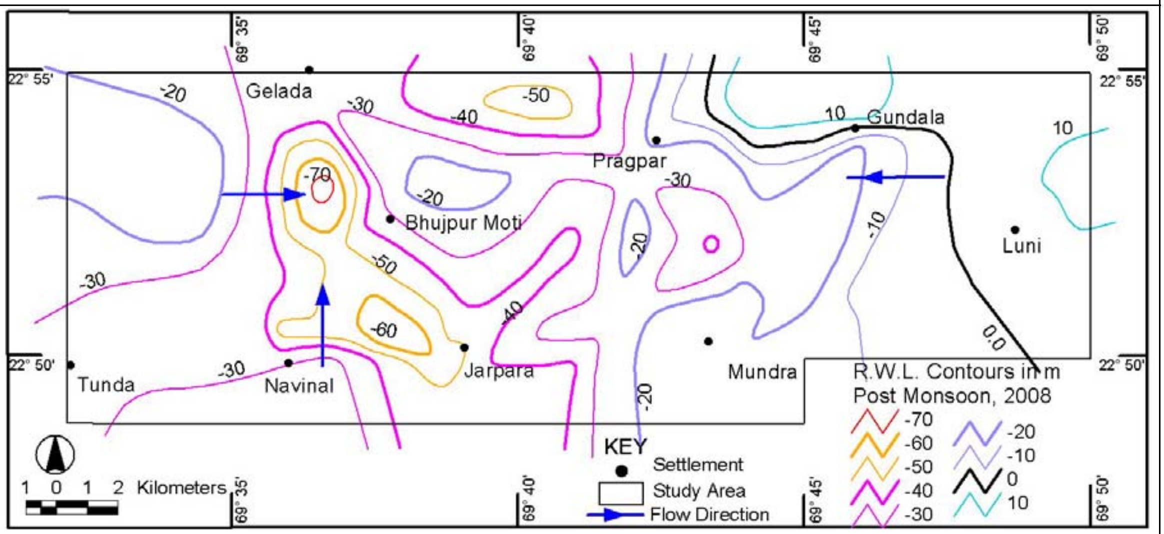


Fig. 9.6 Reduced Water Level Contours of Post Monsoon, 2008

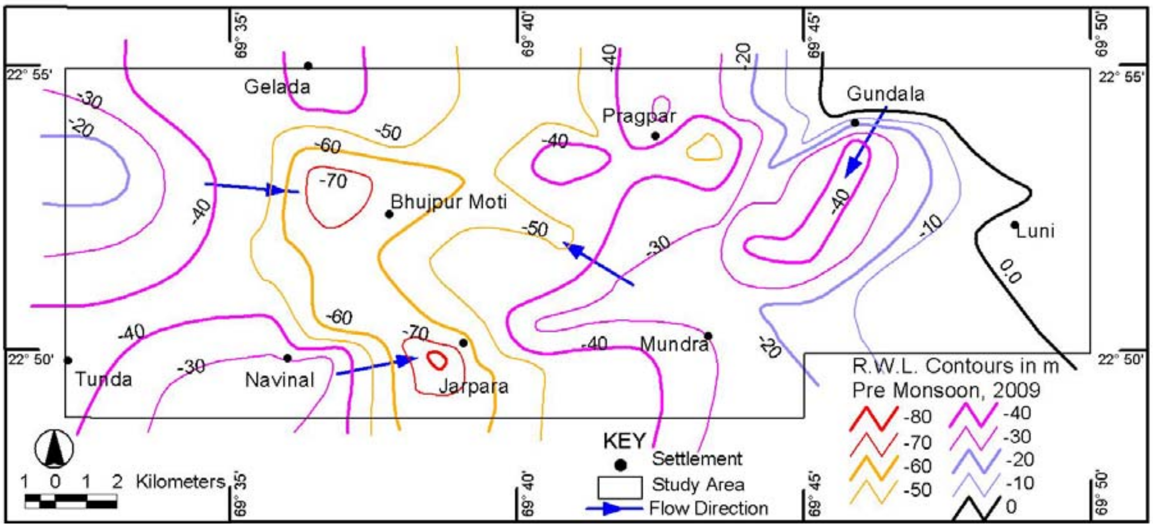


Fig. 9.7 Reduced Water Level Contours of Pre Monsoon, 2009

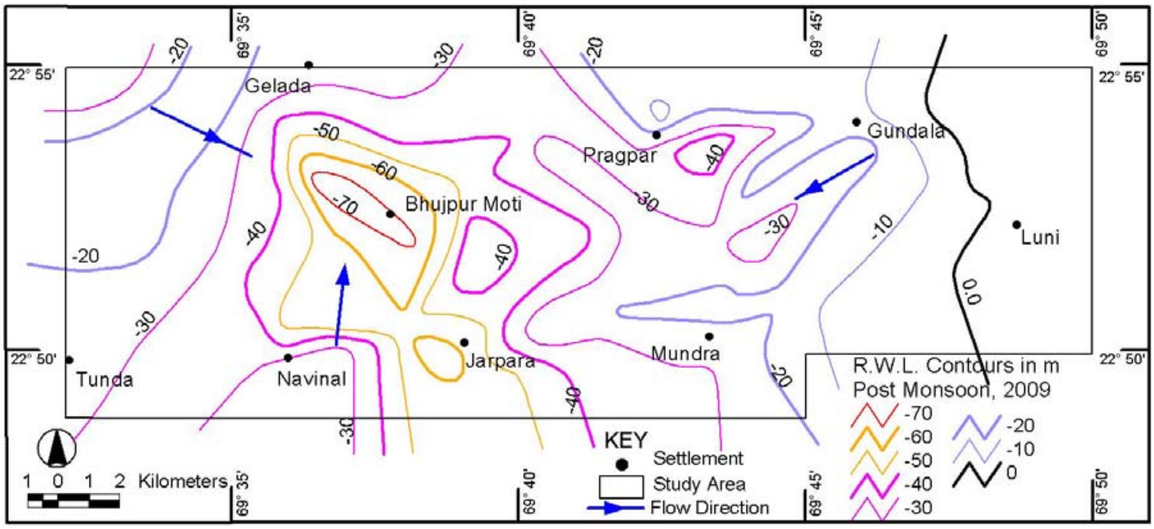


Fig. 9.8 Reduced Water Level Contours of Post Monsoon, 2009

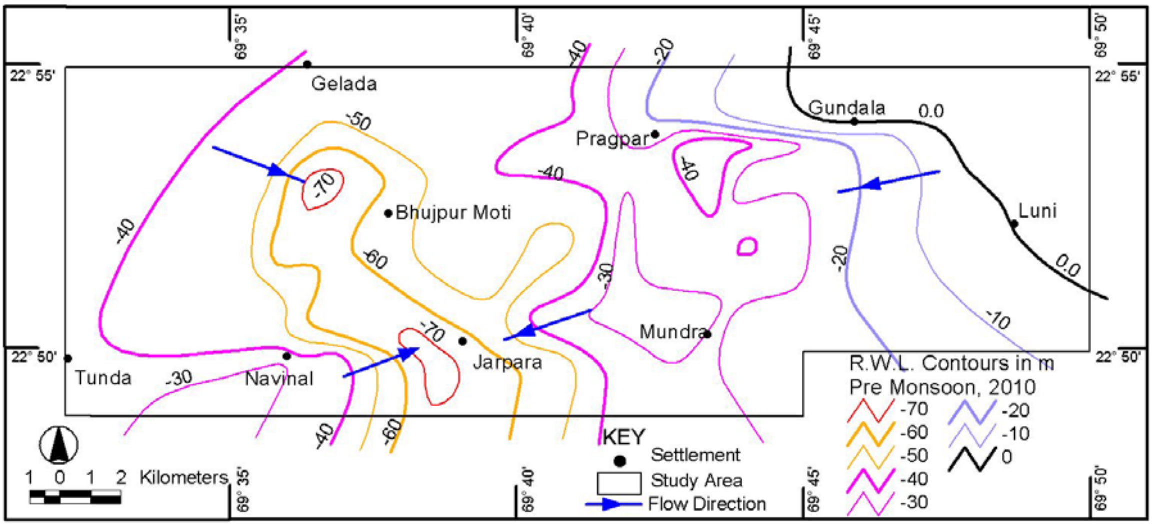


Fig. 9.9 Reduced Water Level Contours of Pre Monsoon, 2010

As explained above, water level has gone down below MSL, therefore Principle of Ghyben-Herzberg i.e. seawater/ freshwater interface is 40 hf, is not applicable. As the aquifer is under the influence of active sea water intrusion, the candidate has constructed a RWL profile to delineate sub surface trend of RWL from SW coast to NE (Fig. 9.10). The graph shows sharp decline up to 70 m in RWL near coast indicate impact of over exploitation of groundwater mainly in industrial area. In NE part, it shows gentle trend and reach to MSL. Water table below mean sea level has developed a cone at 70 m depth. The chemical content of this cone area groundwater has the highest concentration like TDS (>5000 mg/l), chloride (>5000 mg/l) and boron (4.2 mg/l). Although, it would be erroneous to call it sea water/ freshwater interface but definitely constitute a part of mixing zone.

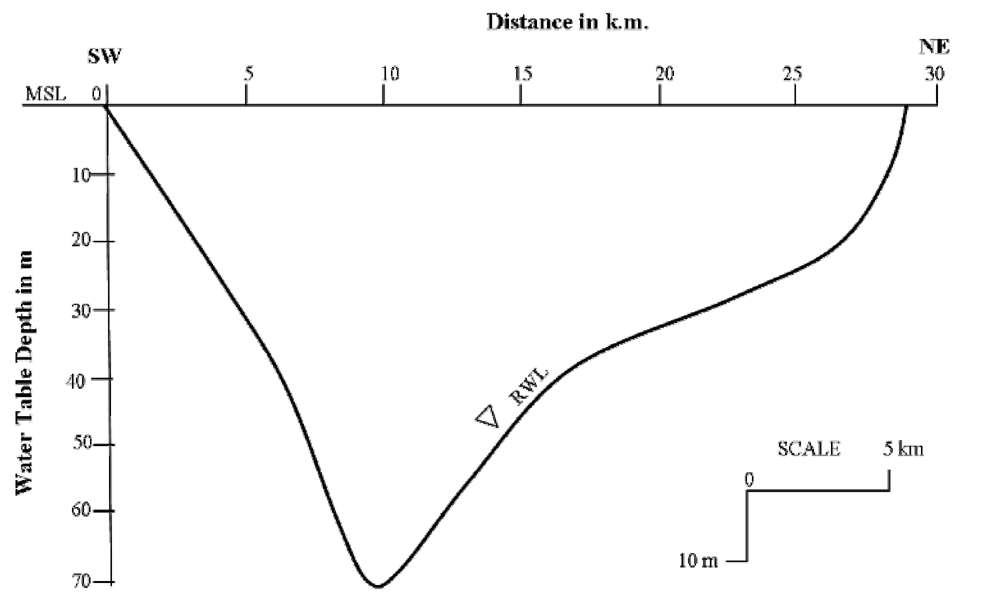


Fig. 9.10 Sub-surface Trend in Reduced Water Level in Core Study Area

TOTAL DISSOLVED SOLIDS

TDS being a primary indicator of salinity has been analyzed by generating isobath maps. TDS Isobath maps have been prepared for pre monsoon seasons for the years 2008 and 2010. (Fig 9.11, 9.12). As per WHO (2005) groundwater

Table 9.5 TDS Isobaths Area in sq.km.

Category mg/l	Pre 2008	Pre 2010
<1500	8.8	28.6
1500-2000	30.2	106.8
2000-3000	103.1	102.6
3000-5000	138.0	61.4
>5000	48.5	29.2
Total Area sq.km.	**328.6**	**328.6**

potability standards (<1500 mg/l), potable groundwater occurs in 8.8 sq.km. area (year 2008) which has increased up to 28.6 sq.km area in year 2010. This may be attributed to good rainfall received by the area during this period. However, area having potable groundwater is mere 8.7 % of the total area (Table 9.5). In remaining groundwater salinity categories, some categories show dilution in TDS, but the TDS content fall within non potable class.

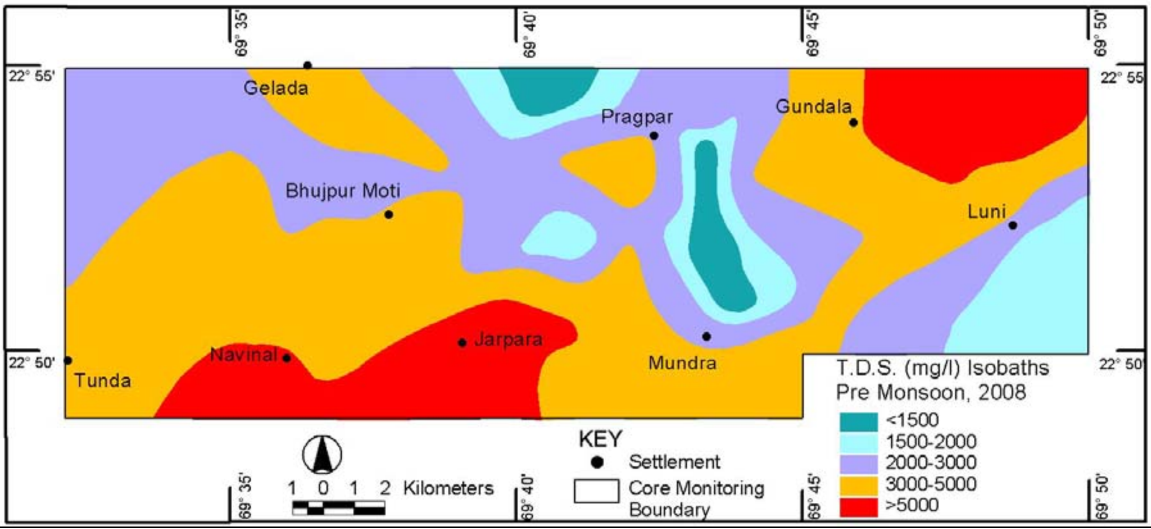


Fig. 9.11 T.D.S. Isobaths of Pre Monsoon, Year 2008

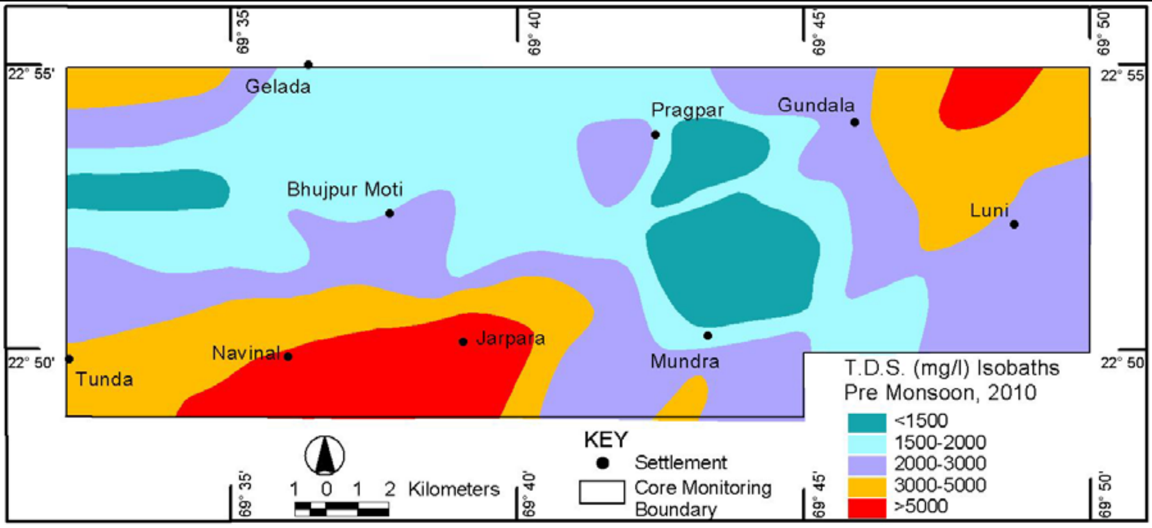


Fig. 9.12 T.D.S. Isobaths of Pre Monsoon, Year 2010

Similarly, annual change in TDS concentration has been evaluated through isobaths for the years 2008 and 2011 (Fig. 9.13, 9.14). The annual TDS change pattern shows an overall negative change similar to water table fluctuation.

Net area showing positive change (decrease) in TDS after monsoon has in fact reduced from year 2008 to 2011 (Table 9.6). In year 2008, about 231.4 sq.km.(70.4 %) area show dilution in TDS, which has reduced to 167.5 sq.km. (51 %) in year 2011. The most affected areas due to increased level of TDS are northern, north-eastern and southern parts of the study area around Gundala, Pragpar and Jharapar villages.

Table 9.6 Annual Change in TDS Concentration

Category	Change mg/l	Area in Sq.km.	
		Pre-Post 2008	Pre-Post 2011*
Decrease (+)	>3000	34.2	0
Decrease (+)	2000-3000	33.8	2.6
Decrease (+)	1000-2000	107.3	12.9
Decrease (+)	<1000	56.0	152.0
Increase (-)	<1000	35.9	106.4
Increase (-)	1000-2000	55.0	54.7
Increase (-)	>2000	6.4	0.0
Total Area sq.km.		**328.6**	**328.6**

*** Source: GWRDC, 2011**

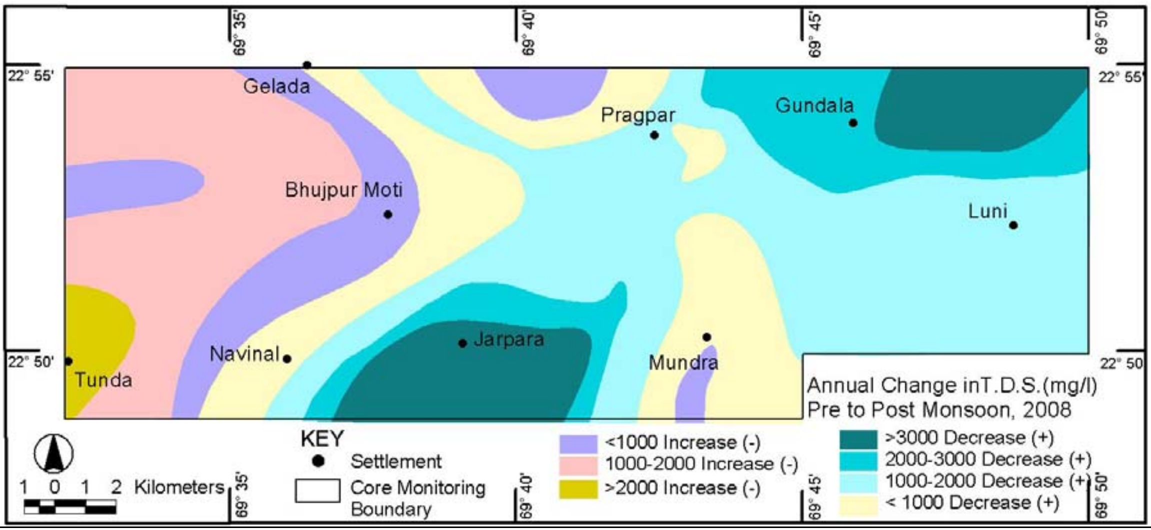


Fig. 9.13 Isobaths of Annual Change in TDS from Pre to Post Monsoon, 2008

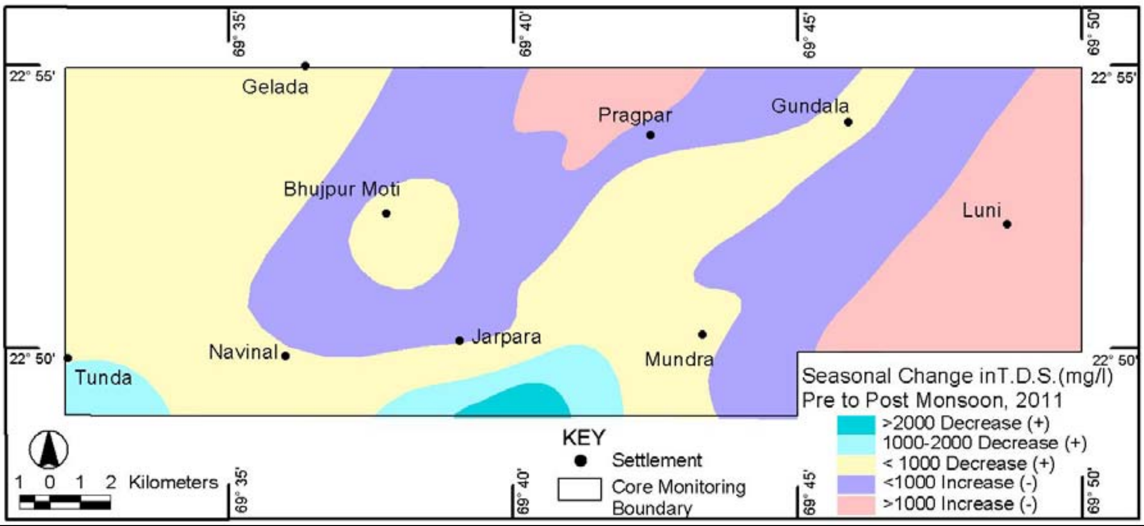


Fig. 9.14 Isobaths of Annual Change in TDS from Pre to Post Monsoon, 2011

CHLORIDE CONTENT

Chloride ion has been monitored seasonally for the core area. Based on analytical data, chloride isobath maps have been prepared for pre monsoon seasons of year 2008 and 2010 (Fig 9.15, 9.16). As per drinking water quality standard (WHO, 1993), chloride in potable limit (600 mg/l) occur in 98.48 Sq.km (30 %) area (Table 9.7). Similar to TDS pattern, the potable area has increased from year 2008 to year 2010 but chloride concentration has increased > 5000 mg/l especially in southern part of the study area around Jharpara.

Table 9.7 Chloride Isobaths Area in sq.km.

Category mg/l	Pre 2008	Pre 2010
<600	54.2	98.48
600-1000	142.6	101.66
1000-2000	89.0	71.79
2000-3000	26.1	31.28
3000-5000	16.7	15.22
>5000	0.0	10.2
Total Area	**328.6**	**328.6**

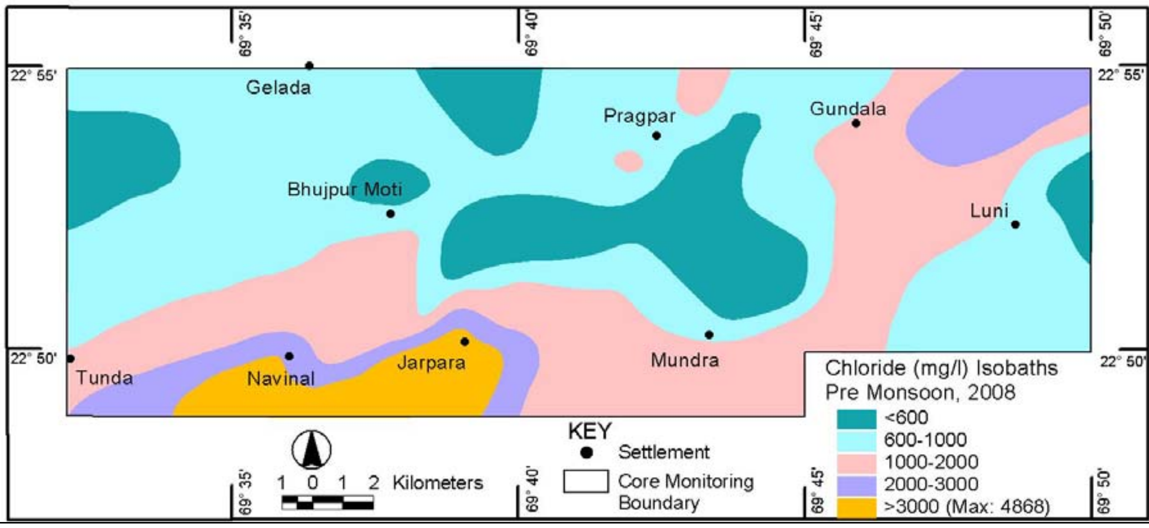


Fig. 9.15 Chloride Isobaths of Pre Monsoon, Year 2008

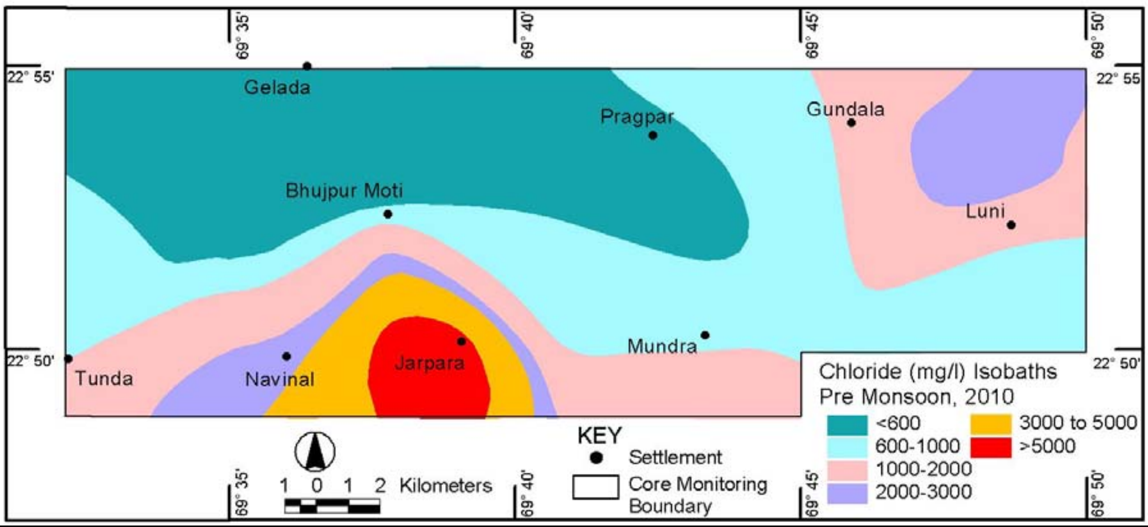


Fig. 9.16 Chloride Isobaths of Pre Monsoon, Year 2010

Chloride isobaths on annual change have been generated for the years 2008 and 2011 (Fig. 9.17, 9.18). Isobath evaluation suggests that there has been a decrease in chloride concentration in almost 250.7 sq.km. (76.3 %) during 2008, that has been reduced to almost 50 % i.e. 127,8 sq.km. in year 2011 (Table 9.8). The areas' experienced chloride enrichment (+3000 mg/l) are around Navinal and Jharpara villages in south- central part; and around Luni and Gundala villages in north east.

Table 9.8 Annual Change in Chloride Concentration

Category	Change mg/l	Area in Sq.km.	
		Pre-Post 2008	Pre-Post 2011*
Decrease (+)	>3000	2.2	0
Decrease (+)	2000-3000	4.3	0
Decrease (+)	1000-2000	13.8	6.4
Decrease (+)	500-1000	62.1	27.6
Decrease (+)	<500	168.3	93.8
Increase (-)	<500	61.9	156.2
Increase(-)	>500	16.1	44.6
Total Area		**328.6**	**328.6**
*** Source: GWRDC, 2011**			

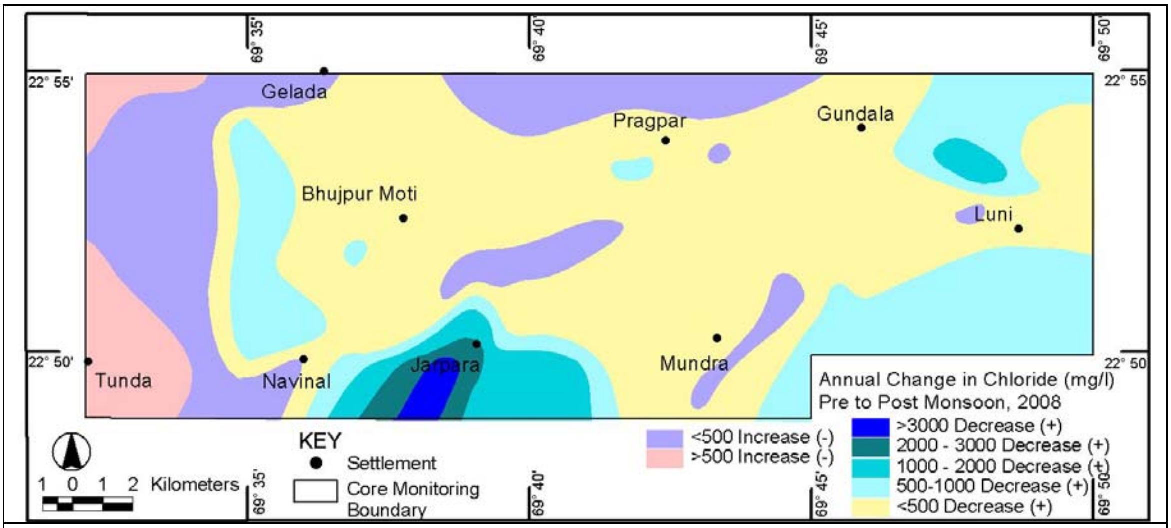


Fig. 9.17 Isobath of Annual Change in Chloride, Year 2008

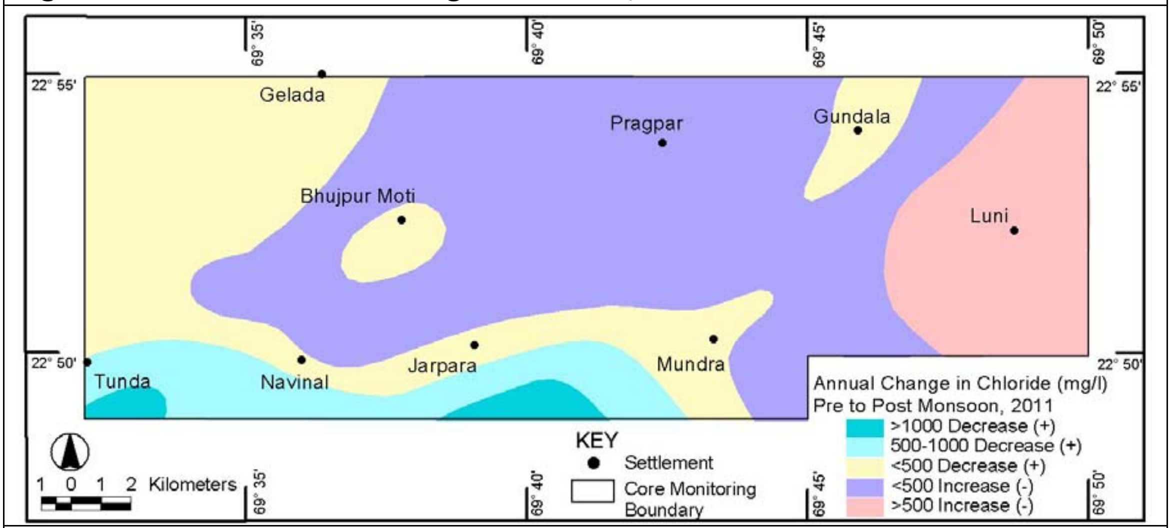


Fig. 9.18 Isobath of Annual Change in Chloride, Year 2011

BORON CONTENT

Dissolved boron in groundwater >1 mg/l (BS, 1999) form water non-potable. Boron enrichment is maximum in ocean waters. The coastal regions vulnerable to sea water intrusion would show high concentration of boron in groundwater. The candidates' assessment on observed boron concentration in coastal aquifers' groundwater is up to 4 mg/l (Fig. 8.7). The iso-boron concentration contours have very much similar pattern as that of TDS and chloride, therefore again pointing to active sea water intrusion in coastal aquifers.

IMPACT ASSESSMENT

Impact of industrial development in core area has been assessed through various indices viz.; socio-economic set up, livelihood, land resource, water resources and ecology. The impact assessment on the considered indices has been done by using primary data i.e. groundwater and land resource and secondary data i.e. relevant reports on EIA studies carried out by government institutions , NGOs or individuals. Beside this, the candidate has made consultation with selected individuals.

In the core area important impact assessment studies carried out are (1) For Ultra Mega Power Plant project of TATA by an independent Fact Finding Team during June, 2006; and (2) For Mundra Port, Adani Power Plant and SEZ by Ministry of Environment, Forest and Wildlife (GOI) during April, 2013. The impact assessment of core area through mentioned indices is discussed as under-

SOCIO–ECONOMIC IMPACT

Socio-economic status is an important impact indicator in establishing the changing trends due to developmental activities. In the present case, change in socio-economic conditions of the region has been assessed through population growth and livelihood parameters.

Impact on Population

As per census, 2011, total population of the core area stands 1,12,988 (Table 9.9). The core area has observed drastic change in demography during last one decade (Table 9.10). Data on decadal population growth in core area villages from 1961 to 2011 suggests noteworthy increase due to industrial immigrants. Villages like Baroi (445 %), Nana Kapaya (603 %), Pratappar (332 %) and Tunda (933 %) shows significant rise in population between year 2001 and 2011 (Table 9.10). Till 1991, the average decadal growth rate of the area remained up to 11.2 %, which has more than doubled (25.8 %) in 2001. From 2001 to 2011 the decadal growth rate became more than 04 times of 2001 (Fig. 9.19). This sudden outburst in core area population certainly attributed to industrial development, attracting immigrants from within the state and out side state for employment and job assignments. Incidentally, the demographic decadal growth rate of core area for the year 2011 is much higher (116 %) than the whole Mundra taluka growth rate i.e. 84 % for the same decade.

Under this scenario of population out burst, one can easily visualize the fate of the core area on its complete accomplishment of targeted industrial development which is bound to worsen the situation further, on basic resources management front, specifically the water resources.

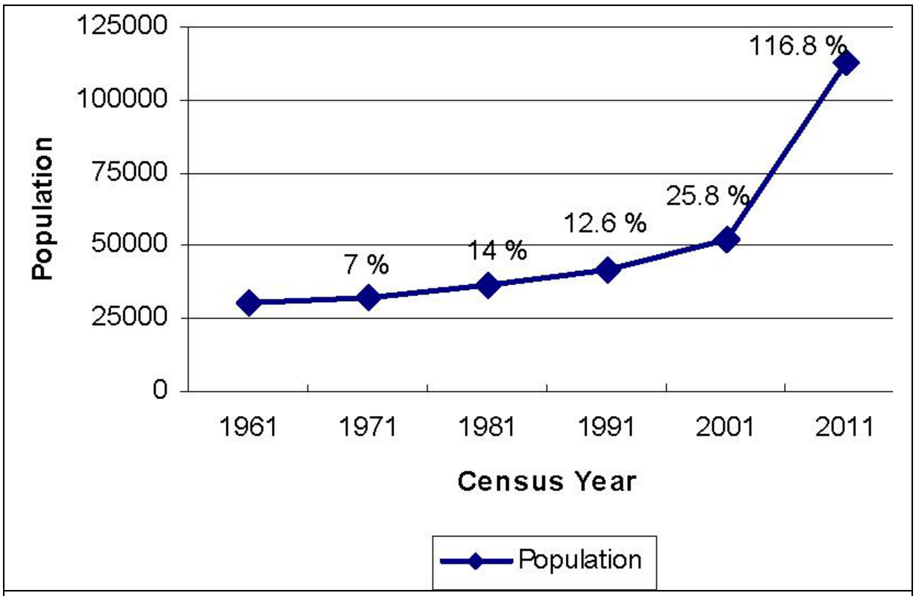


Fig. 9.19 Demographic Decadal Growth Rate of Core Area

Table 9.9 Demographic Status of Core Area Villages, Year (2011)

Sr. No.	Village	Male	Female	Total	M/F Ratio	
					2001	2011
1	Baraya	440	324	764	1: 0.90	1: 0.74
2	Baroi	8316	6644	14960	1: 0.96	1: 0.80
3	Bhorara	528	476	1004	1: 0.97	1: 0.90
4	Borana	185	192	377	1: 0.1.07	1: 1.04
5	Deshalpar	1353	1260	2613	1: 0.93	1: 0.93
6	Dhrab	2026	1256	3282	1: 0.84	1: 0.62
7	Gelda	553	535	1088	1: 0.1.01	1: 0.97
8	Goersama	510	479	989	1: 0.87	1: 0.94
9	Gundala	1466	1315	2781	1: 0.96	1: 0.90
10	Jarpara	3874	3479	7353	1: 0.99	1: 0.90
11	Luni	1706	1672	3378	1: 0.96	1: 0.98
12	Mangra	622	590	1212	1: 0.95	1: 0.95
13	Mota Kapaya	1606	1462	3068	1: 0.93	1: 0.91
14	Moti Bhujpar	4761	4516	9277	1: 0.1.02	1: 0.95
15	Nana Kapaya	6405	2476	8881	1: 0.94	1: 0.39
16	Nani Bhujpar	554	502	1056	1: 0.94	1: 0.91
17	Navinal	2410	690	3100	1: 0.92	1: 0.29
18	Pragpar	633	301	934	1: 0.1.01	1: 0.48
19	Pragpar 2	217	185	402	----	1: 0.85
20	Pratappar	135	133	268	1: 1	1: 0.99
21	Raga	82	82	164	1:1.2	1: 1
22	Sadau	1006	965	1971	1: 0.97	1: 0.96
23	Samagogha	5119	2585	7704	1: 0.98	1: 0.50
24	Shekhadiya	498	472	970	1: 0.98	1: 0.95
25	Siracha	1170	712	1882	1:1.02	1: 0.61
26	Toda	361	349	710	1: 0.91	1: 0.97
27	Tunda	11248	1223	12471	1: 0.99	1: 0.11
28	Mundra (Urban)	10903	9426	20329	1: 0.94	1: 0.86
Total		**68,687**	**44,301**	**1,12,988**	**1: 0.96**	**1: 0.64**

Source: Census Record, Year 2011

Male: Female ration is also an indicator that establishes adverse socio-economic impact due to on-going industrial development, particularly by the immigrants. Educated/qualified immigrants normally settle with their families as they are extended residential facilities by industries in their townships or outside viz; Adani Wilmar, Santiwan Colony, Samudra Township, Shiv Township etc. Whereas, non qualified/skilled labors normally immigrate single. In order to get cheaper rented accommodation they move to neighboring villages thereby adding to village population. It is this immigrant population which has caused gross imbalance in M:F ratio of the villages. The M/F ratio is very high in villages surrounding to major industries i.e. Baroi, Dhrab, Nana Kapaya, Navinal, Pragpar, Samagogha, Siracha etc. The M:F ration in Tunda village stand at 1:0.11 and the male population is 10 times higher than females. The only village having M:F ratio 1:1 is Ragha. Apart from causing imbalance in M:F ratio; immigrants from different social and cultural backgrounds posses threat of erosion to traditional culture and can incite adverse social impacts.

Table 9.10 Progressive Growth in Population of Core Area over the Period (Year 1961-2011)

Sr. No.	Village	Decadal Change in Population						Change in Population (2001 to 2011)	
		Year 1961	Year 1971	Year 1981	Year 1991	Year 2001	Year 2011	Change	%
1	Baraya	280	283	299	349	434	764	330	76.0
2	Baroi	1271	1159	1409	1701	2741	14960	12219	445.8
3	Bhorara	665	647	631	617	823	1004	181	22.0
4	Borana	111	160	228	209	339	377	38	11.2
5	Deshalpar	1634	1587	1439	1555	2013	2613	600	29.8
6	Dhrab	599	681	905	1136	2007	3282	1275	63.5
7	Gelda	506	556	599	661	918	1088	170	18.5
8	Goersama	231	249	307	443	727	989	262	36.0
9	Gundala	1524	1513	1401	1426	1730	2781	1051	60.8
10	Jarpara	2163	3193	4246	4870	5762	7353	1591	27.6
11	Luni	1308	1594	2221	2215	2666	3378	712	26.7
12	Mangra	255	315	526	627	757	1212	455	60.1
13	Mota Kapaya	1298	1244	1242	1383	1506	3068	1562	103.7
14	Moti Bhujpar	3382	3373	3924	4124	5952	9277	3325	55.9
15	Nana Kapaya	399	513	732	884	1262	8881	7619	603.7
16	Nani Bhujpar	209	296	350	719	717	1056	339	47.3
17	Navinal	883	858	785	833	1146	3100	1954	170.5
18	Pragpar	390	416	438	495	598	734	136	22.7
19	Pragpar 2	Included in Pragpar village up to year 2001					402		
20	Pratappar	150	139	120	47	62	268	206	332.3
21	Pratappar 2	No Habituation							
22	Raga	49	63	82	107	130	164	34	26.2
23	Sadau	993	1026	1068	1029	1345	1971	626	46.5
24	Samagogha	1174	1253	1305	1506	2021	7704	5683	281.2
25	Shekhadiya	264	316	419	542	715	970	255	35.7
26	Shiracha	357	465	580	701	923	1882	959	103.9
27	Toda	538	532	553	473	595	710	115	19.3
28	Tunda	683	616	784	1050	1207	12471	11264	933.2
29	Mundra	8817	9183	10149	11652	12931	20329	7398	57.2
Rural		**21316**	**23047**	**26593**	**29702**	**39096**	**92459**	53363	136.5
Total		**30133**	**32230**	**36742**	**41354**	**52027**	**112788**	60761	116.8

The increasing population obviously depends on local natural resources for their basic needs i.e. land and water. This population needs houses which can only be fulfilled by acquiring private land probably agricultural land. Besides this, water requirement for drinking and domestic needs will increase drastically with an increase in human population. This is bound to create pressure on water resources especially the groundwater. This can be visualize from estimated total industrial water demand which is about 78.06 MCM/year and the projected water demand of SEZ only is about 55 MCM/year (REAI, 2006).

Impact on Livelihood

The industrial development may cause adverse impact on traditional livelihood which is solely dependent on natural resources of the region. Due to continual deteriorations in groundwater quality and increasing demand of land and its price, farmers are tempted and/or intimidated to sell their agriculture land to industries or to builders for residential and commercial purposes after due conversion as non-agricultural land. Thereby, there has been a gradual transformation of a skilled farmer to un-skilled labor. The study carried out by Raju (2003) suggests that only 10 % member of farming community had switched to jobs in the decade 1961-70, which has increased up to 20 to 30 % in next two decades (1971-1990). In the present pace of industrial development, this percentage has increased by more than 53 % after 1990. This clearly points to colossal loss in agriculture economy and also least preference to traditional occupation. Besides this, animal husbandry livelihood has also been affected badly due to drastic reduction in grazing and open land as well as farmers paradigm shift to non-fodder cropping pattern (cash crop) in agriculture.

Due to demarcated SEZ territory along the coast, fishermen movement from one port to another is restricted. Besides this M/s CGPL (TATA) and Adani Power Ltd have developed a sea water intake channel (Plate 9.4) for hot water cooling in their thermal power plants. After cooling high temperature water is drained back to sea. Thereby, causing adverse effects to marine ecosystem especially the fish production.

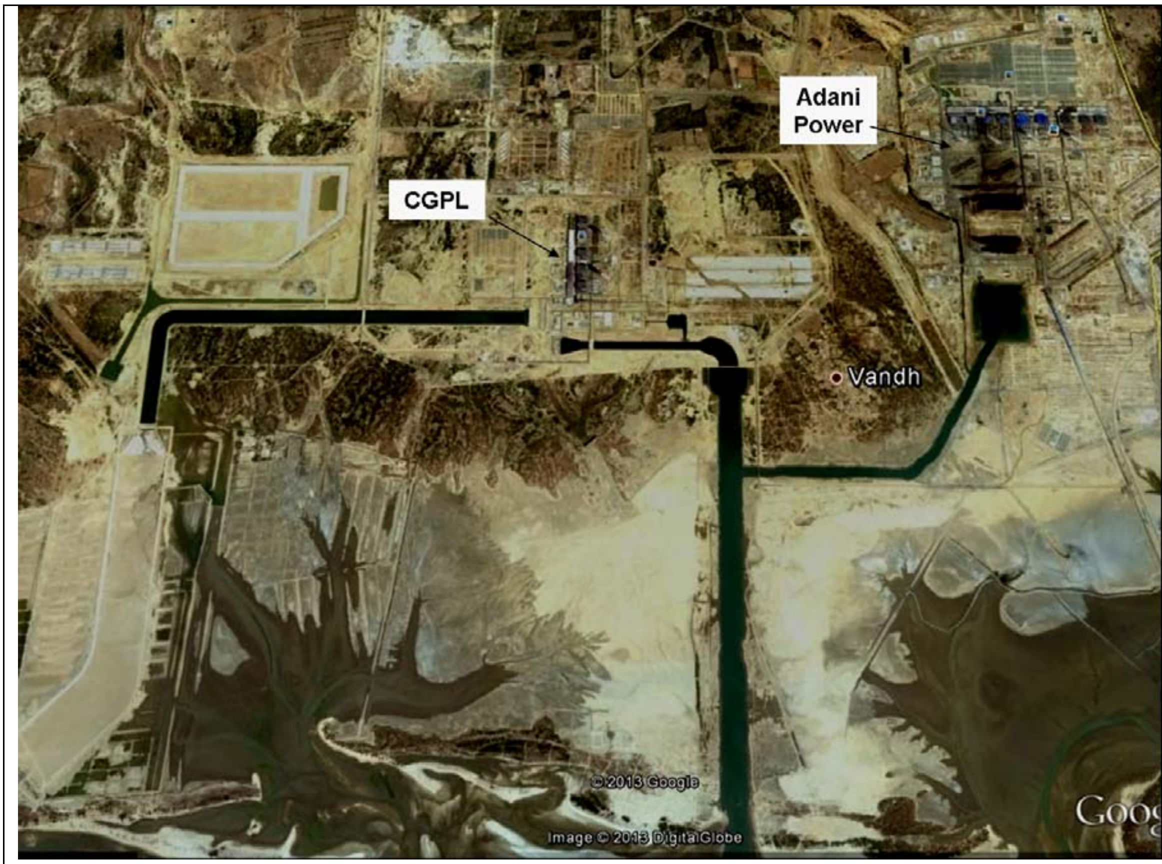


Plate 9.4 Space Image viewing Sea Water Intake and Outlet Channels for Thermal Power Plants at Tunda Vandh

LAND RESOURCE

Land is the foremost important resource being used for various purposes. Existing land use systems in the core area are residential, industrial, agricultural, pasture land, cultivable and non cultivable waste land and forest land. In core area now, industries have become a major stake holders of land.

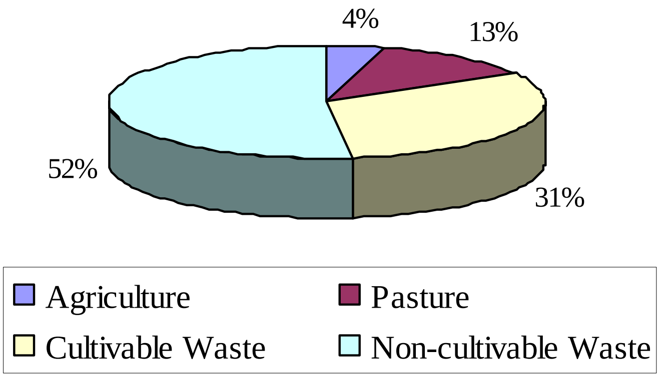


Fig. 9.20 Classification of Land Diverted for Industrial Use (66.49 Sq.km.)

Data on land acquired by industries have been collected from Mundra Taluka Panchayat (2012), and EIA Reports of industries. Through study of these records have revealed that, total land acquired by industries is 66.49 sq.km., that includes (Fig.9.20) agriculture land (2.8 sq.km.), cultivable waste land including pasture land (29.3 sq.km.) and non-cultivable waste land (34.5 sq.km.). Details on village wise land allotment for industrial development and land acquired by different industries from different land use categories are given in Annexures- 9.3 and 9.4 respectively. Out of this total 66.49 sq.km. land, 57.08 sq.km. land belongs to core study area only.

There is lack of data of some villages where land has been allotted but its area is not specified viz;. Adani Chemicals and Aadinath Polifils Pvt. Ltd in Dhrab village, Gujarat Adani Port Ltd in Goersama village, Rishi Container Station Pvt Ltd in Kapaya Mota village, and Mundra SEZ in Pawadiyara village. Further, EIA Report of IFFT (2012), the CGPL (Tata) Power Plant has acquired 1,250 ha (12.5 sq.km.) land in Tunda village which is 95.1 % of total village land (1314 ha). Adani Power Ltd. has acquired 293. 81 ha additional land in Tunda and Siracha villages (MoEF, 2013) but these records are not available with the Taluka Panchayat.

The proposed and identified area for SEZ by Adani Port is 180.00 sq.km of which 56.12 % is land area and 43.88 % fall within inter tidal zone of Gulf of Kachchh. Further, the proposed land area of SEZ is 101.01 sqkm that covers almost one third part of total area (348.4 sqkm) of coastal villages.

Besides this, mudflat regions along the core study area covers about 131 sqkm area (Fig. 9.1). This mudflat area is now mostly covered by the industries (Fig.9.2). Major stack holders in mudflat region are Mundra SEZ, Adani Port Ltd, Adani Chemicals Limited and Aadinath Prolifits. Total mudflat land acquired by these units is 68.12 sq.km. (52 % of total). Adani Chemical Ltd has acquired about of 2946.22 ha for the establishment of high purity salt works, surprisingly out of this 1850 ha is the forestland for which sanction is accorded in May 2004 (MoEF, 2013).

This above cited diversion of land for different industrial uses and overall industrial development of the core area, following impacts are fore seen.

- The grazing land allotted partially or fully to industries has adversely affected animal husbandry occupation in Jarpara, Tunda villages (Annexure 9.3).
- SEZ Airport in south of Shekhadia village spread over 1200 ha land (MoEF, 2013) has blocked traditional ways to the fishing sites.
- Tunda village land is mostly acquired by mega power plants which has completely ruined the social set up of village and animal husbandry occupation.
- Mangrove degradation has lead to erosion of coast and also affected fishing occupation.
- Mudflat perform balancing act between in-land area and sea as the mudflat area is mostly occupied by industries, it has disturbed cycle of the ecosystem and Gulf of Kutch sedimentation pattern.

GROUNDWATER RESOURCE

Impact on groundwater regime has been assessed for long term duration of 15 years from 1995 to 2010. Long term change in groundwater regime of core area has been studied through static water level, TDS and chloride parameters and analyzed in terms of isobath maps (Fig 9.21, 9.22 and 9.23 respectively). Besides this, the secular impact in terms of spatial change has been attempted for each parameter (Table 9.11).

Over the period of last 15 years, groundwater quality shows deterioration along with lowering of water levels. So far TDS is concern, it has increased and encompasses almost 79.6 % (261.6 Sq.km.) area whereas only 20.4 % area shows improvement in groundwater TDS concentration. Concerning change in chloride concentration, only 1 % area shows improvement. Remaining 99 % area shows increased concentration of chloride. Maximum deterioration in water quality has been observed in southern part of study area between Bhujpur and Jarpara villages and in eastern part around Luni village. These villages also show high order of water level depletion (>80 m). There has been an overall depletion in water levels in the core area ranging between 20 m and >80 m (Fig. 9.21).

TDS isobaths for year 1995 suggests that about 63 sq.km of core study area has potable groundwater which has reduced to 28.6 sq.km. in year 2010. Therefore, in all 34.4 sqkm area having potable groundwater has been affected due to salinity. Area having high TDS concentration (>3000 mg/l) has increased from 47.5 sq.km (1995) to 99.6 sq.km. (2010) i.e. 43.1 sq.km. increase. This sharp rise in salinity in groundwater is attributed to over exploitation of groundwater leading to sea water intrusion.

Table 9.11 Secular Change in Groundwater Quality and Groundwater Storage in 15 Years

Area under Change in Quality						Area under Change in Static Water Level (Sq.km.)		
Category	**Change in mg/l**	**Chloride**		**T.D.S.**				
		Sq.km.	**%**	**Sq.km.**	**%**			
Decrease (+)	>1000	0	0.0	3.5	1.1			
Decrease (+)	500-1000	0	0.0	15.5	4.7	**Depletion in m**	**Sq.km**	**%**
Decrease (+)	<500	3.2	1.0	48.0	14.6			
Increase (-)	<500	198.1	60.3	50.1	15.3	<20	48.7	14.8
Increase (-)	500-1000	57.3	17.4	46.5	14.2	20-40	126.1	38.4
Increase (-)	1000-2000	50.5	15.4	137.9	41.9	40-60	68.0	20.7
Increase (-)	2000-3000	9.2	2.8	22.3	6.8	60-80	66.1	20.1
Increase (-)	>3000	10.3	3.1	4.8	1.5	>80	19.7	6.0
Total Area Sq.km.		**328.6**	**100**	**328.6**	**100**	**-----**	**328.6**	**100**

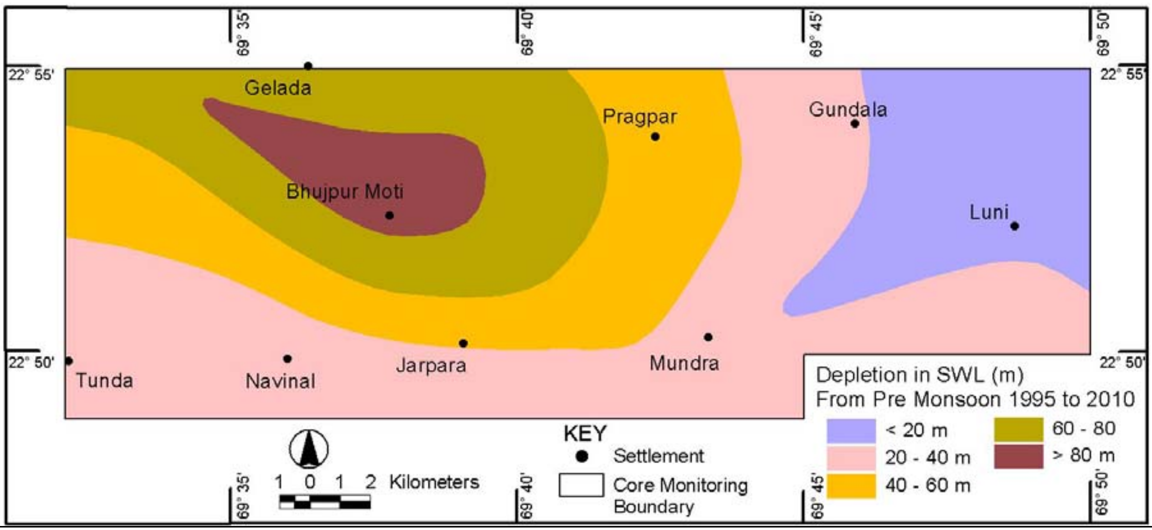


Fig. 9.21 Secular Change in Groundwater Storage in 15 years (1995 to 2010)

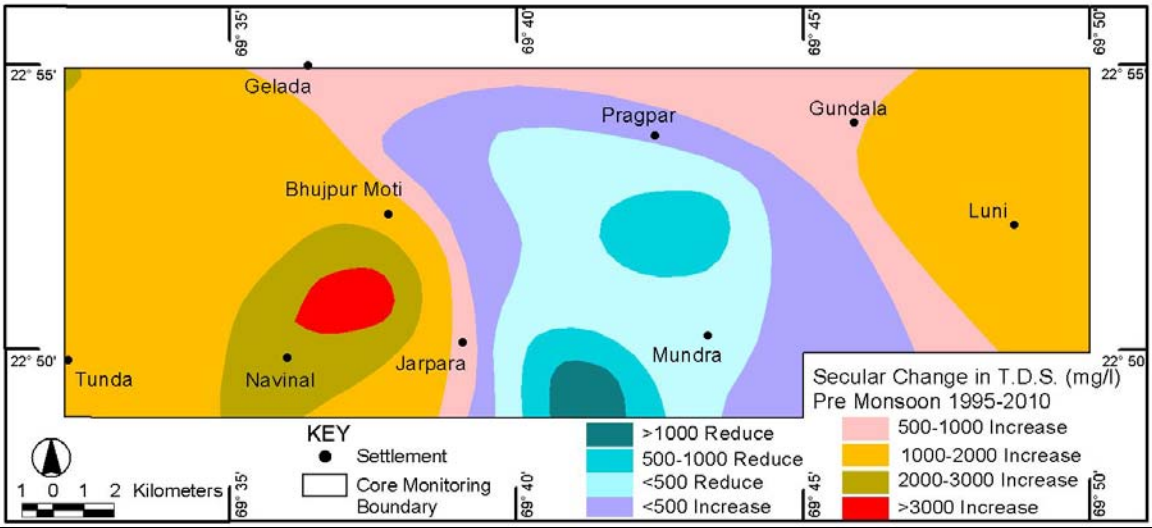


Fig. 9.22 Secular Change in Total Dissolved Solids in 15 years (1995 to 2010)

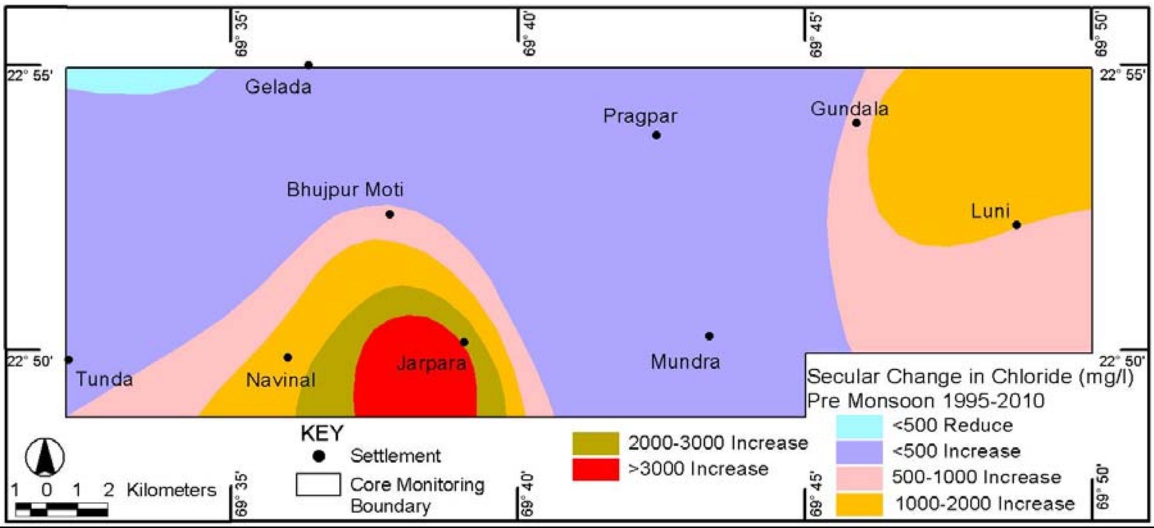


Fig. 9.23 Secular Change in Chloride in 15 years (1995 to 2010)

ECOLOGY

Development attitude of human being at times harmful to ecological balance and existence. The coastal area has a characteristic diversity in terms of mangroves, creeks, aquatic life etc which are very fragile and sensitive.

The coastal belt of Mundra taluka has pockets of rich mangrove forest. Mangroves play multiple role in ecology as it provide food and breeding ground to fish, protect coastal land from sea water ingress and erosion; and supply fodder for cattle in scarcity. During development phase (1998) of Mundra Adani Port, rich mangroves have been destroyed

(Plate 9.5 A & B) which has adversely affected land erosion and fish production. A mangrove patch (100 m belt) along the west bank of Navinal creek was existing in the year 2005, but the same has vanished in 2011 (MoEF, 2013). Study carried out by National Centre for Sustainable Coastal Management through remote sensing has revealed about the destruction of mangroves in 75 ha land in Bocha Island located in south-west of Mundra (MoEF, 2013).

Plate 9.5 A. A View of Destruction of Rich Mangrove Forest for Land Clearance (Loc. South to Mundra Town)

Plate 9.5 B. Barren Land after Removal of Mangroves (Loc. South to Mundra Town)

The ultimate damage is caused to the sea shore because of injudicious cutting of mangroves and other vegetation as now sea has encroached the inland areas and spoiling the cultivable land along the coast (VRTI, 2003). The coastal area is vulnerable to cyclone hazard and had suffered from cyclone many times in the past. The mangrove cutting has added more vulnerability to the area for this natural hazard.

The cooling channels of thermal power plant are unlined and made the inland areas vulnerable to soil and groundwater salinity. The Gujarat Pollution Control Board (GPCB) has conducted a site inspection of these channels along with village representatives. After that, GPCB in April, 2011 has issued directives to the company to carry out a detailed assessment of underground water quality, including salinity ingress, in surrounding area through a reputed agency. The similar issues have also been raised in EIA study recommended by MoEF in April, 2013. Ash generation from thermal power plant is also harmful to the surrounding areas, particularly the coal ash dump sites as it may cause land degradation and effect to human health.

Another threat is river sand mining. In the core area, there exists very high demand of sand for construction purpose. The river beds and river bank areas along Bhukhi, Phot, Nagmati rivers, the sand mining is undergoing at large scale. This uncontrolled and illegal sand mining activity has caused adverse impact on groundwater resource.

BENEFIT

The industrial development also has positive impacts too. Industries are the large sector of employment for various disciplines from highly qualified personnels to labor level. Due to growing employment opportunities in industrial sector, per capita income has also increased. The industrial development also support large service sector for various purposes i.e. transport, hotels, schools, hospitals, commercial shops etc. Due to increasing demand of land, land prize in core area has gone very high which has provided good opportunity to real estate and land development business. Also, land and houses are providing rent economy. Industrial sector has developed and supports many infrastructure and basic amenities that includes road, railway, health facility, education etc (Plate 9.6).

Plate 9.6 A View of Development of Four Lane Road Infrastructure in Progress, (Loc.- Pragpar-Mokha Sector)

Industries do facilitate upliftment of the local society under CSR (Corporate Social Responsibility) policy. It mainly includes health facility, education facility, Self Help Group (SHG) for money savings etc. As discussed earlier that, grazing and open land of Tunda village have been acquired by CGPL ltd. Therefore, CGPL arranges fodder for the cattles of village through Fodder Depot. CGPL has also initiated education support i.e. ILEAD centre (Institute for Livelihood Education and Development) imparting education on computer hardware, electrical maintenance etc. to the local people. Adani Industries is providing facilities for health and education at concessional rates. Health check-up camps are organized regularly for senior citizens, women and children.

The core area region is contributing its major part to power sector. Total existing and proposed power production is 15,971 MW which is supplied to other parts of Gujarat and other states like Rajsthan, Haryana, Punjab, Maharashtra, Delhi through National Power Grid.

However, the above cited benefit can hardly compensate damages caused to The Core Area's natural resources. These damages are bound to cause long term effects and if not taken care, it would be set to irreversible path, beyond any control.

Chapter - X

WATER RESOURCE MANAGEMENT

CHAPTER – X

WATER RESOURCE MANAGEMENT

"Our Entire Society Rests Upon and Is Dependant Upon Our Water, Our Land, Our Forests and Our Minerals. How We Use These Resources Influences Our Health, Security, Economy and Well Being" *(John F. Kennedy, 1962)*

GENERAL BACKGROUND

Development is a process that closely linked with the ecological evaluation. In ancient time, development of Harappan, Mesopotamian civilizations were based on natural resources especially soil and livestock. Man has also evolved and developed appropriate techniques to live comfortably with such natural resources. This development has been tagged as "soil economy". Now in the modern phase of development, emphasis is lead on industrialization which is based on fossil fuel and hydro energy. In the modern development, man has started exploiting more and more natural resources using energy resource resultantly, potential of natural resources started gradually decline. Over exploitation of basic resources that includes land and water has impacted adversely causing an irreparable damage to land and water systems. The present study of Mundra region is one such case example where in a major crisis is emerged out due to over exploitation of natural resources in general and groundwater in specific.

On-going industrial development activities in the study area have emerged several issues that are concerned to natural resources i.e. groundwater and land resources, human resource and ecology which have already been described in detail in preceding chapters. In core area, part of land resource acquired by industries has impacted adversely is land use pattern. Out of total 66.49 sq.km. land allotted for industrial development which includes 2.8 sq.km. (280 Ha) agriculture land, 29.3 sq.km. (2930 Ha) cultivable wastelands including *gauchar* and 34.5 sq.km. (3450 Ha) non cultivable waste land. (Table 2.14 & Fig. 9.20). Besides this, 68.12 sq.km. (52 % of total) mudflat area is utilized by industries. This diversion of land to industries from different land use categories has adversely impacted the traditional occupations i.e. agriculture, animal husbandry, fisheries and marine ecosystem thereby socio-economic status of the local inhabitants is severally affected.

So far, groundwater resource is concern, over exploitation has lead to acute lowering of groundwater levels ranging between <20 m and >80 m, inviting problems of groundwater quality deterioration in inland aquifers and sea water intrusion in coastal aquifers falling within the core area. The rate of lowering of water table in present case stands at 5 m/year (Fig. 5.21).

The magnitude of groundwater quality deterioration in terms of TDS & Chloride (salinity) concentrations and spatial coverage has already been elaborated in preceding Chapters 9 & 10. However, long term change in TDS & Chloride suggests an overall 69.1 % (1152 km^2) area, mainly the coastal region has witnessed deterioration in groundwater quality i.e. groundwater in non-potable (Table 8.5).Groundwater quality has been monitored at closer grid spacing in core area. Groundwater quality assessment of core area suggests that TDS has increased over the period in 79.6 %

(261.6 sq.km.) area, while concentration of chloride has increased in 99 % of the core area (Table 9.11).

As the prime aim of the study is to evolve appropriate strategies to manage groundwater salinization issues of the area; the candidate has envisaged land and water resources development and management plan, mainly emphasizing groundwater resource. In this chapter, candidate has described considerations for development and management strategies, core area specific strategies for groundwater salinity remediation and approach for implementation methodology.

PLANNING CONSIDERATIONS

Past developmental history of state as well as nation has shown many ups and downs in adopted approaches. Parallel to such developments district Kachchh has also experienced many phases of developments. However, the district being disaster prone always remain at advantage and received more opportunities for development. Development footprint of the Kachchh district starts with centralized approach to support traditional economies and water supply for domestic purposes. To resolve the developmental issues in the study area, the candidate has reviewed National Water Policies put-forth in 1987, 2002, Model Bill 2005 and the Twelfth Five Year Plan on Sustainable Groundwater Management, prepared by Planning Commission, 2012.

Based on recommendations of national documents, previous experiences of various organizations working in Kachchh district and findings of the present study, the candidate has adopted following thematic aspects to work out framework of actions for groundwater resource management plan for the study area.

WATERSHED DEVELOPMENT

Watershed is a close system where precipitated runoff from surrounding area flow from a single point to river or sea. Land and water are fundamental natural resources of any watershed where both are closely linked. Water resources are available in the form of river basins for surface water and aquifer systems for groundwater. Land resource development is considered as a part of water resource development only.

The study area represents an integration of eight meso level watersheds or river basins. (Fig. 4.3) Considering it as a part of planning unit, the candidate has identified different issues observed from ridgeline to coast. In upper parts of the study area, problem of soil erosion, land productivity and management of existing surface water structures. Middle part of the study is comprised of basalt, land surface is having a very thin soil cover and problem of deforestation due to mining activities. In lower part of the study area, there are problems of soil salinity, lowering of water table and groundwater salinity. As the study is focused on groundwater salinization, emphasis has been given on envisaging strategies to minimize salinity hazard.

Although, there exists voluminous literature on watershed development and management aspects, the candidate has referred and utilized some of the noteworthy contributions that has facilitated the candidate in strategizing the framework of groundwater management plan of her study area viz; Anonymous (1979), Balakrishna (1986), Hufschmist (1986), Pacey & Cullis (1989), Dhruvanarayana et. al. (1990), Sebastianetal (1995) and CGWB (2007).

In Kachchh region Jadeja (2005) has carried out water resource management planning in Pachchham area of Kachchh district. He has recommended a systematic approach for watershed management based on hydro-geological characteristics considering saline nature of terrain (Table 10.1). In the presented study also, the candidate has adopted similar approach i.e. de-centralized system of water resource development and management.

To maintain sustainability of the resource and its management, community participation becomes equally essential. Therefore, the candidate in her envisaged framework of actions also included social engineering components viz; management institutions and community capacity building. Candidate being associated with an NGO has already validated the efficacy of social engineering aspects in adjoining talukas of her study area.

Table 10.1 Watershed Development Strategies Based on Hydro-geological Characteristics (After Jadeja, 2005)

Catchment Description		Water Harvesting Techniques			
Location	Geomorphic Unit	Permeable Stratum		Impermeable Stratum	
		Non Saline	Saline	Non Saline	Saline
Upper Catchment	Hills, Rocky uplands	CD	GS	ST Large	ST Large
Middle-Upper Catchment	Undulating Plains	GS(U/S) SD (M) SCD (D/S)	STp - STr	ST Large	GS & STp
Middle-Lower Catchment	More or less even Plains	GS (U/S) & PT (M) SCD (D/S)	GS (U/S) & PT (D/S)	GS (U/S) & ST (D/S)	GS &STp
Lower Catchment	Flat lands	FB & WW	FB & WW	ST Small	ST Small
		SCD	SCD	FB &WW	FB &WW

Key

Groundwater Recharge	CD	Check Dam	ST	Storage Tank
Soil Moisture Conservation	GS	Gabbian Structure	FB	Farm Bund
Surface Storage	PT	Percolation Tank	STp / STr	Silt Trap/Staggered Trench
Salinity Prevention	SCD	Subsurface Check dam	WW	Waste Weir

WATER BALANCE

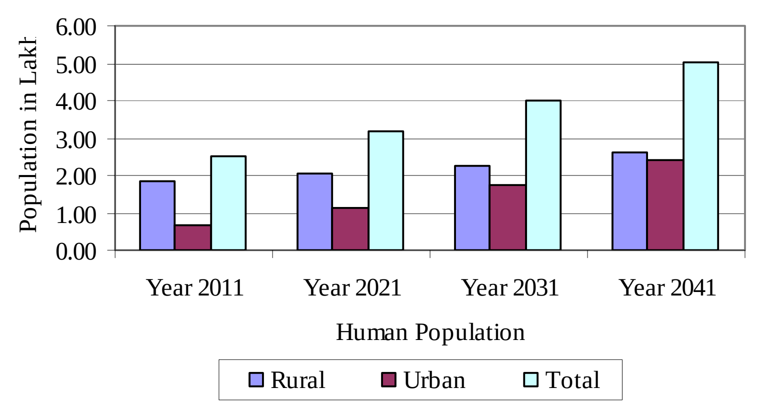
In addition to above considerations, water balance study has been carried out for the entire watershed region. Water balance is an important decision making tool for water resource development and management. The basis of this tool is evaluation of existing water resources as inflow and outflow components and demand estimation for domestic, agriculture and industries need. The outcome will help to frame water resource management strategy to meet the deficit requirement.

Demand Estimation

Water demand has been calculated for the watershed region considering various purposes viz; (I) Drinking and domestic water for human, (II) Drinking water for livestock, (III) Agriculture irrigation water; and (IV) Industrial water demand. Water requirement estimated for each purpose is described as under-

(I) Domestic and Drinking Water Demand for Human: Region must have adequate drinking water availability as it is a primary need for life. Concerning long term sustainability, estimation has been made based on demographic decadal growth rate of

the area for next three decades i.e. year 2041. Average decennial growth rate of the study area is 25.83 % (Census, 2011). The present population of the study area is 2.52 lakh and considering decadal growth rate, the projected population in 2041 shall stand at 5.01 lakh. For water demand estimation, study areas' population has been divided into two categories viz; rural and urban. Due to fast growing industrial economy, Mundra city is spreading fast and the surrounding villages are now attaining the status of town. Villages which have been considered as urban area, is based on life style, available infrastructure facility like sewerage, surrounding development like roads, street lights etc. The study area has 1.85 lakh as rural population, while 0.66 lakh urban population (Fig 10.1). The considered decennial growth rate for rural population @ 12.05 % and @ 54.39 % for urban population, the projected population shall be of given order (Fig. 10.1)



Present and Projected Population (Lakh)			
Year	**Rural**	**Urban**	**Total**
2011	1.85	0.66	2.52
2021	2.03	1.13	3.17
2031	2.24	1.75	3.98
2041	2.61	2.41	5.01

Fig. 10.1 Present and Projected Population of Study area

As per norms of Ministry of Rural Drinking Water and Sanitation of India (2009-10), provision for drinking and domestic demand is 70 liter/capita/day for rural people while it is 140 liter/capita/day for urban people as per Ministry of Urban Development of India (2009-10). Therefore, annual water demand estimation for projected rural population is 6.66 MCM while it is 12.30 MCM for urban population. In totality, drinking and domestic water demand of the study area stand at ***18.96 MCM per year*** (Table 10.5).

(II) Drinking Water Demand for Livestock: Drinking water demand for livestock has been calculated based on Livestock Census of year 2007. Population of each livestock type has been converted in Adult Cattle Unit (ACU) to estimate drinking water demand. Ministry of Rural Drinking Water and Sanitation of India (2009-10) has set norms for drinking water for livestock which is 30 liter/day/ACU. Total livestock population of the study area is 1,73,047. Based on ACU norms, total ACU of the study area stand at 1,04,921 therefore the estimated annual drinking water demand is ***1.15 MCM*** (Table 10.2).

Table 10.2 Estimated Livestock Drinking Water Demand

Type	Population	ACU unit	Total ACU
Cow	63,452	1.25	50,762
Buffalo	22,094	1	22,094
Sheep	39,002	3	13,001
Goat	45,185	3	15,062
Horses & Ponies	130	1	130
Donkey	429	1	429
Camel	2,755	0.8	3,444
Total	**1,73,047**	**----**	**1,04,921**
Annual Drinking water demand @ 30L/ACU/Day is 1.15 MCM			

(III) Agriculture Water Demand: Agriculture contributes major part to the economy of the area. Agriculture land cover of the entire region has been derived from IRS-1D Liss-III satellite image of year 2010. Accordingly, total agriculture land of the study area is about 1004 sq km., where in rainfed agriculture land area is 702.03 km^2 and irrigated agriculture land area is 302.10 km^2. To estimate water demand, irrigated agriculture land is further divided into field crop area (222 sq.km.) and horticulture (80.1 sq.km.). Rainfed agriculture is dominant with mix cropping pattern that includes sesamum, green gram, black gram, guar etc. Irrigated filed crops include cotton, wheat, groundnut, bajara, fodder etc. while date palm is a main fruit in horticulture.

Water demand for rainfed agriculture is considered about 400 mm water column per unit area for one season (Michael, 1978). Based on this, total water demand for rainfed agriculture comes to 280.81 MCM. For irrigated agriculture, average five irrigations have been considered for one season with total 500 mm water column per unit area (Michael, 1978). Accordingly, estimated water demand for field crop irrigation stand at 222 MCM for two seasons. For horticulture, computed water demand is 120.15 MCM for whole year. Therefore, total annual agriculture water demand stand at ***622.96 MCM*** (Table 10.3).

Table 10.3 Agriculture Water Demand Estimation					
Type		Area	Season	Water Column/ Season (mm)	Total Water Demand MCM
Rainfed		702.03	1	400	280.81
Irrigated	Field Crop	222.00	2	500	222.00
	Horticulture	80.10	3	500	120.15
Total		**1004.1**	**----**	**-----**	**622.96**

<u>(IV) Industrial Water Demand:</u> Water requirement data for established industrial units in study area have been obtained from Federation of Kutch Industries Association (FOKIA) and E.I.A. Study Reports. As per available information, total industrial water requirement is about 78.06 MCM (Table 10.4).

Table 10.4 Industrial Water Demand

Sr. No.	Name of Industry	Water Requirement	
		MLD	Annual MCM
1	Adani SEZ Ltd.	121.84	44.47
2	Coastal Gujarat Power Ltd.-TATA Power Company	66.95	24.44
3	OPG Power Plant	6.00	2.19
4	Jindal Saw Pipe Ltd	11.05	4.03
5	Ramco Industries Ltd.	0.10	0.04
6	Lakshmiwadi Mines & Minerals Pvt.Ltd.	0.10	0.04
7	Phillips Carbon Black Limited	2.20	0.80
8	Excel Crop Care Ltd	0.13	0.05
9	Man Industries (India) Ltd.	2.00	0.73
10	Mahashakti Coke	2.00	0.73
11	Saurashtra Fertilizer Ltd.		
12	Ashapura Minechem Ltd	0.50	0.18
13	Surya Global Ltd	1.00	0.37
Total		**213.87**	**78.06**

Source: FOKIA, Kutch & EIA Reports

Therefore, taking in to account, the estimated water demands for various purposes cumulative water demand for the study area is about 721.13 MCM/year. (Table 10.5)

Table 10.5 Cumulative Water Demand of the Study Area	
Demand Type	**Demand (MCM)**
Domestic and Drinking Water for Human	18.96
Drinking Water for Livestock	1.15
Agriculture Demand	622.96
Industrial Demand	78.06
Total Demand	**721.13**

Available Water Resources:

Water supply to the study area is considered as available surface and groundwater resources. Net available groundwater resource has been computed using water balance approach. Water received from Narmada canal is also considered in available water resource estimation.

As it has already been elucidated in preceding chapter on water balance study, total estimated groundwater recharge is 207.93 MCM. As a part of surface water resource, total water filled in surface water structures is 75.94 MCM, while Narmada water supplied to industrial units by Gujarat Water Infrastructure Limited (GWIL) is 4.03 MCM and in addition to this, the taluka receives 2.19 MCM water @ 6 MLD for drinking water supply (GWSSB, 2013). Therefore, ***total available water resource (supply) through various sources comes to 290.09 MCM*** against 721.13 MCM demand. Consequently, the study area witness ***water deficit of about 431.04 MCM*** (Table 10.6).

Table 10.6 Water Resource Scenario of the Study Area

Supply Source	Volume (MCM)
Groundwater (recharge)	207.93
Surface Storage	75.94
Supply from outside basin (GWIL)	6.22
Total Supply	**290.09**
Total Demand	**721.13**
Water Deficit	**431.04**

Similar approach can be adopted at micro level for individual village. Considering water resource availability, study area villages can be divided into 04 categories ranging from surplus water village to severe deficit village (Table 10.7). Further, in each water balance category, candidate has proposed various approaches to fulfill the water requirement viz, (01) Sharing mechanism; (02) Strengthening capacity of local resources by enhancing groundwater recharge or rain water harvesting; (03) improving water use efficiency; (04) Use and reuse of resources i.e. recycling; (05) Scope for Introducing new technology; and (06) Addition of external resources (import) if required.

Table 10.7 Proposed Water Resource Management Strategies Based on Water Balance Approach

Water Balance Category	Internal Sharing	Strengthening Capacity of Existing Water Resources	Augment Recharge	Improve user level efficiency	Reuse and Recycling	Technology Induced	External Source (Import)
Surplus (Supply > Demand)	Water can be distributed near by marginal deficit areas	Need management institutions e.g. River basin management federation, aquifer management institute etc.		Promote low water require crops in irrigated farming	Treat all urban, and semi-urban area sewage water and supply for irrigation purpose within village or deficit villages	Techniques for consumptive use of water e.g. Micro irrigation	N.A.
Marginal Deficit (Supply Deficit <20 %)	Micro or village level balance estimation and share within adjacent villages	Increase capacity of existing surface water bodies and maintenance	Watershed Programme Identify good groundwater recharge pockets	Horticulture promotion and Planned agriculture for food securities.			N.A.
Moderately Deficit (Supply deficit between 20-50 %)	Not recommended	Irrigation through small irrigation structures Aquifer management	Encourage Recharge with different methods (Runoff Harvesting)	Strongly recommendation for practice level changes such as promote and encourage securities in rainfed farming production	DWATS* should be Compulsory for Municipality and Industries DWATS	Promote Rainwater Harvesting techniques at household level, campus and for industry	Yes for critical period only
Severe Deficit (Supply Deficit > 50%)	Not recommended	De-centralized drinking water source development and protection Sustainability	Groundwater protection for drinking water source sustainability. Protect good groundwater pockets	Livestock based occupation and promotion of fodder based crops Promote Improved crop/seed variety		Where ever feasible e.g. modern agriculture practices, water harvesting, soil moisture conservation	Yes for some part of year

De-centralized Waste Water Treatment System (DWATS)

HYDRO-GEOLOGICAL POTENTIAL CATEGORIZATION

Groundwater potential of any area depends on multiple factors viz; lithology, structures and geomorphic characteristics etc. These are the controlling factors for groundwater occurrence, recharge and surface runoff. Therefore, it is essential to give weightage to these factors for better groundwater management. Systematic study of an individual factors and its attributes in terms of its function as infiltration and/or surface runoff; assigning an appropriate rating can facilitate in categorizing the area from the point of view of groundwater potential (discharge) and recharge zones. This approach was adopted by the Environment Planning Collaborative (EPC, 2003) in water resource planning of Kachhch region and duly supported by UNDP. Afterward Jadeja (2005) has modified and adopted this approach for water resource planning of Pachchham Island. In present study, the candidate has adopted same approach to carry out hydro-geological categorization. The categorization is based on developing 03 important thematic layers viz; i.e. Hydro-Lithological (HL), Hydro-Structural (HS) and Hydro-morphological (HM).

Approach and Methodology

A multi-technique and intra-disciplinary approach has been adopted to derive hydro-geologic potential categorization. The information and data required for hydro-geologic categorization have been sourced from primary and secondary data viz. geology, Survey of India topographic maps, landuse and soil maps, satellite imagery, DEM etc.

The information thus assimilated in terms of respective thematic layers on GIS environment. Important software packages used viz. Carta linx, Idrisi, Arc View 3.2a for hydro-geologic categorization. For this, each layer has been categorized in three groundwater potential classes viz, High (Rank 3), Medium (Rank 2) and Low (Rank 1) depending on recharge ability. Salient characteristics of functional hydro-geologic categories are discussed as under-

Hydro-Lithological Categorization :

The study area comprises sedimentary and volcanic rocks. These rocks have been divided into three major groups viz. Consolidated rocks, Semi-consolidated rocks, and Un-consolidated rocks. (Devis and DeWest, 1967). Considering the broad genetic character of rocks, the area has been divided into three classes viz. Consolidated category (HL1) includes compact and weathered basalt having low recharge capacity, Semi-consolidated category (HL2) includes Laterite, Sandstone, Limestone, Shale and Miliolite having medium recharge capacity; and Un-consolidated category (HL3) includes alluvium, river sand, dunal sand having high recharge ability. The derived hydro-lithologic categorization is given in Table 10.8 and Fig. 10.2.

Table 10.8 Hydro-Lithological Categorization of Study Area

Sr. No.	Class	Potential	Formation	
1	HL1	Low	Compact Basalt, Weathered/Fractured Basalt	Consolidated
2	HL2	Medium	Laterite, Sandstone, Limestone, Miliolite	Semi-consolidated
3	HL3	High	Alluvium, River Sand comprising pebble, sand, kankars, silt etc.	Un-consolidated

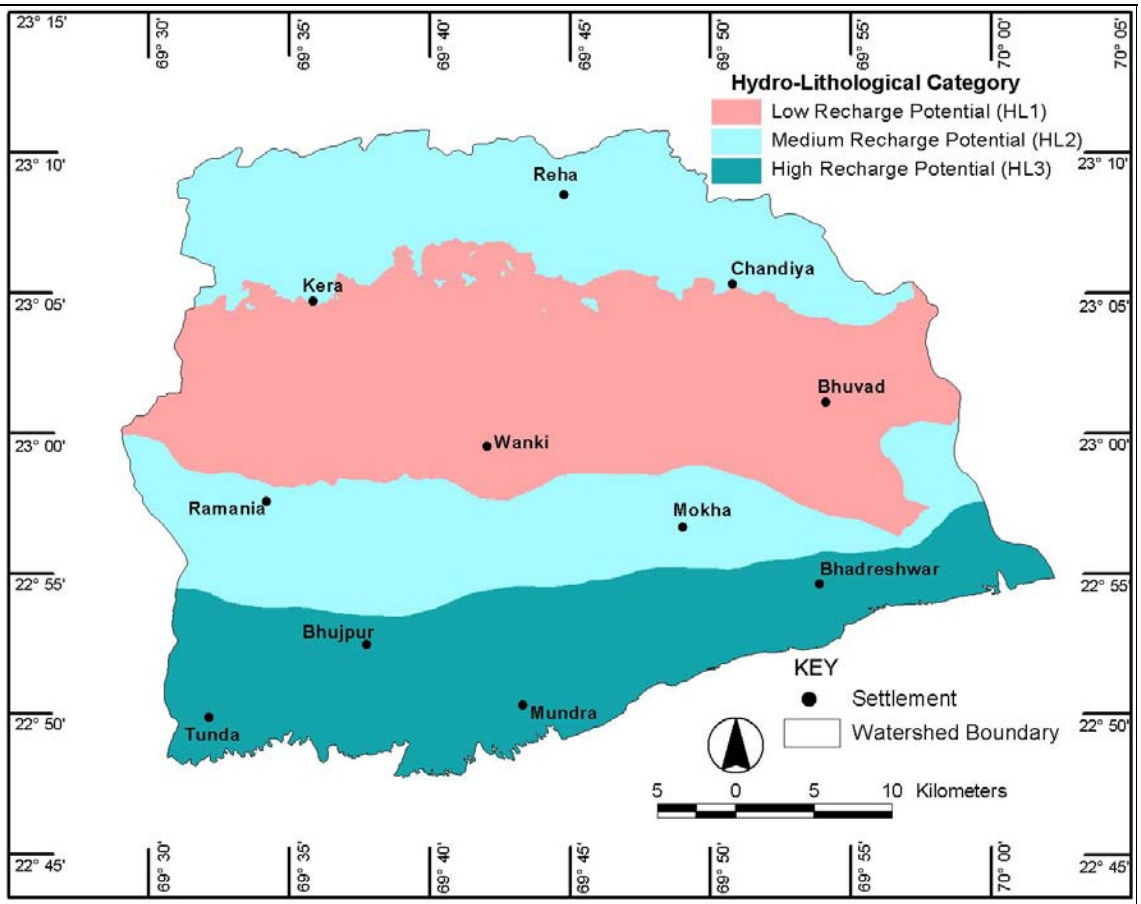


Fig. 10.2 Hydro-Lithological Categorization of the Study Area

Hydro-Structural Categorization:

Table 10.9 Hydro-Structural Categorization of Study Area			
Sr. No.	Class	Potential	Density/ Sq.Km.
1	HS1	Low	<3
2	HS2	Medium	3-5
3	HS3	High	>5

Tectonic features are reflected through the presence of fractures, dykes, fault, fold, regional joints etc. Structural part is one of the important aspects to define groundwater potential as it influence groundwater movement and storage in terms of secondary porosity. To derive hydro-structural categorization, the study area has been divided into 1 sq. km. grid and the lineament density has been calculated. The computed hydro-structural categorization (Table 10.9) is given in Fig.10.3. Looking to the categorization, the area has low frequency of lineaments. Maximum 7 nos of lineaments found in 1 sq. km. grid. Major area falls in low potential category while upper reaches and basalt area suggests medium potential.

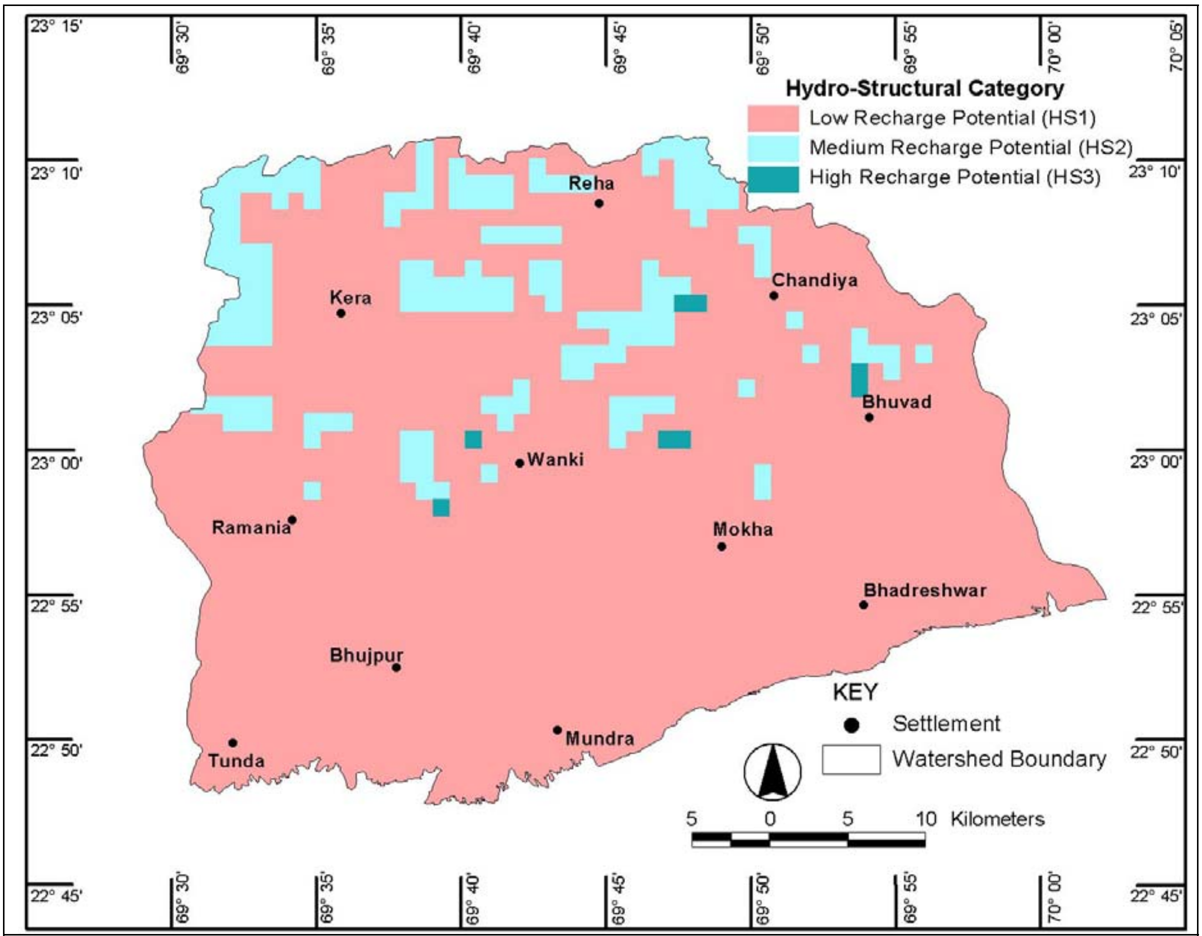


Fig. 10.3 Hydro-Structural Categorization of the Study Area

Hydro-Morphological Categorization: Distribution of rainfall is governed by terrain characteristics after it reaches to surface. Considered terrain attributes are landforms, drainage, slope, soil, land use etc. which control rate of run off and infiltration. Accordingly, hydro-morphologic categorization (Table 10.10) has been done and presented as (Fig 10.4).

Table 10.10 Hydro-Morphic Categorization Based on Terrain Attributes

Hydro-morphic Class	Potential	Landform	Slope
HM1	Low	Dissected Hills, Ravines	$>5^0$
HM2	Medium	Pediment Zone, Alluvial Plain	$2^0 - 5^0$
HM3	High	Valley Deposit, Coastal Plain, River fan, Dune	$<2^0$

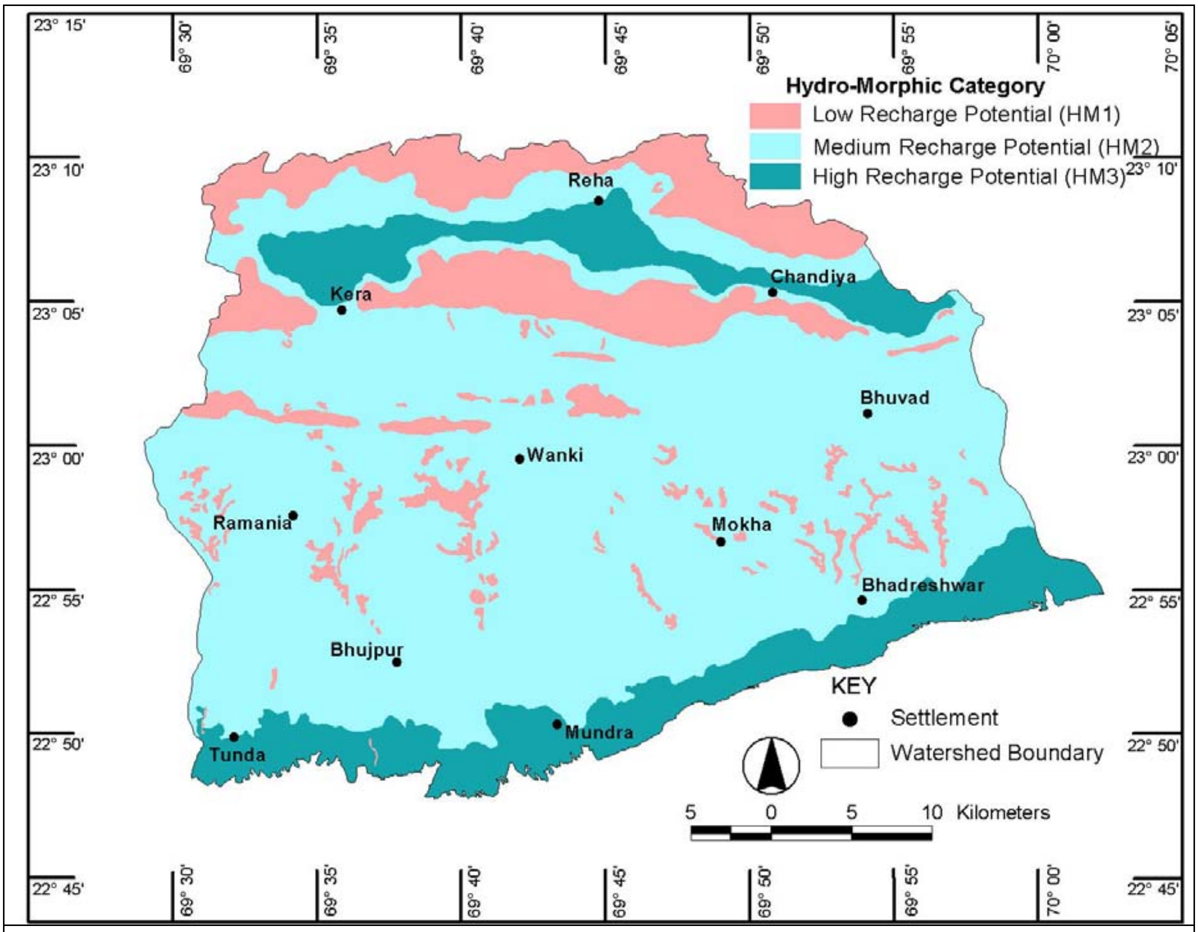


Fig. 10.4 Hydro-Morphic Categorization of the Study Area

Hydro-Geological Categorization: The study area has been evaluated in three fold classifications of hydro-geological recharge categories by overlaying of layers of lithology, structures and geomorphology using Idrisi software. First of all, two layers of hydro-lithology (HL) and hydro-structural (HS) have been overlayed to derive Hydro-litho-structural (HLS) categories. In the synthesized layer, each HLS category is automatically ranked by addition of rated scores of both HL and HS layers e.g. HL3 + HS3 = 6; HL3 + HS1 = 4 and so on. The obtained ranking again classified in to three categories viz. HLS-1, HLS-2 and HLS-3 (Table 10.11). a composite thematic map on hydro-litho-structural layers (Fig. 10.5) has further refined the recharge potential sites in the study area.

Table 10.11 Rating for Hydro-Litho-Structural Categorization

Lithology (HL)	**Structural (HS)**				**Hydro-Litho Structural Categories**	
	Class	**HS3**	**HS2**	**HS1**		
Class	Score	3	2	1	Score	Category
HL3	3	6	5	4	6-5	HLS3
HL2	2	5	4	3	4	HLS2
HL1	1	4	3	2	3-2	HLS1

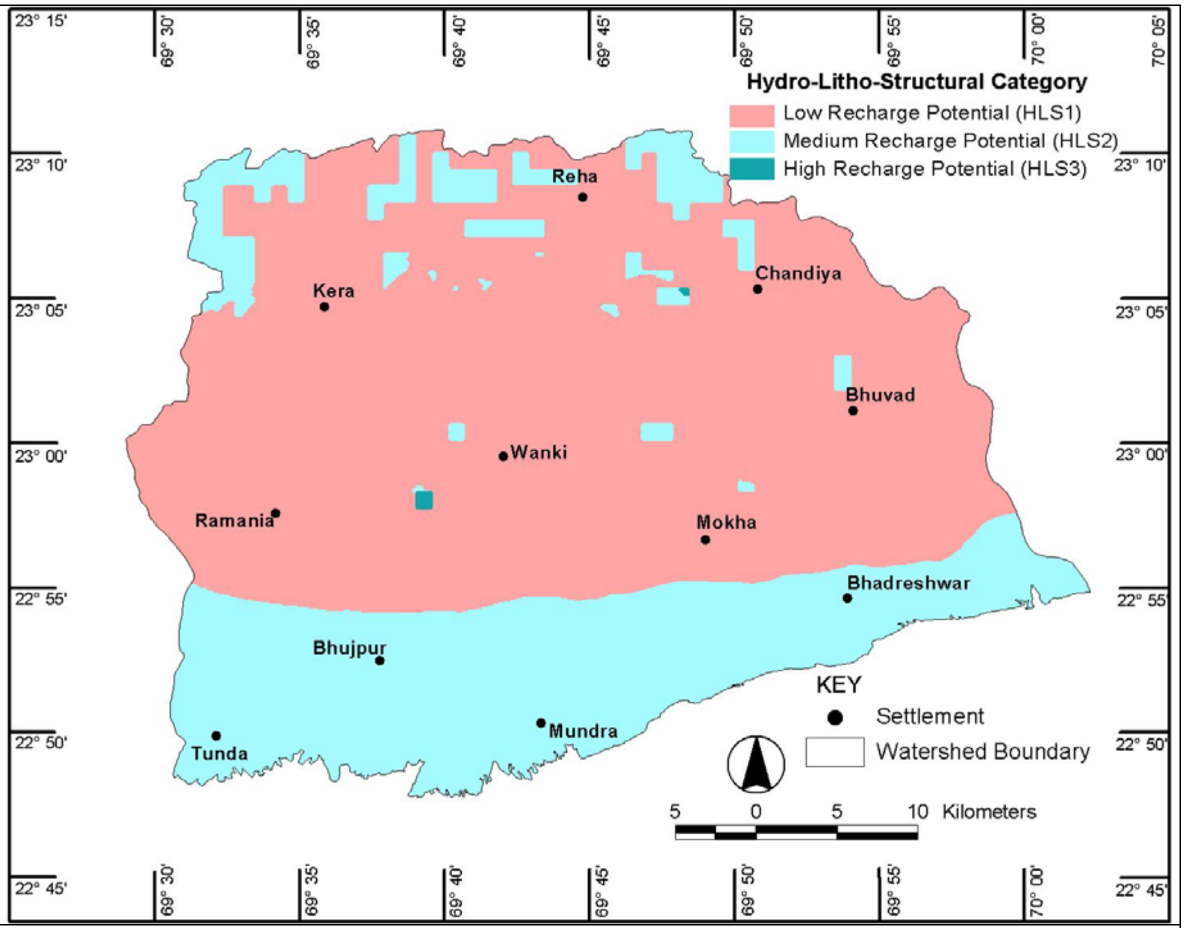


Fig. 10.5 Hydro-Litho-Structural Categorization of the Study Area

The above generated layer of hydro-litho-structural (HLS) thematic layer has been overlayed on hydro-morphology (HM) thematic layer to synthesize an integrated thematic map i.e. hydro-geological potential (HG) map (Fig. 10.6). The addition of rank of each layer i.e. HLS and HM again rated to derive HG-1, HG-2 and HG-3 categories as described in Table 10.12. The study area has been classified into three categories as low (HG 1), moderate (HG 2) and high (HG 3) potential recharge categories (Fig. 10.6). The derived hydro-geologic recharge potential categories have been utilized as a part of framework of actions for groundwater resource development and management.

Table 10.12 Rating for Hydro-Geological Categorization of Study Area

Hydro-Litho-Structural	Hydro-Morphic				Hydro-Geological Categories	
	Class	HM3	HM 2	HM 1		
Class	Score	3	2	1	Score	Category
HLS3	3	6	5	4	6-5	HG3
HLS2	2	5	4	3	4	HG2
HLS1	1	4	3	2	3-2	HG1

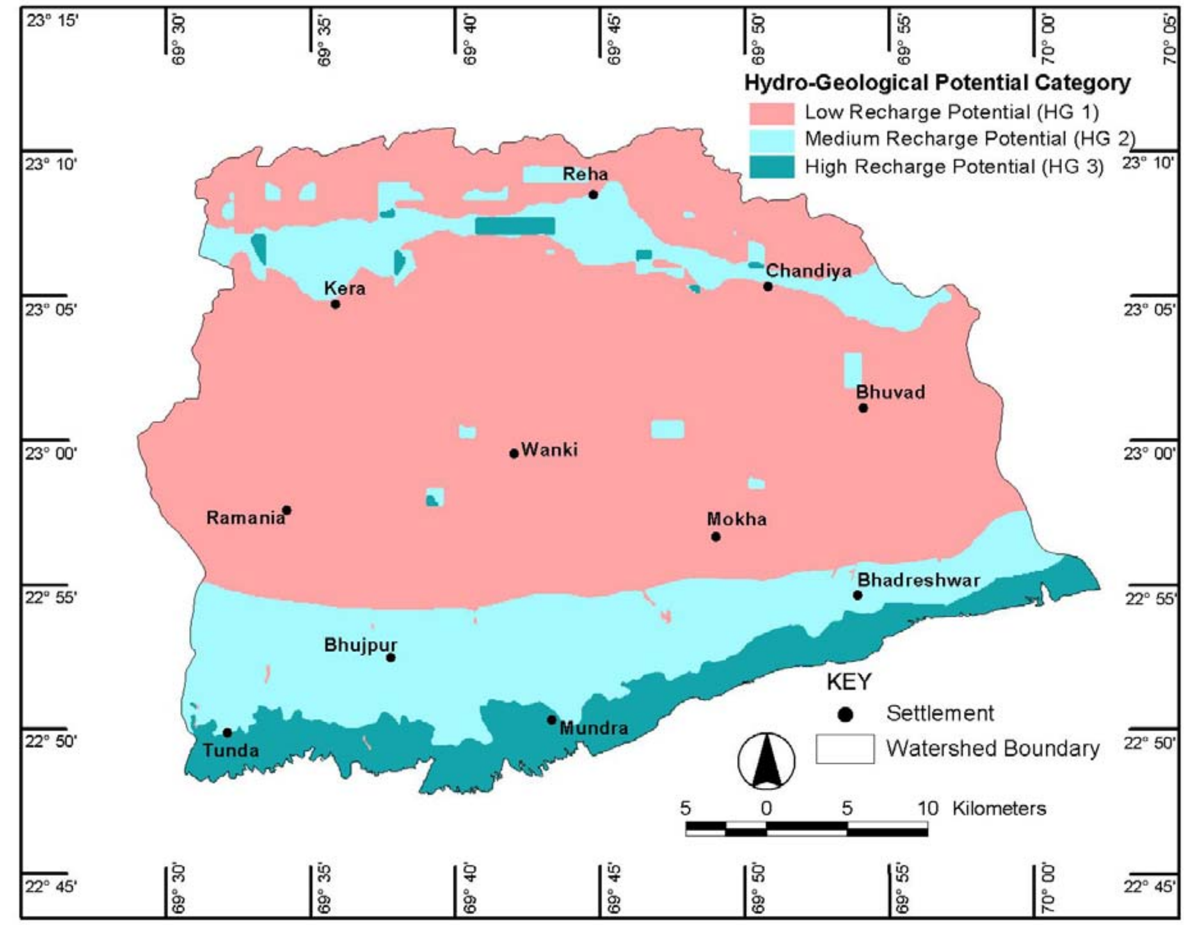


Fig. 10.6 Hydro-Geological Recharge Potential Categorization of the Study Area

The hydro-geological recharge potential map (Fig 10.6) suggests that northern hilly region and central part of the study area have low groundwater recharge potential whereas alluvium area and valley deposits have moderate recharge potential. Coastal region has high potential of groundwater recharge. Based on hydro-geologic recharge potential categorizations, the candidate has proposed water resource management activities in the study area (Table 10.13).

Candidates' endeavor to frame water resource development and management strategies includes three major components i.e. (01) Development aspects; (02) Management aspects; and (03) Protection mechanism.

Development aspects would mainly focus on strengthening and up-gradation of existing resources contributing in fulfillment of need of the area. This component includes those activities, which facilitate in development of additional water resource to satisfy growing demand.

Management aspects include two categories one that deals with social and institutional aspects with an aim to built community capacity and second that deals with alternative technologies and practices that facilitate water resource conservation and its judicious use.

Protection Mechanism largely encompasses development of regulatory mechanism to protect important locations/resources such as good groundwater pockets, drinking water sources etc from over exploitation and quality degradation.

Above described planning considerations suggest a way forward for overall water resource development and management in the study area. For groundwater management, the candidate has worked out problem specific strategies and approach to realize the goals. The important groundwater management strategies that can be implemented are artificial recharge, changing crop pattern, conjunctive use, develop well specific pumping schedule, reuse of waste water and modern irrigation practices (Galloway, 2003).

As it has already been discussed that the study areas' groundwater resource is suffering from 02 kinds of stresses viz. lowering of water levels due to increase in sectoral demand and groundwater quality degradation due to over exploitation and sea water intrusion in coastal aquifers. Therefore, addressing management solutions to remediate aforesaid problems following strategies are recommended.

Table 10.13 Water Resource Development and Management Plan Based on Hydro-geological Categorization

<table>
<tr><th rowspan="3">Category</th><th rowspan="3">Objective</th><th colspan="4">Development and Management Plan</th></tr>
<tr><th colspan="2">Resource Development</th><th rowspan="2">Management Initiatives</th><th rowspan="2">Protection Measures</th></tr>
<tr><th>Water</th><th>Land</th></tr>
<tr><td>Low Recharge Potential (HG1)</td><td>Soil Water Conservation Surface Water Resource Development</td><td>Upgrade existing water bodies through deepening and de-silting especially for Domestic and cattle drinking water supplying tanks
Roof water harvesting to meet domestic needs
De-silting of irrigation structures
Identify and develop new sited for rainwater storage</td><td rowspan="2">Farm bund for soil moisture conservation in rainfed areas
Silt traps, contour trenches, staggered trenches in grasslands and forest areas
Land leveling and tank silt amendments to increase land fertility</td><td>Drinking water management committee
Management of irrigation structures through PIM (Participatory Irrigation Management) approach</td><td>All drinking water body should be registered as common property asset of Gram Panchayat</td></tr>
<tr><td>Moderate Recharge Potential (HG2)</td><td>Increase Groundwater Recharge</td><td>Construction of New Recharge Structures like Check dams and percolation tanks
Provision of silt control measures in catchment areas of existing recharge structures to maintain efficiency
Roof water harvesting to meet domestic needs
Well recharge activities</td><td>Drinking water management committee
Aquifer based stakeholder's management committee
Compulsion of micro irrigation to increase water use efficiency</td><td rowspan="2">Identification and demarcation of critical areas as zone of influence and important recharge areas for all drinking water supply sources by Gramsabhas
Development of protocols for aquifer based water users within the framework of identified aquifer potential
Identification of salinity prone areas and declare notified area for restriction of specific activities</td></tr>
<tr><td>High Recharge Potential (HG1)</td><td>Manage Groundwater Quality and Water Levels</td><td>Roof water harvesting to meet domestic needs
Artificial recharge through dug well, channel and basin spreading methods
Construction of salinity prevention structures along the coast</td><td>Soil amendments like Gypsum etc for maintain soil salinity
Restriction of water intensive crop</td><td>Participatory monitoring groundwater salinity
Restriction on well pumping in coastal area</td></tr>
</table>

GROUNDWATER RECHARGE STRATEGIES

Groundwater recharge or artificial recharge may be defined as augmenting the natural movement of surface water into under ground formation by some method of construction by spreading of water or by modifying natural conditions (Todd & Mays, 2005 and Bouwer, 1999). CGWB (2005) has suggested two types of artificial recharge methods viz; Surface Recharge Techniques include - flooding, percolation tank; and Sub-surface Recharge Techniques include - recharge pit, injection wells, dug wells. Surface recharge techniques are most widely practiced where water is spread over large permeable ground surface in order to increase quantity of water in-filtering in to ground and percolating towards aquifers (Todd & Mays, 2005). Considering local situations, the following methods have been recommended for groundwater recharge in the study area (Fig.10.7).

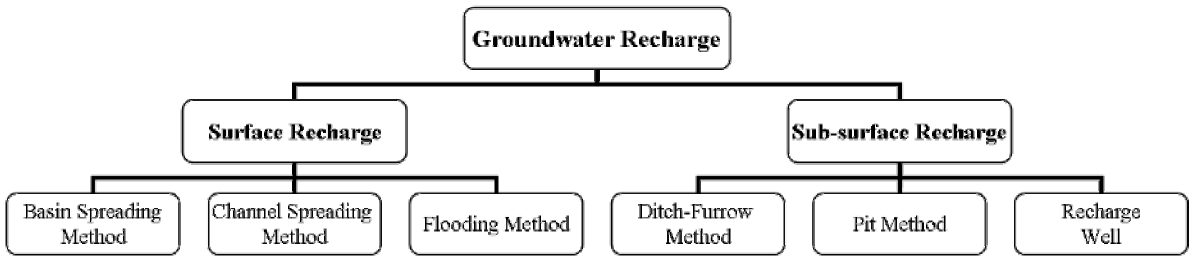


Fig. 10.7 Flow Chart showing Artificial Recharge Techniques

BASIN SPREADING METHOD

In basin spreading method, water is released in to basin/surface depression by constructing dyke or check dam across the stream (Todd & Mays, 2005). To increase recharge input, stream water flow is diverted to surrounding depression area and again connect to the natural stream in lower reaches. This multi basin recharge approach supports groundwater recharge at larger scale. In study area, three locations have been identified in upper reaches of Bhuj sandstone and lower reaches of Kankavati sandstone viz. (i) basin in south of Naranpar village, (ii) Reha village, and (iii) North-West of Luni village (Fig. 10.8). It is proposed to link tributaries to increase recharge and again divert it to main stream.

CHANNEL SPREADING METHOD

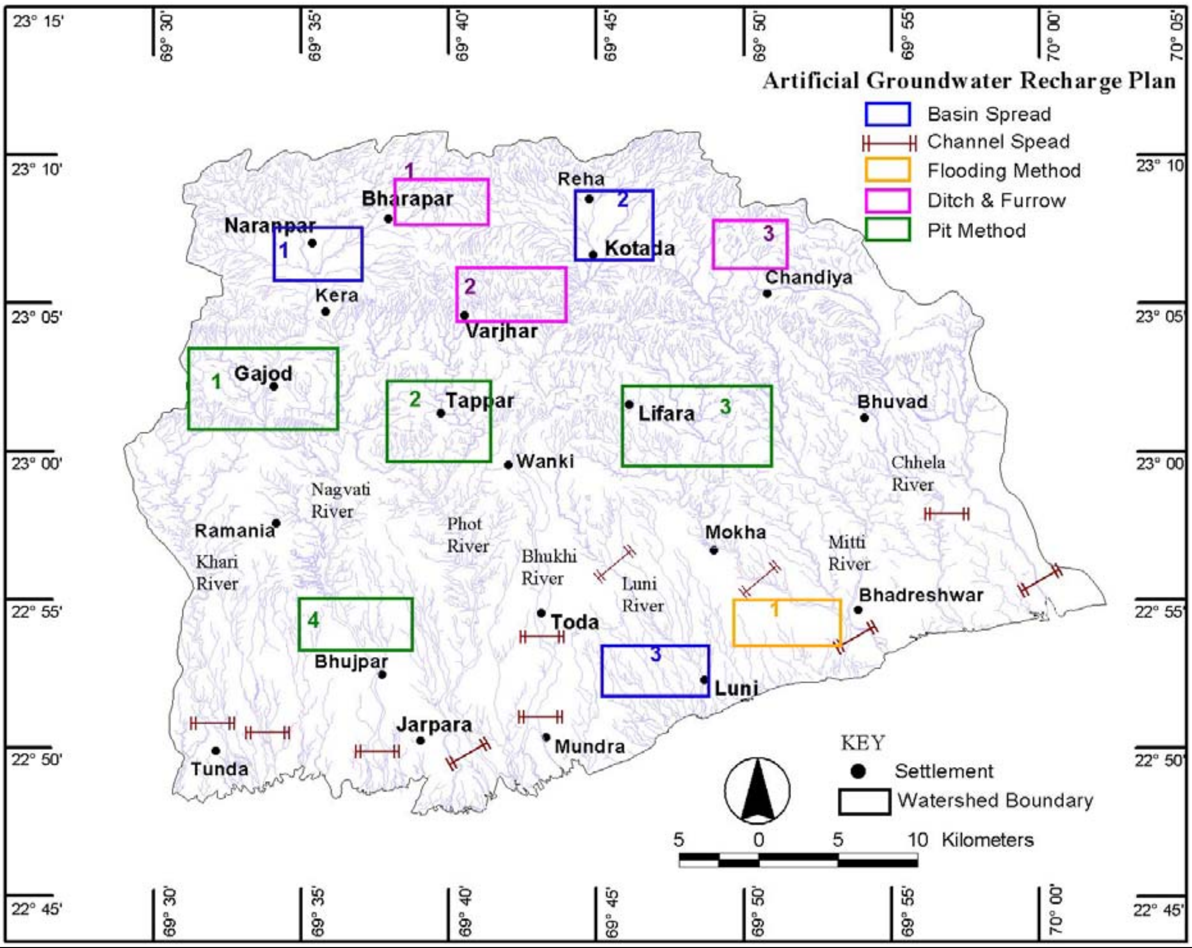
This is the most widely practiced method where water is allowed to spread in a natural stream/channel by checking water flow. The principle of this method is to increase the time and area over which water is recharged to a wide naturally loosing stream (Todd & Mays, 2005). Method includes channel modification in terms of winding, leveling, ditches for infiltration. The stream channel should have wide spread area rather than depth, a sandy river bed to provide large porosity and reduce evaporation loss. Such ideal locations have been identified in lower reaches of watershed comprising Kankavati sandstone and alluvium. Fig. 10.8 shows identified location (11) for channel barrier across major river systems along the coast. Government has supported such activity through various programs of constructing check dam.

Beside this, the area already has number of existing surface structures that have issues of siltation, minor repairs and encroachment of *prosopis juliflora* which gradually counter recharge efficiency. Therefore, it is recommended to carry out de-silting, repair of structural damage and removal of scrubs from these sites so as to enhance groundwater recharge efficiency.

FLOODING METHOD

In this method, water is flooded over the large area to in-filter in sub-soil region. This technique is feasible to implement in relatively flat topography regions (Todd & Mays, 2005). Water flow of main stream can be diverted to surrounding area by canal to spread evenly on large area. However, water should flow at very low velocity with minimum water column to protect land erosion. It can also be managed by construction of reservoir on main river and by flooding the area periodically to increase recharge.

In the study area, lower reaches comprising Kankavati Fm. sandstone and alluvium has flat topography where this method can be applied by diverting river flow to nearer low lying and open land area with a facility of inflow and outflow channels. Eastern coastal area between Luni and Bhadreshwar villages are favorable sites i.e. flat and open land where water can be diverted from Mitti River (Fig. 10.8). Implementation of this method need site specific studies and protection measures against flooding.



Basin Spread	*Channel Spread*	*Flooding Method*	*Ditch and Furrow*	*Pit Method*
1. South of Naranpar village 2. Between Reha and Kotda villages 3. North-West of Luni village	Total 11 proposed channel barrier in coastal part of Kankavati Sandstone	The open land between Luni and Bhadreshwar village	1. East of Bharapar village 2. North of Varjhar village 3. North of Chandiya village	1. Around Gajod village 2. Around Tappar village 3. East to Lifra village 4. North to Bhujpar village

Fig. 10.8 Artificial Groundwater Recharge Plan of the Study Area

DITCH-FURROW METHOD

It's an effective method to recharge shallow depth aquifers; however it is only feasible in moderate slope area, wherein runoff water can be delayed and distributed in series of ditches (Todd & Mays, 2005). The ditches are shallow depth structures with flat bottom and closely spaced. There are three types of ditches viz. (i) Contour Type:

follows ground surface contours; (ii) Tree Shaped Type: pattern is a sort of irrigation canal network where in main canal is successively distributed in branches; and (iii) Lateral Type: where a series of small ditches like minor distributory extend laterally from the main canal (Todd and Mays, 2005).

In study area, the method is proposed in area having moderate slopes to reduce runoff water velocity. The locations are based on Bhuj sandstone viz. (i) East of Bharapar Village, (ii) North of Varjhar village; and (iii) North of Chandia village (Fig. 10.8). Along with groundwater recharge, it also controls erosion.

PIT METHOD

This is a low cost technique to recharge shallow depth aquifer by excavated shallow depth pits and fill water to in-filterate in aquifer. It is most widely practiced method in those areas where, surface layer is impermeable and having the permeable substratum. In the study area, this method can be most effective in basaltic terrain having a cap of black cotton soil and the upper region of Kankavati sandstone comprising clay beds as surface layer. The Fig 10.8 suggests location for pit method recharge activities viz. (i) around Gajod village, (ii) around Tappar village, (iii) East to Lifra village, and (iv) North to Bhujpar village.

RECHARGE WELL METHOD

It may define as a well that admit water from surface to freshwater aquifer (Todd & Mays, 2005). A recharge well creates cone pattern flow. It is feasible method to recharge deep aquifers viz. Bhuj Fm and Kankavati Fm. Sandstone. As water admits to aquifer, it creates cone of recharge which is opposite to cone of depression developed due to pumping. In this method it need to take some precautions as silt load carried by overland flow may reduce porosity and permeability by clogging aquifer openings. Therefore, it is mandatory to have provision of siltation chamber where silt and other impurities settle in tank and then pure water is allow to in-filter to aquifer (Fig. 10.9). In recharge well development, well should be lined with gravel pack in permeable strata and cemented in impermeable strata especially in alluvium areas.

Beside this, existing dug wells which are not in use can be developed as a recharge well by upgrading it by mean of dimension, depth and silt chamber. This is very cost effective structure which can execute at farm level and also receives financial aide under government program.

Hydro-geological categorization and numbers of existing dug wells (1773) and dug cum bore wells (1845) show very good potential for shallow aquifer recharge. Average depth of dug wells is 10 to 15 m. Irrigation Department of Government of Gujarat has promoted this activity on large scale in coastal Saurashtra region for prevention of salinity (HLC, 1972), similar activity can be promoted in the study area also.

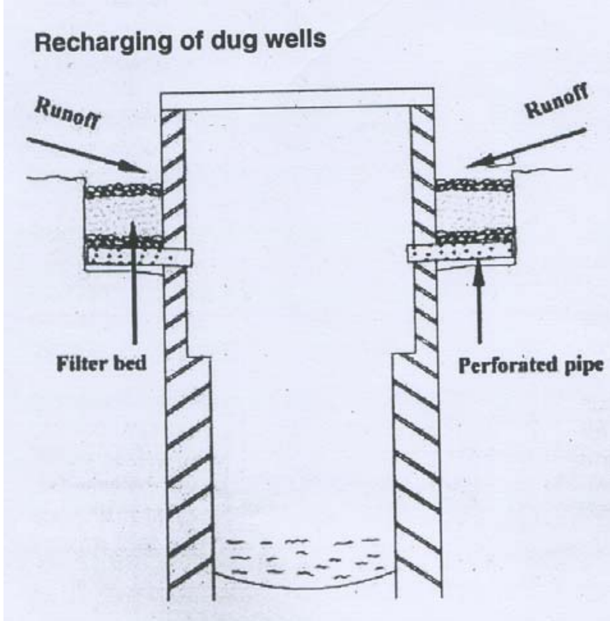


Fig. 10.9 Schematic Diagram of Dug Well Recharge

ROOFTOP RAINWATER HARVESTING

Rainwater has always been considered as excellent quality water and its conservation attains more significance where there is severe water quality and scarcity issues prevail. Present trends of industrialization has also results into economical up-liftment of local people and due to this in many villages people have replaced kachcha roof by a concrete roof of their houses. The feasibility and efficacy of roof water harvesting technique is now a proven fact, especially in arid regions; as this has been practiced since ages and highly cost effective. Roof rain water can be stored in a sub-surface tank and may have provision for groundwater recharge. Considering such multiple benefits it is proposed as many as buildings and campuses should be facilitated with roof rainwater harvesting structures having combination of surface storage and groundwater recharge (Fig. 10.10). It is simple technique which requires to connect outlet pipe from rooftop to divert water to storage tank or existing well or recharge pit.

In order to prevent solid particulates entry and other impurities, a provision of graded filter is must.

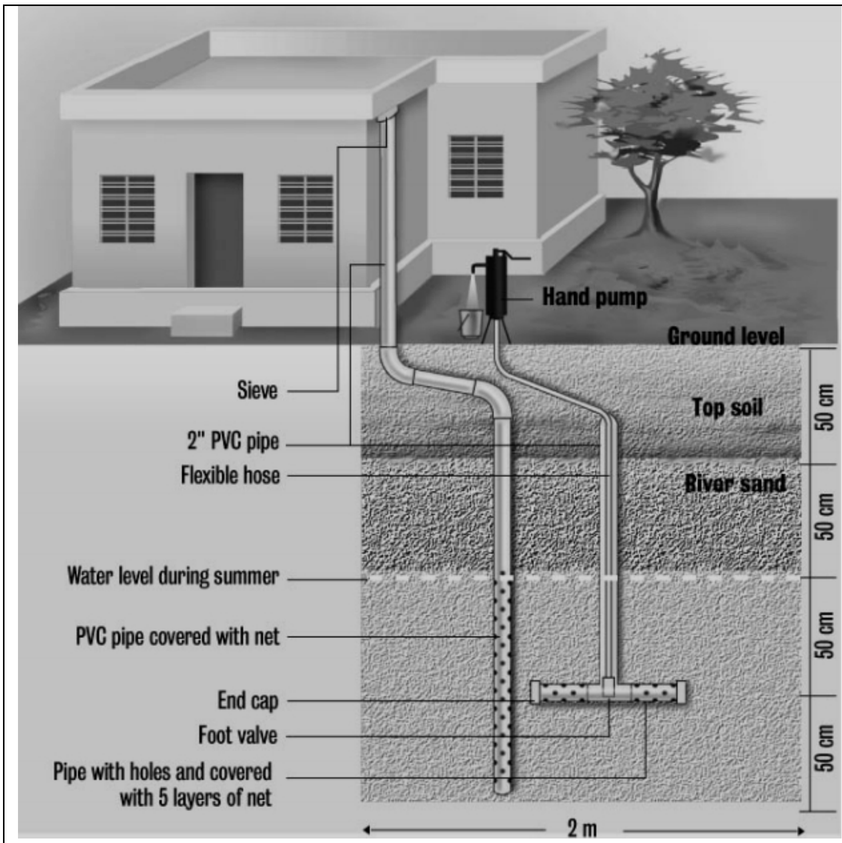


Fig. 10.10 Schematic Diagram of Roof Water Harvesting for Groundwater Recharge (Source: www. rainwater harvesting.org)

GROUNDWATER SALINITY REMEDIATION

Saline water is the most common pollution in fresh groundwater where saline water mixes with freshwater in aquifer (Todd & Mays, 2005). In shallow aquifer, fresh water overlies saline water flush salts during monsoon but in deep aquifer, movement is less and it is difficult to replace saline water at deeper level. Previous chapters on groundwater chemistry and core area have concluded that there is an issue of salinity in groundwater in core study area. Source of saline water in coastal aquifer is sea water ingress i.e. active sea water intrusion due to reverse groundwater gradient. The affected areas are around the villages Jharpara, Navinal and Tunda. The salinity issue is a matter of grave concern because 2 % of saline water intrusion can render water non-potable (Todd & Mays, 2005). Therefore, it is very much require to replenish groundwater through various methods to push the saline water from coastal aquifer in the study area. Salinity remediation has been suggested based on extent of intrusion and hydro-geological characteristics of the aquifer at large (Fig.10.11 & 10.12).

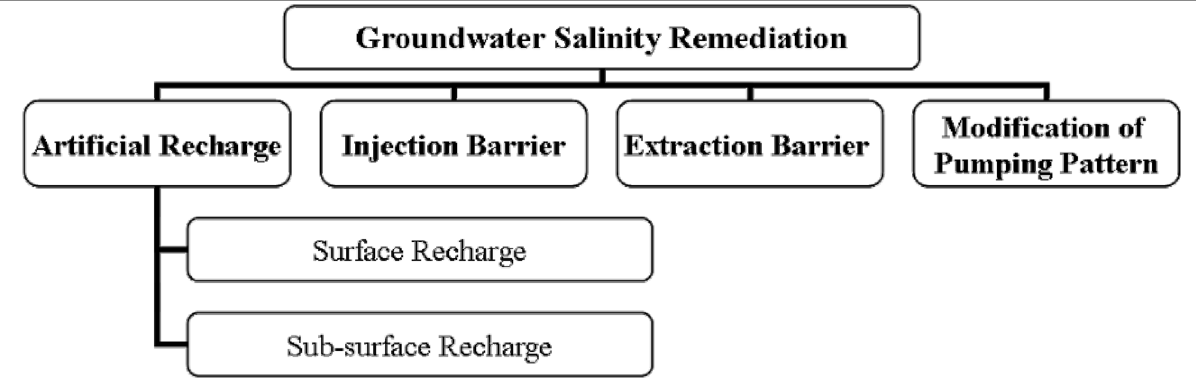


Fig. 10.11 Flow Chart Showing Groundwater Salinity Remediation Strategies

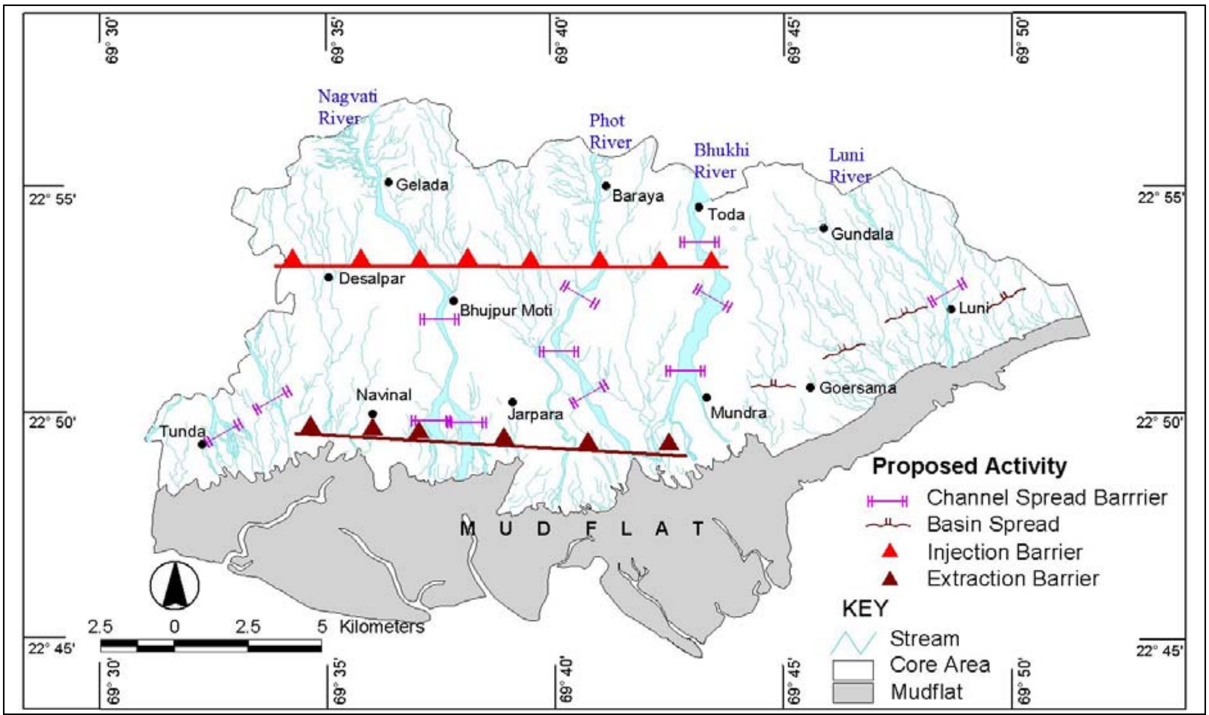


Fig. 10.12 Proposed Salinity Remediation Plan of Core Study Area

ARTIFICIAL RECHARGE

The basic objectivity behind adopting artificial recharge methods i.e. surface recharge and subsurface recharge in the study area is three fold viz. to address the problem of groundwater depletion; to improve groundwater quality; and to match groundwater demand.

Surface recharge i.e. basin spread and channel spread have been proposed in coastal region (Fig.10.12). Rivers flowing in the core study area are characterized by wide sandy bed with influent stream conditions, therefore it is feasible to recharge ample of water to aquifer. The proposed sites are located in eastern part of study area around Luni village (Fig. 10.12). The area has very gentle slope and having number of short distance channels. These channels can be interlinked and utilized for spreading storm water over the large area to recharge aquifer. However, it needs site specific studies.

INJECTION BARRIER

It is the most effective method prevails to prevent and revive fresh water aquifer inflicted by active sea water ingress. The injection barrier can be developed through a system of injection wells that are arranged linearly along RWL contours showing its gradient away from sea i.e. towards land (Fig. 10.13).

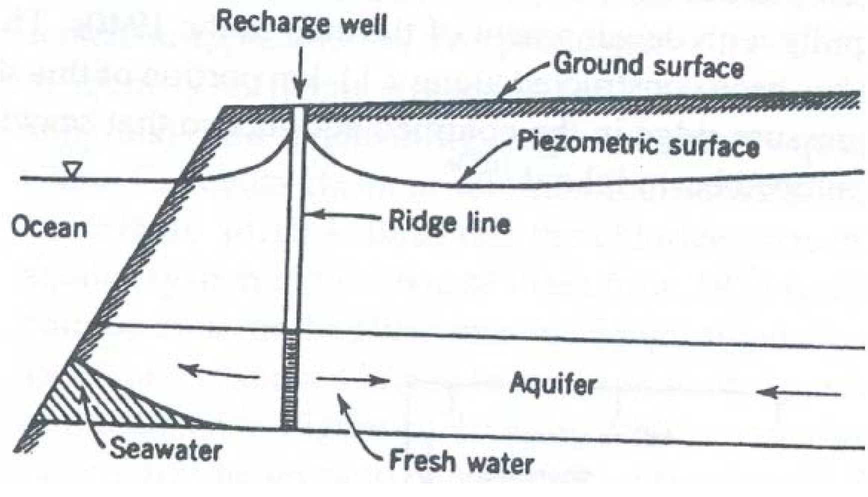


Fig. 10.13 Schematic Sketch - Control of Sea Water Intrusion by an Injection Barrier (Source: Todd & Mays, 2005)

As it has already been stated that, the core study area has potential deep aquifer developed with in the Kankavati Sandstone. The developed RWL map (Fig. 9.9) of the core study area shows reverse gradient in groundwater around Gelada, Baraya, Gundala with a depression created around Bhujpar. The average water table depth varies from 40 m in east to 70 m in west while aquifer thickness varies from 80 m to 130 m. A standard schematic diagram of injection recharge bore well is given in Fig. 10.14. As a part of sea water intrusion remediation, the candidate has proposed a row of injection wells by taking advantage of wide river beds of Bhukhi, Phot, Nagmati, Khari and Mithi Rivers (Fig. 10.12). Similar approach to mitigate groundwater salinity has been proposed by Raju (2003). He has also carried out artificial recharge experiments with specific design in Nagmati river bed near Bhujpur village, which has made positive impact on groundwater regime.

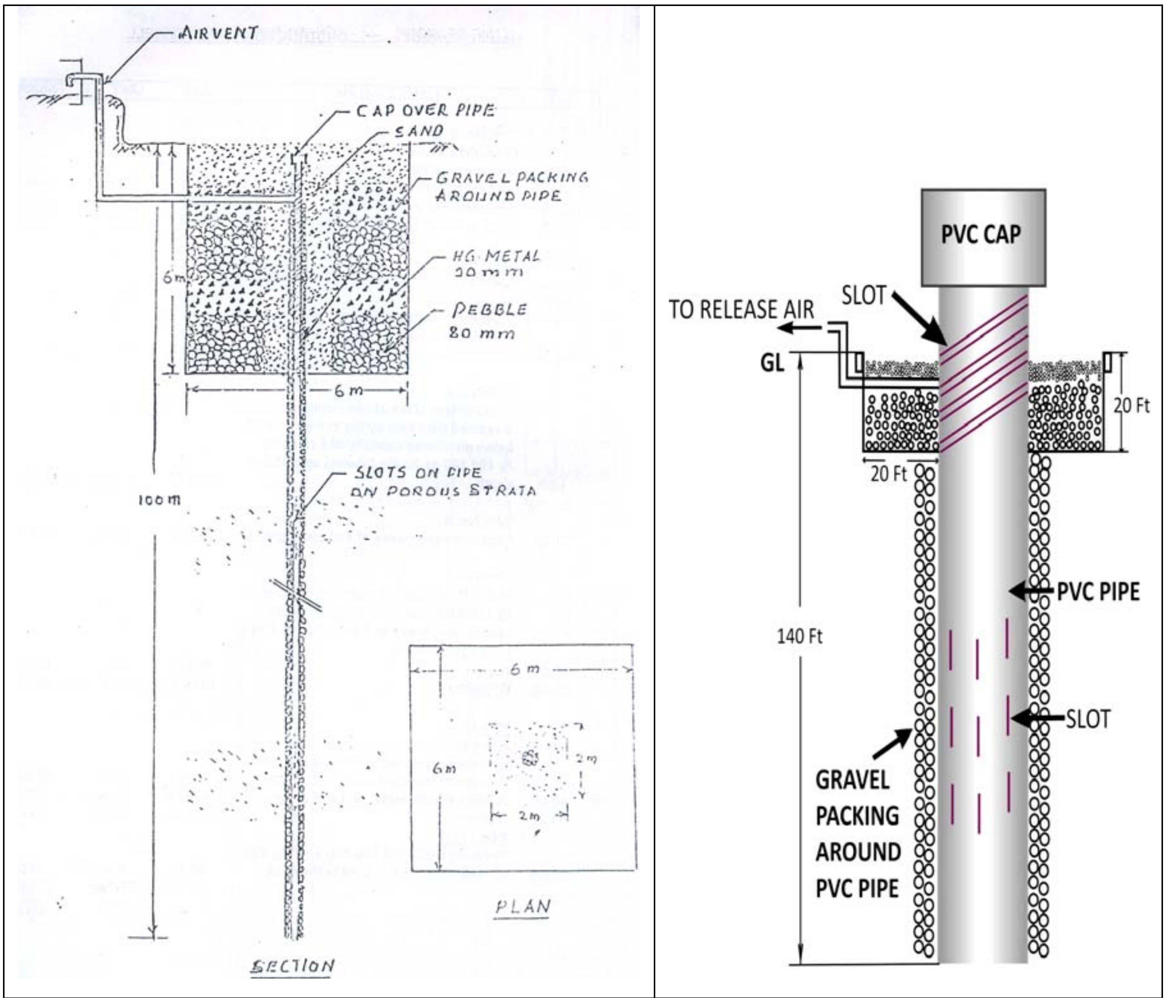


Fig. 10.14 Schematic Diagram of Artificial Recharge Bore well

EXTRACTION BARRIER

The principle of the extraction barrier is to pump out saline water from aquifer (Fig.10.15). The barrier can be created by maintaining a continuous pumping through a line of wells adjacent to sea (Todd & Mays, 2005). The pumping out of saline water will reduce pressure of saline water. This method is costly and prevails where aquifer became highly saline due to sea water ingress. In the present case, RWL study shows sea water ingress direction is from seaward side i.e. southern parts of Jharpara and Naivnal villages. The alignment of extraction barrier is shown in Fig. 10.12. The area has highly saline groundwater which can be extracted by pumping and allow to drain to adjacent creeks through excavated channel.

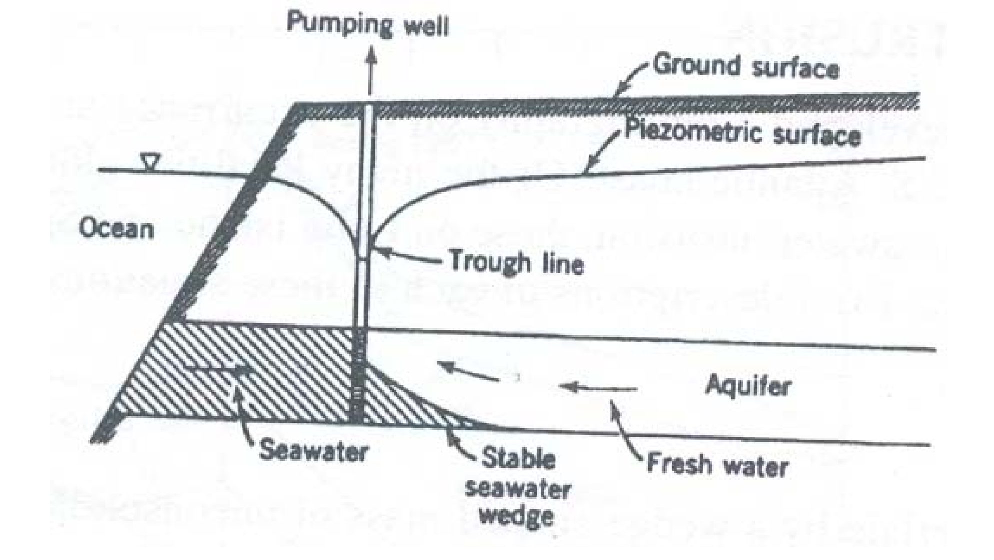


Fig. 10.15 Schematic Sketch - Control of Sea Water Intrusion by an Extraction Barrier
(Source: Todd & Mays, 2005)

MODIFICATION OF PUMPING PATTERN

Along with described recharge plan, pumping pattern of groundwater extraction also need to revised. Changing the location of pumping wells by dispersing them in inland area can aid in re-establishing a stronger seaward hydraulic gradient (Todd & Mays, 2005). Considering the case of study area, it is suggested to change locations of drinking water wells in good quality groundwater pockets in inland areas. Beside this, wells in use for irrigation or industrial purpose should be restricted adjacent to coast having higher salinity viz. Jharpara, Naivnal, Luni and Bhadreshwar villages. This will facilitate in restoring groundwater gradient towards sea.

GROUNDWATER UTILIZATION AND MANAGEMENT

Groundwater is sustainable and feasible water resource being extracted to meet drinking, irrigation and industrial needs. Groundwater in the study area occurs at shallow and deeper levels. Based on the groundwater status and emerged issues of the study, there is need to frame groundwater management strategy along with water resource development strategy described above. As the groundwater is a dynamic resource it needs continuous attention i.e. regular monitoring and management by users' collectiveness. Recently in Andhra Pradesh, FAO has supported a program with the basic objective of improving the water use efficiency; by empowering farmers having involvement in monitoring and management of groundwater resource by development of peoples' institutes named as Andhra Pradesh Farmer Managed Groundwater System -APFMGS (FAO, 2011).

Therefore, utilization and management of groundwater resource of study area has to be viewed as collective responsibility; involving strong inputs of capacity building and institutional mechanism. For this, following important considerations have to be adopted.

- Prioritization of groundwater use-
    - The study area has limited potable groundwater pockets especially in coastal part which must be protected and reserved for drinking water purpose only for the surrounding villages.
    - Groundwater can be used for irrigated agriculture with specific management intervention such as drip/sprinkler irrigation, low water consumption cropping pattern, use of organic manure and cultivation of fodder based crops to support animal husbandry livelihood.
    - Drinking water requirement for industrial population must be planned in integration with roof rain water harvesting, Reverse Osmosis (RO) plant and groundwater recharge.

- Water use efficiency as-
    - Water for gardening and cleaning in industrial residence must be managed through recycled water of sewerage and/or by RO plants.
    - Improve knowledge on agriculture practices i.e. mulching for soil fertility, crop selection, time of plantation (FAO, 2011).
    - Use of drip and sprinkler as micro irrigation method
    - Low water consumption cropping pattern and/or rotation in crop pattern
- Industrial water must be managed through other source i.e. RO, Roof rain water, recycled water or import from outside source i.e. Narmada Canal etc.
- Imposing restriction on groundwater pumping in coastal saline area other than domestic purpose.
- Re-forestation of mangrove should be carry out to protect coastal belt from lateral sea water ingress.
- Prohibition on sand mining in coastal river bed areas to facilitate groundwater recharge by constructing check dams.

GROUNDWATER MANAGEMENT APPROACH

The water resource management in general requires an integrated approach where resource development process should be strongly followed by quantitative and qualitative assessment through management institutions. During the development phase one must consider resource wise mapping of stakeholders along with their participation in resource management. In case of present study groundwater is threatening resource due to on-going industrial development; therefore perspective for groundwater management should incorporate a very well defined role for its stakeholders and management institutions.

Groundwater related issues are mainly concern with management and social aspects rather than technical issues. Government of India has framed National Water Policy (1998, 2002) with a view to protect country's dwindling groundwater resources, which is complex, multilayered and does not have any statutory status (India Groundwater Governance Study, 2011). Central government has also regulated Groundwater Model

Bill to the State Governments which infact has been executed by a few state governments only. Although, the existing legal framework has detailed out institutional framework but not included any technical guidelines and participation at stakeholder level.

If one see the history of groundwater development of any area, it is clearly seen that people have observed good practices of water management in their respective areas. But in this modern period, the emphasis is rather more development – centralized and the traditional water harnessing practices are either made redundant or archived.

Now looking to the existing state of water resource in terms of its availability, diversified requirement and issues related to its over-exploitation, there is a need for re-examine the current model of water management and re-strategizing the entire approach. This can be certainly achieved if attitude of people who are utilizing groundwater resource i.e. the stake holders is changed positively by educating about the consequences of present practices and benefits of participatory management having amalgamation of traditional and modern scientific techniques that may provide sustainability to the region at large. The management strategies can be derived for resource development, resource management, equity in distribution among, legal processes for groundwater protection, and institution building for management of resources with in the framework of statutory regulations.

Considering present social and technical aspects, groundwater is a common property resource utilized at individual stockholders' level but having its centric management approach failed to achieve any mark. Therefore, it necessitates to adopt a participatory and people centered approach involving all stakeholders in the management process.

Therefore, looking to inherent drawbacks in development based resource management approach; the candidate has recommended groundwater management approach based on societal aspects with two vital interventions viz. capacity building and institutional framework, an important tool for community empowerment.

CAPACITY BUILDING

It is recognized that there is a shortfall of qualified groundwater specialists and very few accept living and working in remote blocks of the country. In addition there exists a knowledge gap between users' and scientific/technical community. Therefore, there is need for developing linkages between users' and government authority by providing information, awareness, understanding and knowledge to the users and their involvement in decision making. This suggested approach will certainly plug the gaps in the existing management approach and shall sustain on long term basis.

On the other side, candidates' own experience on capacity building in Kachchh that youth from these remote regions have shown the ability to grasp the scientific inputs, which is pre-requisite under this suggested management approach and their focused training and the commitment to live and work in remote areas. If such youth empowered with the appropriate orientations, they have demonstrated abilities of communication and participation which is rarely seen amongst qualified technical professionals. Two groups of such youth are already functioning and providing their knowledge support to local communities. One such group named "Parab" is working for the last more than 10 years in Abadasa Taluka for supporting the communities for their own water management. Based on learning experiences of "Parab" candidate has set following objectives for capacity building

To develop understanding about linkages between land and water resource, imparting knowledge on rocks, aquifers and groundwater; role of groundwater in shaping human development; and the problems associated with over-extraction and local level management plan.

Develop skills both technical and social; technically to be able to monitor groundwater levels and quality, prepare thematic groundwater maps. Socially, bring local stakeholders to realize their own geo-hydrology, groundwater availability and strategy for sustainable use.

MANAGEMENT INSTITUTIONS

In Kachchh region, there exists many village level Resource Management Committees constituted by the state Government and NGOs' to implement various watershed development programs. The major gap that has been identified in such management practices is lack of coordination and collective decision making.

Very few efforts in the study area have been made for institutional development to look after natural resource management. As discussed in preceding chapters, the development approach has been framed out by considering watershed unit; therefore, the candidate has proposed a management system for her study area based on river basin unit. Candidate's own involvement in river basin management study, carried out for Rukmavati River basin of Mandiv taluka by Arid Communities and Technologies in collaboration with Vivekanand Research and Training Institute, Mandvi have carried out a detailed hydro-geological investigation of entire river basin. The management approach adopted during the study of Rukmavati River basin has been taken as a base for the presented study described as under.

The suggested implementation and management mechanism encompassing administrative, financial, techno-economic, and human resource management aspects have been adequately synthesized and illustrated through a flow chart (Fig. 10.16).

Southern Kachchh region has very good traditional social mechanism for decision making person known as *Mahajans* i.e. Rural Expert. *Mahajans* are reputed persons irrespective of political reputation and recognized by communities. Considering this traditionalism of area the three layer implementation and management structure has been developed along with communities through cluster level consultation workshops (Plate 10.1).

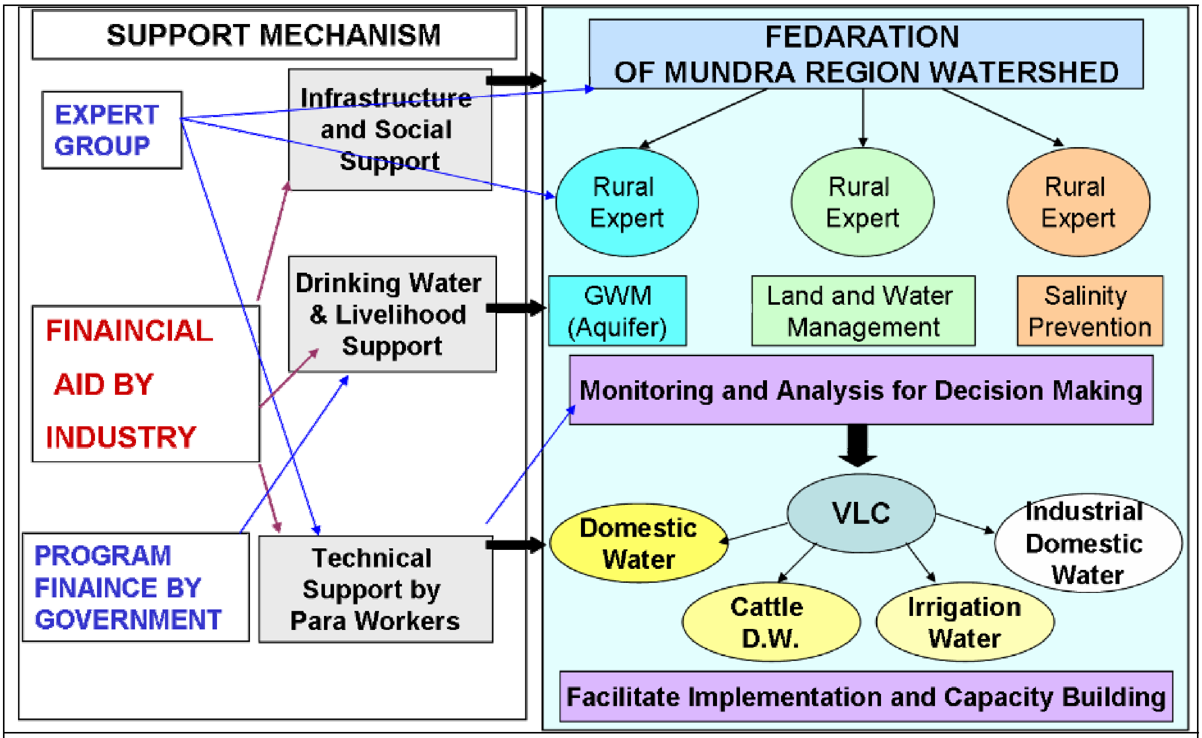


Fig.10.16 Proposed Mechanism for Implementation of Strategic Water Resource Plan

Plate 10.1 Consultation with Cluster Level Community

Watershed Federation: The main structure has been proposed as basin level federation i.e. Federation of Mundra Region Watershed consists of all rural expert i.e. *Mahajans*. The role of federation is management of basin and will act as basin level decision making team. The federation will receive technical and management level guidance from appointed expert group of members from different field i.e. hydro-geology, agriculture, social management etc. Further to involve different stakeholders, there will be several infrastructural development plans such as basin level agriculture unit, processing units, dairy plants etc. The planning and management of entire basin will be responsibility of the Watershed Federation and financial aid proposed to receive from industries of the region.

Rural Expert: Rural Expert i.e. *Mahajans* are decision makers and planners at cluster level. They will work on planning, development and management at cluster level with the support of expert group. The finance for such planning and development activities can manage from various government programs and from industries as a part of CSR policy. The one of crucial roles of rural expert is to resolve and manage inter village resource conflicts.

Village Level Committee and User Groups: This committee will coordinate all implementation and management activities at village level. They will also coordinate user groups and various stake holders at village level i.e. drinking water, agriculture, livestock and industries (Fig. 10.16). Representatives of User Groups will be the main founders of the Village Committee. User Groups i.e. Groundwater Users will implement and act on groundwater management strategies.

Support Groups: In addition to above main responsible structure there will be some Support Groups recommended to support entire management efforts made by community. These groups are seen in the form of para worker groups to facilitate initiatives of different level decision making groups. These groups will provide support by their knowledge, skills, monitoring, implementation of activities etc. Further, this group will get technical guidance from experts' group. The scale of operation of such groups varies from user group level to federation level. Financial assurance for implementation of groundwater management plan will be the responsibility of industrial sector.

The execution of candidate's above cited groundwater management plan having manifold benefits is a herculean task. However, there are success stories too from within the region characterized by similar geological and climatic environments.

Candidate being an active groundwater practioner, having sufficient awareness and exposure to the intricacies and efficacies of the recommended groundwater management plan. Candidate would make every effort to achieve targeted goals as a part of her future endeavor.

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ANNEXURES

Demographic Details of Mundra Taluka (Census, 2011)

Sr. No.	Village	Population			Literacy		
		Male	Female	Total	Male	Female	Total
1	Tumbadi Nani	613	597	1210	422	351	773
2	Tumbadi Moti	558	488	1046	390	272	662
3	Babia	56	48	104	32	36	68
4	Tappar	436	420	856	290	252	542
5	Kanjara	347	314	661	253	154	407
6	Lifara	353	324	677	233	152	385
7	Vaghura	543	566	1109	433	310	743
8	Bagada	400	445	845	291	231	522
9	Fachariya	205	214	419	129	95	224
10	Patri	1272	1202	2474	1001	653	1654
11	Wanki	846	809	1655	445	343	788
12	Bocha	104	96	200	77	53	130
13	Beraja	741	673	1414	472	311	783
14	Ramania	913	885	1798	708	553	1261
15	Depa	193	200	393	142	118	260
16	Gelada	553	535	1088	331	232	563
17	Karagogha	412	394	806	289	224	513
18	Lakhapar	833	732	1565	563	407	970
19	Kandagara Nana	123	101	224	86	57	143
20	Kundrodi	494	492	986	318	245	563
21	Chhasara	824	692	1516	483	268	751
22	Vavar	688	648	1336	475	334	809
23	Hatadi	312	314	626	201	163	364
24	Kuvai Padhdhar	75	87	162	42	32	74
25	Kukadasar	266	263	529	84	71	155
26	Bhadreshwar	2295	2252	4547	1306	889	2195
27	Pavadiyara	127	121	248	94	76	170
28	Wadala	1510	1229	2739	1031	566	1597
29	Mokha	425	353	778	343	205	548
30	Ratadiya	670	664	1334	506	398	904
31	Viraniya	463	443	906	323	242	565
32	Toda	361	349	710	288	234	522
33	Baraya	440	324	764	329	169	498
34	Deshalpar	1353	1260	2613	955	698	1653
35	Khakhar Moti	1100	1038	2138	777	589	1366

ANNEXURE 2.1

(2 of 2)

Sr. No.	Village	Population			Literacy		
		Male	Female	Total	Male	Female	Total
36	Kandagara Mota	2725	1733	4458	2185	988	3173
37	Tunda	11248	1223	12471	9680	561	10241
38	Shiracha	1170	712	1882	936	378	1314
39	Moti Bhujpur	4761	4516	9277	3512	2657	6169
40	Samagogha	5119	2585	7704	4128	1540	5668
41	Pragpar 1	633	301	934	485	170	655
42	Pragpar 2	217	185	402	173	106	279
43	Bhorara	528	476	1004	370	286	656
44	Gundala	1466	1315	2781	1038	746	1784
45	Ragha	82	82	164	60	30	90
46	luni	1706	1672	3378	1108	716	1824
47	Shekhadia	498	472	970	265	138	403
48	Sadau	1006	965	1971	634	423	1057
49	Magra	622	590	1212	445	342	787
50	Mota Kapaya	1606	1462	3068	1276	927	2203
51	Nana Kapaya	6405	2476	8881	5372	1548	6920
52	Borana	185	192	377	131	88	219
53	Pratappar	135	133	268	96	69	165
54	Nani Bhujpur	554	502	1056	381	234	615
55	Navinal	2410	690	3100	2020	387	2407
56	Zarpara	3874	3479	7353	2602	1539	4141
57	Dhrab	2026	1256	3282	1485	593	2078
58	Baroi	8316	6644	14960	6387	4524	10911
59	Goersama	510	479	989	320	229	549
60	Mundra	10903	9426	20329	8463	6115	14578
Total		**89,609**	**63,138**	**1,52,747**	**67,694**	**35,317**	**1,03,011**
Rural		**78,706**	**53,712**	**1,32,418**	**59,231**	**29,202**	**88,433**
Urban		**10,903**	**9,426**	**20,329**	**8,463**	**6,115**	**14,578**

ANNEXURE 2.2

Rainfall of Mundra Taluka over 100 years

Year	Total Rainfall mm	Year	Total Rainfall mm	Year	Total Rainfall mm
1901	141.7	1935	680.3	1969	374.9
1902	359.8	1936	364.5	1970	825.7
1903	685.8	1937	550.9	1971	378.4
1904	157.3	1938	344.3	1972	224
1905	186.2	1939	70.4	1973	331.4
1906	621.2	1940	311.9	1974	111.2
1907	493	1941	349.2	1975	465.4
1908	423	1942	235.6	1976	456.3
1909	716.7	1943	620.6	1977	527.7
1910	612.6	1944	645.1	1978	554.3
1911	92.8	1945	479.5	1979	735.8
1912	703.2	1946	350.3	1980	793.3
1913	724.4	1947	352	1981	570.8
1914	513.6	1948	260.1	1982	328.9
1915	256.6	1949	541.6	1983	540.2
1916	409.2	1950	349.6	1984	349.6
1917	577.2	1951	316.2	1985	377.6
1918	79.1	1952	549.2	1986	218.7
1919	428.3	1953	573.6	1987	30.8
1920	368.5	1954	579.5	1988	580.9
1921	495.1	1955	268.9	1989	418.3
1922	284.6	1956	719.7	1990	193.7
1923	188.4	1957	392.2	1991	142.1
1924	226.6	1958	622	1992	676
1925	228.4	1959	790.8	1993	244.5
1926	509.1	1960	305.1	1994	481.6
1927	592.5	1961	1079.6	1995	206.1
1928	580.4	1962	453.2	1996	305.3
1929	445.8	1963	308.1	1997	793
1930	489.7	1964	496.3	1998	861.1
1931	336.5	1965	447.3	1999	300.9
1932	502	1966	315.9	2000	581.9
1933	864	1967	848.2	2001	680.9
1934	419.1	1968	252	2002	191

ANNEXURE 5.1

Well Inventory Format

Date : ____________________ Code : _____________

Village		Owner's Name			
Taluka		Longitude			
District		Latitude			
Type of Well	Open Well		Borewell		Dug cum Borewell	
Use	Regular		Frequently		No Use	

Direction and distance from village Settlement: ______________________________

Farm Survey No : _________________ Remark for location : ___________________

Measurement Point : ____________________
Total Depth : ______________ m Dimentsion/Diameter : _____________m
Depth of Casing : ____________ m

Water Table in m							
Present		Previous Year Pre monsson		Previous year Post monsoon			
Dug- cum- Borewell				Yes		No	
Number							
Type					Horizonatl or Verical		
Diameter					in inch		
When					how much ttime after the well existance		
Pumping Machinery	Diesel Engine		Electrict Motor		Submercible Pump		
	HP		HP		HP		
Pumping Time		Hours	Time for make well empty		Water table depletion m		
			Recuperation time				

Well Litholog				
Strata No.	Type	Depth from RL	Thickness	Remark
1				
2				
3				
4				
5				

Use of Well								
Drinking water	Human Population		Domestic Use		Irrigation		Area in acre	
	Cattle Population							

Water Quality

1. Clour: Colourless______________Clourful__________Turbid _____________
2. Odor : Odorless _______________Mild odor ________Strong odor_________
3. Taste : Sweet ______________ Brackish________________ Saline________ _______

Landform Surrounding to Well					
Alluvial Plain		Undulating plain		Hilly area	
River Bank		Distance from river km			
Sea coast		Distance from sea coast km			
Location in Watershed	Upper		Middle		Lower	

Groundwater Situation in Drought

Quality	Remains same				Degrad	
Quantity	Remains same		Deplete		Empty	

History of well

Name of Surveyor: ____

ANNEXURE 5.2

(1 of 2)

Details of Observation Wells of Watershed Area

Sr. No.	Grid No.	Code	Village	Source Type	Depth (m)	Aquifer	Latitude	Longitude	Owner	Use
1	1.1	F1	Meghpar	Borewell	130	Sandstone	23^{0} 06' 55.1''	69^{0} 33' 31.4''	Dhanji Devji Patel	Irrigation
2	1.2	F2	Sujapar	Borewell	120.0	Sandstone	23^{0} 07' 49.7''	69^{0} 37' 48.4''	Dhanaji Natha Senghani	Irrigation
3	1.3	F3a	Sanosara	Borewell	152.4	Sandstone	23^{0} 06' 51.3''	69^{0} 41' 41.2''	Rajabhai Rabari	Irrigation
4	1.3	F3b	Reha nana	Borewell	146.0	Sandstone	23^{0} 08' 11.2''	69^{0} 44' 33.4''	Velubha Harisang	Irrigation
5	1.4	F4	Varali	Borewell	305.0	Sandstone	23^{0} 06' 42.0''	69^{0} 47' 28.9''	Rava Dahya	Irrigation
6	1.5	F5	Wada	Borewell	107.0	Sandstone	23^{0} 07' 02.2''	69^{0} 52' 52.7''	Sumar Megha	Irrigation
7	2.1	G1a	Chunadi	Borewell	81.0	Basalt+Sandstone	23^{0} 03' 39.7''	69^{0} 32' 42.7''	Hemubha Umaraji	Irrigation
8	2.1	G1b	Tumbadi Moti	Borewell	12.2	Weathered Basalt	23^{0} 00' 12.5''	69^{0} 34' 38.8''	Modha Khetaji	Irrigation
9	2.2	G2a	Kera	Borewell	360.0	Sandstone	23^{0} 03' 4.42''	69^{0} 37' 18.7''	Girubha Akubha	Irrigation
10	2.2	G2b	Babiya	Borewell	30.0	Weathered Basalt	23^{0} 01' 07.3''	69^{0} 37' 10.0''	Village Panchayat	No use
11	2.3	G3a	Kanajra	Well	18.4	Weathered Basalt	23^{0} 01' 56.2''	69^{0} 41' 22.2''	Lakhu Arjan	Irrigation
12	2.3	G3b	Bandra Nana	Borewell	293.0	Sandstone	23^{0} 03' 42.9''	69^{0} 44' 4.7''	Mulubha Lakhmanji	Irrigation
13	2.4	G4a	Bhalot	Well	24.0	Weathered Basalt	23^{0} 02' 54.2''	69^{0} 48' 38.0''	Duda Sura	Irrigation
14	2.4	G4b	Vagura	DCB	14.0	Weathered Basalt	23^{0} 00' 36.9''	69^{0} 47' 56.7''	Village Panchayat	Domestic
15	2.5	G5	Mathada	Borewell	152.0	Sandstone	23^{0} 03' 0.9''	69^{0} 52' 35.1''	Jusabbhai Ibrahim	Irrigation
16	2.6	G6	Mindiyana	Borewell	122.0	Sandstone	23^{0} 03' 22.4''	69^{0} 57' 45.0''	Pala Arjan Rabari	Irrigation
17	3.1	H1a	Ramaniya	Well	16.0	Laterite	22^{0} 57' 30.2''	69^{0} 33' 17.0''	Ladhubha Dajibha Jadeja	Irrigation
18	3.1	H1b	Depa	Borewell	91.5	Sandstone	22^{0} 55' 06.0''	69^{0} 33' 20.6''	Village Panchayat	Drinking
19	3.2	H2a	Bocha	Borewell	27.4	Laterite	22^{0} 57' 50.3''	69^{0} 38' 50.4''	Lakhubhai Rabari	Domestic
20	3.2	H2b	Gelda	Borewell	122.0	Sandstone	22^{0} 56' 11.7''	69^{0} 37' 44.1''	Shivaji khimaji	Irrigation
21	3.3	H3a	Vanki	Well	18.3	Weathered Basalt	22^{0} 59' 31.5''	69^{0} 42' 14.8''	Village Panchayat	Drinking

ANNEXURE 5.2

(2 of 2)

Sr. No.	Grid No.	Code	Village	Source Type	Depth (m)	Aquifer	Latitude	Longitude	Owner	Use
22	3.3	H3b	Kandagara (N)	Borewell	70.1	Basalt	22^0 57' 17.6''	69^0 43' 22.4''	Karsan Seja	Irrigation
23	3.4	H4a	Bagda	Well	21.3	Basalt	22^0 59' 48.1''	69^0 46' 53.5''	Samat Budher	No use
24	3.4	H4b	Mokha	Borewell	30.5	Sandstone	22^0 56' 44.0''	69^0 49' 05.2''	Village Panchayat	Drinking
25	3.4	H4c	Ratadiya	Borewell	91.5	Sandstone	22^0 55' 55.9''	69^0 45' 23.0''	Dr. Sumit Rao	Irrigation
26	3.5	H5a	Vovar	Borewell	27.4	Sandstone	22^0 57' 25.7''	69^0 51' 42.3''	Khoda Vala Sumaniya	Drinking
27	3.5	H5b	Bharudiya	Borewell	30.5	Sandstone	22^0 56' 58.7''	69^0 53' 21.9''	Meghraj Pala	Irrigation
28	3.6	H6a	Hatadi	Borewell	39.6	Sandstone+ Basalt	22^0 56' 07.1''	69^0 56' 10.9''	Jagubha Kakubha Jadeja	Irrigation
29	3.6	H6b	Kuvai	Well	12.8	Sandstone	22^0 55' 20.7''	69^0 57' 25.8''	Parsotam Meghji	Irrigation
30	4.1	I1a	Khakhar Moti	Borewell	106.7	Sandstone	22^0 52' 53.6''	69^0 33' 06.6''	Jain Trust	Drinking
31	4.1	I1b	Shiracha	Borewell	121.0	Sandstone	22^0 51' 04.8''	69^0 34' 09.4''	Madhubah Ladhubha	Industry
32	4.2	I2a	Moti Bhujpur	Borewell	100.6	Sandstone	22^0 52' 56.8''	69^0 37' 33.3''	Maraj Moti Sagar	Irrigation
33	4.2	I2b	Pratappar	Borewell	106.7	Sandstone	22^0 51' 27.1''	69^0 38' 53.1''	Vora Anil Revji	Irrigation
34	4.3	I3a	Baraya	Borewell	79.3	Sandstone	22^0 54' 51.4''	69^0 41' 04.6''	Mahendrasing	Domestic
35	4.3	I3b	Mota kapaya	Borewell	168.0	Sandstone	22^0 52' 50.6''	69^0 42' 32.5''	Radhvani Kesarben Naran	Irrigation
36	4.3	I3c	Mundra	Borewell	73.0	Sandstone	22^0 50' 52.3''	69^0 43' 43.3''	Mahobattsinh jadeja	Irrigation
37	4.4	I4a	Ragha	DCBW	35.0	Sandstone	22^0 53' 22.8''	69^0 47' 51.9''	Karaman Gopal Gaghavi	Irrigation
38	4.4	I4b	Goyersama	DCBW	61.0	Sandstone	22^0 50' 43.5''	69^0 45' 22.5''	Damji Shivji Maheshwari	Irrigation
39	4.5	I5	Bhadreshwar	Dug Well	18.9	Sandstone	22^0 53' 42.0''	69^0 53' 11.0''	Jusab Isa	Irrigation
40	4.6	I6	Kukadasar	well	8.2	Sandstone	22^0 55' 11.8''	69^0 56' 58.5''	Aashabhai Rabari	Irrigation
41	5.1	J1	Tunda	Borewell	76.2	Sandstone	22^0 50' 00''	69^0 31' 59.0''	Umarsang Sarpanch	Irrigation
42	5.2	J2	Navinal	Borewell	109.8	Sandstone	22^0 49' 47.1''	69^0 35' 47.5''	Khumbhar Amadbhai	Irrigation
43	5.3	J3a	Dharub	Borewell	122.0	Sandstone	22^0 49' 47.9''	69^0 41' 03.9''	Fakir Mamad Ali Mamad	Irrigation
44	5.3	J3b	Mundra	Borewell	107.0	Sandstone	22^0 49' 31.5''	69^0 43' 4.7''	DatePalm Research Center	Irrigation

ANNEXURE 5.3

(1 of 2)

Details of Observation Wells in Core Study Area

Sr. No.	Code	Village	Source Type	Depth (m)	Latitude	Longitude	Aquifer	Owner	Use
1	A1	Desalpar	Borewell	137	22^0 54' 10.3''	69^0 35' 42.1''	Sandstone	Dilubha Velubha	Irrigation
2	A2	Gelada	Borewell	122	22^0 54' 30.3''	69^0 36' 41.3''	Sandstone	Harijan Malsi Deva	Irrigation
3	A5	Baraya Nana	Borewell	43	22^0 54' 31.9''	69^0 40' 33.6''	Sandstone	Lakhuram K Gordiya	Drinking
4	A6	Pragpar	Borewell	63	22^0 54' 12.5''	69^0 42' 26.9''	Sandstone	Amarnath Dham	Domestic
5	A7	Toda	Borewell	76	22^0 54' 22.1''	69^0 43' 6.7''	Sandstone	Rayma Ayub	Irrigation
6	A8	Bhorara	Borewell	107	22^0 54' 24.0''	69^0 44' 3.2''	Sandstone	Banubha Vishaji	Irrigation
7	A9	Gundala	Borewell	76	22^0 54' 16.4''	69^0 45' 43.9''	Sandstone	Haresh Velji Satra	Irrigation
8	A11	Ragha	Borewell	82	22^0 54' 5.0''	69^0 47' 38.6''	Sandstone	Karaman Gopal Gaghavi	Irrigation
9	B1	Desalpar	Borewell	107	22^0 53' 6.9''	69^0 35' 28.3''	Sandstone	Nagshi Meghraj Gadhvi	Irrigation
10	B2	Bhujpur Moti	Borewell	137	22^0 53' 2.3''	69^0 36' 36.7''	Sandstone	Punja Pala Gadhvi	Irrigation
11	B3	Bhujpur Moti	Borewell	146	22^0 52' 58.2''	69^0 37' 53.0''	Sandstone	Khetubha Jadeja	Irrigation
12	B4	Samagogha	Borewell	107	22^0 53' 3.7''	69^0 39' 7.0''	Sandstone	Khamu Murji Maheshvari	Irrigation
13	B5	Samagogha	Borewell	95	22^0 53' 27.3''	69^0 40' 33.7''	Sandstone	Vanubha Narbheram	Irrigation
14	B6	Kapaya Mota	Borewell	91	22^0 53' 23.1''	69^0 41' 57.7''	Sandstone	Gurukrupa Hotel	Domestic
15	B7	Bhorara	Borewell	122	22^0 53' 39.1''	69^0 43' 22.3''	Sandstone	Hathubha Sangramji Jadeja	Irrigation
16	B8	Bhorara	Borewell	122	22^0 53' 6.5''	69^0 44' 10.4''	Sandstone	Gopal Devraj Sumar	Irrigation
17	B9	Gundala	Borewell	98	22^0 53' 42.1''	69^0 45' 52.9''	Sandstone	Jesa Karman Parmar	Irrigation
18	B10	Ragha	Borewell	70	22^0 53' 35.7''	69^0 47' 37.8''	Sandstone	Khetshi Vishram	Irrigation
19	B11	Ragha	DCB	35	22^0 53' 22.8''	69^0 47' 51.9''	Sandstone	Karaman Gopal Gaghavi	Irrigation
20	B12	Luni	Well	10	22^0 52' 52.5''	69^0 49' 34.5''	Alluvium	No Data	No use
21	C1	Bhujpur Moti	Borewell	130	22^0 51' 38.4''	69^0 35' 38.8''	Sandstone	Rayshi Gopal	Irrigation
22	C2	Bhujpur Moti	Borewell	113	22^0 51' 51.9''	69^0 36' 51.7''	Sandstone	Velji Khetsi Maheshwari	Irrigation
23	C3	Bhujpur Nani	Borewell	128	22^0 51' 58.9''	69^0 38' 8.2''	Sandstone	Aspan Jivraj Jasani	Irrigation

ANNEXURE 5.3

(2 of 2)

Sr. No.	Code	Village	Source Type	Depth (m)	Latitude	Longitude	Aquifer	Owner	Use
24	C4	Pratappar	Borewell	61	22^0 51' 32.3''	69^0 39' 10.1''	Sandstone	Manga vishram	Irrigation
25	C5	Samagogha	Borewell	122	22^0 52' 1.2''	69^0 40' 49.4''	Sandstone	Gadhavi Ram Khetsi	Irrigation
26	C6	Kapaya Mota	Borewell	85	22^0 52' 19.7''	69^0 42' 0.8''	Sandstone	Turk Abdulkadar Suleman	Irrigation
27	C7	Mangra	Borewell	112	22^0 51' 59.6''	69^0 43' 24.4''	Sandstone	Dhirubha Madhubha	Irrigation
28	C8	Mangra	Borewell	91	22^0 51' 55.3''	69^0 44' 4.0''	Sandstone	Dayaram Naran Tank	Irrigation
29	C9	Sadau	Borewell	91	22^0 51' 45.5''	69^0 44' 58''	Sandstone	Sadau Mumbai mahajan	Drinking
30	C11	Luni	Borewell	46	22^0 52' 37.2''	69^0 47' 58.8''	Alluvium+ Sandstone	Panjarapol Trust	Drinking
31	C12	Luni	Well	6	22^0 52' 29.1''	69^0 49' 45.1''	Alluvium	No Data	No use
32	D1	Navinal	Borewell	107	22^0 50' 33.7''	69^0 35' 54.6''	Sandstone	Mangal Seth	Irrigation
33	D2	Zarpara	Borewell	152	22^0 50' 31.5''	69^0 36' 44.7''	Sandstone	Dada Naran Lakhaniya	Irrigation
34	D3	Zarpara	Borewell	122	22^0 50' 24.8''	69^0 37' 57.6''	Sandstone	Hari Manga Gelva	Irrigation
35	D4	Zarpara	Borewell	128	22^0 50' 45''	69^0 39' 36.9''	Sandstone	Gangji Deva Pingol	Irrigation
36	D5	Dhrab	Borewell	52	22^0 50' 31.4''	69^0 40' 27.9''	Sandstone	Turk Amad Ismail	Irrigation
37	D6	Kapaya Nana	Borewell	99	22^0 50' 45.6''	69^0 41' 39.1''	Sandstone	Devraj Dhanraj	Irrigation
38	D7	Mundra	Borewell	73	22^0 50' 52.3''	69^0 43' 43.3''	Sandstone	Mahobattsinh jadeja	Irrigation
39	D8	Baroi	Borewell	58	22^0 51' 1.3''	69^0 44' 43.8''	Sandstone	Mukesh Jethalal Thakkar	RO D.W. supply
40	D9	Goyarsama	DCB	61	22^0 50' 43.5''	69^0 45' 22.5''	Sandstone	Damji Shivji Maheshwari	Irrigation
41	E1	Navinal	Borewell	110	22^0 49' 47.1''	69^0 35' 47.5''	Sandstone	Khumbhar Amadbhai	Irrigation
42	E2	Navinal	Borewell	107	22^0 49' 57.8''	69^0 36' 46.0''	Sandstone	Raymal Punsi	Irrigation
43	E3	Zarpara	DCB	107	22^0 49' 53.7''	69^0 38' 37.3''	Sandstone	Kalyan Karsan Natha	Irrigation
44	E4	Zarpara	Borewell	122	22^0 49' 45.8''	69^0 39' 14.7''	Sandstone	Tharu Devraj Asariya	Irrigation
45	E5	Dhrab	Borewell	107	22^0 49' 47.4''	69^0 40' 44.5''	Sandstone	Turk Husain Kasam	Irrigation
46	E6	Dhrab	Borewell	137	22^0 49' 50.2''	69^0 41' 40.5''	Sandstone	Maheshwari Bhoja Tejbhar	Irrigation
47	E7	Mundra	Borewell	107	22^0 49' 31.5''	69^0 43' 4.7''	Sandstone	Date Palm Research Center	Irrigation

ANNEXURE 5.4

Details on GWRDC's Observation Wells in the Study Area

Sr. No.	Well Code	Taluka	Village	Well Type	Geology	Total Depth (m)	Static Water Level (M)	
							Pre-Monsoon, 1995	Pre Monsoon, 2005
1	NCCA-254	Mundra	Luni	Tube Well	Sandstone	41.1	----	5.7
2	NCCA-255	Mundra	Mundra	Tube Well	Sandstone	60.97	----	36.1
3	NCCA-256	Mundra	Navinal	Tube Well	Sandstone	40	----	25.5
4	KC-40	Mundra	Bhujpur (m)	Tube Well	Sandstone	120.0	21.7	77.8
5	KC-41	Mundra	Tunda	Tube Well	Sandstone	120.0	12.0	80.7
6	KC-46	Mandvi	Nani Khakhar	Tube Well	Sandstone	152.0	26.1	80.2
7	KCT-12	Mundra	Deshalpar	Tube Well	Sandstone	172.0	28.9	63.8
8	KCT-11	Bhuj	Meghpar	Tube Well	Sandstone	128.0	61.4	53.8
9	KC-24	Anjar	Vira	Dug Well	Alluvium	9	3.7	3.8
10	KC-25	Anjar	Chandroda	Dug Well	Basalt	17.7	11.9	16.4
11	KC-26	Anjar	Khambhra	Tube Well	Sandstone	----	34.8	30.0
12	KC-33	Bhuj	Bharapar	Tube Well	Sandstone	21.3	15.4	11.4
13	KC-34	Bhuj	Chakar Kotda	Tube Well	Sandstone	21	26.6	15.5
14	KC-35	Mundra	Lifra	Dug Well	Basalt	18.3	10.4	16.4
15	KC-36	Mundra	Patri	Dug Well	Basalt	18.4	6.1	18.0
16	KC-37	Mundra	Bhadreshwar	Dug Well	Alluvium	11.8	6.3	11.0
17	KC-39	Mundra	Mundra	Tube Well	Sandstone	----	8.5	36.0
18	KC-42	Mundra	Ramania	Dug Well	Basalt	15.5	9.0	15.4
19	KC-43	Mundra	Beraja	Dug Well	Basalt	14.3	7.0	6.8
20	SHP/200	Bhuj	Nana reha	Tube Well	Sandstone	90	----	65.7
21	SHP/202	Mundra	Bhadreshwar	Tube Well	Sandstone	60	----	8.1
22	SHP/203	Mundra	Lakhapar	Tube Well	Sandstone	60	----	31.0
23	Shp/II/28	Mundra	Bhujpur (m)	Tube Well	Sandstone	106	----	68.5
24	Shp/II/29	Mandvi	Nani khakhar	Tube Well	Sandstone	140	----	82.8
25	KC22	Anjar	Vidi	Tube Well	Sandstone	---	31	53.8
26	HLT-052	Mundra	Vadala	Dug Well	Sandstone	19.4	6.2	14.2
27	HLT-070	Mundra	Pragpar	Tube Well	Sandstone	117	16.7	41
28	HLT-072	Mundra	Zarpara	Tube Well	Sandstone	120	11.6	41.6

ANNEXURE 5.5

Details on A.C.T.'s Groundwater Observation Wells in the Study Area

Sr. No.	Village	Owner	Latitude	Longitude	Type of Well	Total Depth (m)	SWL (m) Pre Monsoon, 05
1	Moti Bhujpur	Maraj Moti Sagar	22° 52' 56.8"	69° 37' 33.3"	Bore Well	100.6	76.0
2	Mundra	Khoja LadhuGulam Hussain	22° 50' 49.8"	69° 43' 35.8"	Bore Well	91.5	44.0
3	Pragpar	Mahavir Pashu Rakasha	22° 53' 47.2"	69° 41' 47.8"	Bore Well	67.1	60.0
4	Samaghogha	Jadeja Khengarji Unadji	22° 53' 56.0"	69° 39' 52.5"	Bore Well	0.0	
5	Navinal	Khumbhar Amadbhai	22° 49' 47.1"	69° 35' 47.5"	Bore Well	109.8	40.0
6	Zarpara	Seda Nagshi Manga	22° 50' 12.8"	69° 37' 15.3"	Bore Well	97.6	66.0
7	Dharub	Fakir Mamad Ali Mamad	22° 49' 47.9"	69° 41' 03.9"	Bore Well	137.2	40.0
8	Mangara	KVK Farm	22° 51' 55.9"	69° 44' 24.1"	Bore Well	91.5	56.7
9	Sadau	Shah Kantilal Virji	22° 51' 49.9"	69° 44' 47.3"	Bore Well	106.7	60.0
10	Shekhadia	Masjid well	22° 51' 30.6"	69° 45' 45.2"	Bore Well	76.2	34.0
11	Goyersama	Jadeja Hatubha Jesaji	22° 50' 36.0"	69° 45' 25.1"	Bore Well	74.7	21.5
12	Baroi	Panchayat well	22° 50' 44.6"	69° 44' 41.9"	Bore Well	152.4	34.0
13	Gundala	Panjrapole well	22° 53' 57.5"	69° 45' 44.8"	Bore Well	82.3	46.7
14	Bhorara	Vaghela Madhubha Ramsag	22° 54' 47"	69° 43' 38.7"	Bore Well	132.6	83.3
15	Mota kapaya	Radhvani Kesarbhai Naran	22° 52' 50.6"	69° 42' 32.5"	Bore Well	122.0	90.0
16	Nana Kapaya	Khoja Mamadali Karamali	22° 50' 59.3"	69° 42' 37.1"	Bore Well	91.5	50.0
17	Nani Bhujpar	Gadhvi Vala Viram	22° 52' 08.1"	69° 37' 56.0"	Bore Well	102.1	91.5
18	Pratappar	Vora Anil Revji	22° 51' 27.1"	69° 38' 53.1"	Bore Well	106.7	40.0
19	Borana	Gadhvi Veera Ladha	22° 51' 00.2"	69° 40' 06.0"	Bore Well	122.0	54.8
20	Babiya	Village bore	23° 01' 07.3"	69° 37' 10.0"	Bore Well	27.4	15.2
21	Bagda	Samat Budher	22° 59' 48.1"	69° 46' 53.5"	Open Well	21.3	12.2
22	Baraya	Mahendrasing	22° 54' 51.4"	69° 41' 04.6"	Bore Well	79.3	45.7
23	Bharudiya	Meghraj Pola	22° 56' 58.7"	69° 53' 21.9"	Bore Well	30.5	12.2
24	Bocha	Lakhubhai	22° 57' 50.3"	69° 38' 50.4"	Bore Well	27.4	18.3
25	Chhasra	Bhan Husain Nurmamad	22° 57' 23.4"	69° 48' 53.3"	Bore Well	36.6	12.2
26	Depa	Village bore	22° 55' 06.0"	69° 33' 20.6"	Bore Well	91.5	38.1

ANNEXURE 5.5

(2 of 2)

Sr. No.	Village	Owner	Latitude	Longitude	Type of Well	Total Depth (m)	SWL (m) Pre Monsoon, 05
27	Fachariya	Rakhya puna	23° 00' 01.8"	69° 46' 04.6"	Open Well	18.3	3.0
28	Gelda	Shivaji khiraji	22° 56' 11.7"	69° 37' 44.1"	Bore Well	122.0	76.2
29	Kanajra	Lakhu Arjan	23° 01' 56.2"	69° 41' 22.2"	Open Well	15.2	7.9
30	Kandagara Nana	Karsan Seja	22° 57' 17.6"	69° 43' 22.4"	Bore Well	70.1	24.4
31	Karagoga	Bhavan Devaji	22° 56' 04.6"	69° 38' 41.7"	Bore Well	91.5	15.2
32	Khakhar Moti	Bore for Cattle	22° 52' 53.6"	69° 33' 06.6"	Bore Well	106.7	61.0
33	Kundrodi	Rajubhai	22° 58' 52.2"	69° 48' 47.3"	Bore Well	30.5	-----
34	Kuvai	Parsotam Meghji	22° 55' 20.7"	69° 57' 25.8"	Open Well	12.8	4.6
35	Mokha	Cattle bore	22° 56' 44.0"	69° 49' 05.2"	Bore Well	30.5	15.2
36	Ratadiya	P.C. Jadeja	22° 56' 00.4"	69° 45' 25.9"	Bore Well	100.6	48.8
37	Shiracha	Budha vela	22° 50' 53.3"	69° 34' 01.4"	Bore Well	109.8	30.5
38	Sukhpar	Batuksinh	22° 54' 56.4"	69° 31' 48.8"	Bore Well	106.7	94.5
39	Tappar	Kkeraj Kara Matang	23° 00' 49.0"	69° 39' 59.9"	Open Well	12.8	9.5
40	Toda	Rayma Ayub	22° 54' 22.1"	69° 43' 06.6"	Bore Well	88.4	48.8
41	Tumbadi Moti	Modha Khetaji	23° 00' 12.5"	69° 34' 38.8"	Bore Well	7.0	12.8
42	Tumbadi Nani	Manjidi Harun ladha	22° 59' 48.3"	69° 32' 59.2"	Open Well	76.2	7.9
43	Vagura	Village well	23° 00' 36.9"	69° 47' 56.7"	DCBW	14.0	6.4
44	Vanki	Village D.W. well	22° 59' 31.5"	69° 42' 14.8"	Open Well	18.3	15.2
45	Viraniya	Maganbhai Dafada	22° 55' 26.3"	69° 43' 49.8"	Bore Well	109.8	45.7
46	Vovar	Khoda vala rumaniya	22° 57' 25.7"	69° 51' 42.3"	Bore Well	27.4	7.3
47	Lakhapar	Manilal Pasubhai Gala	22° 56' 34.8"	69° 43' 19.2"	Bore Well	85.4	77.7
48	Vadala	Kanjibhai Aalabhai Maheswari	22° 55' 0.1"	69° 52' 15.8"	Bore Well	27.4	18.3
49	Pavadiyara	Lakdhirsinh Kathubha Jadeja	22° 55' 15.3"	69° 53' 15.1"	Open Well	13.7	9.5
50	Hatadi	Jagubha Kakubha Jadeja	22° 56' 07.1"	69° 56' 10.9"	Bore Well	39.6	4.9
51	Kukadasar	Aashabhai Rabari	22° 55' 11.8"	69° 56' 58.5"	Open Well	8.2	4.9
52	Patry	Panjarapol	22° 58' 29.1"	69° 43' 24.5"	Bore Well	76.2	30.5
54	Luni	Panjarapol well	22° 52' 37.2"	69° 47' 58.8"	Open Well	13.7	10.7

ANNEXURE 5.6

Observed Seasonal Water Table Fluctuation Records (m) in Watershed Region

Sr. No.	Code	Village	Total Depth (m)	RL (m)	Winter, 08	Pre Monsoon, 08	Post monsoon, 08	Winter, 09	Pre Monsoon, 09	Post monsoon, 09	Winter, 10	Pre Monsoon, 10
1	F1	Meghpar	130.0	145	88	95	--	106.7	108.5	--	--	92
2	F2	Sujapar	120.0	160.0	90.0	93.20	79.27	107	113.0	74	80	89.9
3	F3a	Sanosara	152.4	190	91.5	96.20	81.2	98.5	101.2	79.8	120	122.7
4	F3b	Reha nana	146.0	150.0	122.0	131.10	98	135	147.7	110	121	122.0
5	F4	Varali	305.0	140.0	110.0	91.46	91.46	106.7	106.7	91	112	115.9
6	F5	Wada	107.0	120.0	69.0	73.17	62.3	68.8	85.4	72	76	82.3
7	G1a	Chunadi	81.0	120.0	56.0	58.00	38.30	42.7	55.0	45	61	62.8
8	G1b	Tumbadi Moti	12.2	80.0	2.8	7.00	0	2.1	Dry	0	0	7.9
9	G2a	Kera	360.0	120.0	60.5	99.60	79.3	90	122.0	110	110	107.2
10	G2b	Babiya	20.0	80.0	6.0	10.20	5.7	7.15	9.1	5.8	8.1	9.6
11	G3a	Kanajra	15.2	100.0	2.7	7.60	6	2.1	7.6	5	5.26	5.4
12	G3b	Bandra Nana	293.0	120.0	30.0	30.00	23.35	61	73.0	45	56	61.0
13	G4a	Bhalot	24.0	100.0	6.0	13.00	11.5	18.1	21.5	17.4	18.2	20.2
14	G4b	Vagura	14.0	80.0	2.5	9.00	6	8.5	9.4	7.5	8.08	8.5
15	G5	Mathada	152.0	80.0	61.0	67.07	45.73	73.2	91.5	76	91	95.4
16	G6	Mindiyana	122.0	75.0	51.5	79.30	73.20	105.3	109.0	76	77	83.0
17	H1a	Ramaniya	16.0	68.0	3.0	3.50	2.5	3.5	6.4	5	3.2	6.7
18	H1b	Depa	91.5	47.0	87.0	86.90	82.30	85.8	87.2	79.8	84.4	85.4
19	H2a	Bocha	27.4	65.0	18.0	18.30	18.30	21	22.3	15	18.3	24.4
20	H2b	Gelda	122.0	55.0	45.0	45.70	43.3	76	76.2	45	74	75.1
21	H3a	Vanki	18.3	75.0	4.0	3.00	2.5	10.1	13.6	5.45	9.32	13.3
22	H3b	Kandagara N.	70.1	57.0	23.0	24.40	24.40	24.4	28.4	27.4	31	39.0

ANNEXURE 5.6

(2 of 2)

Sr. No.	Code	Village	Total Depth (m)	RL (m)	Winter, 08	Pre Monsoon, 08	Post monsoon, 08	Winter, 09	Pre Monsoon, 09	Post monsoon, 09	Winter, 10	Pre Monsoon, 10
23	H4a	Bagda	21.3	62.0	8.5	10.00	4.8	4.8	6.8	5.1	5.2	6.2
24	H4b	Mokha	30.5	37.0	8.0	12.20	--	--	--	--	--	--
25	H4c	Ratadiya	91.5	42.0	15.3	24.40	16.9	20.3	24.7	22.6	28	28.3
26	H5a	Vovar	27.4	35.0	9.0	9.00	5	4.6	4.6	4.5	5	8.2
27	H5b	Bharudiya	30.5	23.0	14.0	--	--	10.7	10.1	12.19	13	--
28	H6a	Hatadi	39.6	19.0	3.0	4.00	--	7.6	5.5	4.7	5.15	--
29	H6b	Kuvai	12.8	9.0	3.0	3.50	2.5	5.6	7.1	4.2	5.2	5.5
30	I1a	Khakhar Moti	106.7	30.0	35.0	39.60	45.70		45.7	41.7	46.9	53.0
31	I1b	Shiracha	121.0	19.0	45.0	46.50	38.10	60	63.3	47.2	61	68.2
32	I2a	Moti Bhujpur	100.6	29.0	50.0	60.90	53.2	106	114.0	97.4	102.7	116.8
33	I2b	Pratappar	106.7	16.0	54.4	63.50	59.8	76.2	89.1	63.2	72.1	74.1
34	I3a	Baraya	79.3	38.0	--	--	--	--	61.0	45	60	--
35	I3b	Mota kapaya	168.0	26.0	42.0	54.88	42.68	60	67.1	51	73	--
36	I3c	Mundra	73.0	13.0	33.0	38.11	22.1	28.3	31.0	27.8	32.3	45.7
37	I4a	Ragha	35.0	20.0	18.3	19.20	19.2	21	28.0	20.2	21.3	28.3
38	I4b	Goyersama	61.0	12.0	26.0	25.20	22.8	30	36.6	25.3	29.6	30.2
39	I5	Bhadreshwar	51.8	10.0	12.0	7.00	7.62	10.7	16.8	16	19.3	21.0
40	I6	Kukadasar	8.2	8.0	3.0	7.25	5.49	5	6.1	3.9	4.53	4.5
41	J1	Tunda	76.2	10.0	48.0	50.49	38.11	50	64.5	45	44	48.8
42	J2	Navinal	109.8	11.0	38.1	51.1	38.1	35.1	38.1	35.1	38.1	38.1
43	J3a	Dharub	122.0	6.0	61.0	67.07	48.00	48	54.9	42.00	54	56.3
44	J3b	Mundra	107.0	5.0	18.0	15.24	18.29	24	28.7	21.2	35.6	42.9

ANNEXURE 5.7

(1 of 2)

Computed Reduced Water Table (m) in Watershed Region

Sr. No.	Code	Village	RL m	Winter, 08	Pre Monsoon, 08	Post monsoon, 08	Winter, 09	Pre Monsoon,09	Post monsoon, 09	Winter, 10	Pre Monsoon, 10
1	F1	Meghpar	145.0	57	50.0	----	38	36.5	----	----	53.0
2	F2	Sujapar	160.0	70	66.8	80.7	53	47.0	86.0	80	70.1
3	F3a	Sanosara	190.0	99	93.8	108.8	92	88.8	110.2	70	67.3
4	F3b	Reha nana	150.0	28	18.9	52.0	15	2.3	40.0	29	28.0
5	F4	Varali	140.0	30	48.5	48.5	33	33.3	49.0	28	24.1
6	F5	Wada	120.0	51	46.8	57.7	51	34.6	48.0	44	37.7
7	G1a	Chunadi	120.0	64	62.0	81.7	77	65.0	75.0	59	57.2
8	G1b	Tumbadi Moti	80.0	77	73.0	80.0	78	67.0	80.0	80	72.1
9	G2a	Kera	120.0	60	20.4	40.7	30	-2.0	10.0	10	12.8
10	G2b	Babiya	80.0	74	69.8	74.3	73	70.9	74.2	72	70.4
11	G3a	Kanajra	100.0	97	92.4	94.0	98	92.4	95.0	95	94.6
12	G3b	Bandra Nana	120.0	90	90.0	96.6	59	47.0	75.0	64	59.0
13	G4a	Bhalot	100.0	94	87.0	88.5	82	78.5	82.6	82	79.8
14	G4b	Vagura	80.0	78	71.0	74.0	72	70.6	72.5	72	71.5
15	G5	Mathada	80.0	19	12.9	34.3	7	-11.5	4.0	-11	-15.4
16	G6	Mindiyana	75.0	24	-4.3	1.8	-30	-34.0	-1.0	-2	-8.0
17	H1a	Ramaniya	68.0	65	64.5	65.5	65	61.6	63.0	65	61.3
18	H1b	Depa	47.0	-40	-39.9	-35.3	-39	-40.2	-32.8	-37	-38.4
19	H2a	Bocha	65.0	47	46.7	46.7	44	42.7	50.0	47	40.6
20	H2b	Gelda	55.0	10	9.3	11.7	-21	-21.2	10.0	-19	-20.1
21	H3a	Vanki	75.0	71	72.0	72.5	65	61.5	69.6	66	61.8
22	H3b	Kandagara Nana	57.0	34	32.6	32.6	33	28.6	29.6	26	18.0

ANNEXURE 5.7

(2 of 2)

Sr. No.	Code	Village	RL m	Winter, 08	Pre Monsoon, 08	Post monsoon, 08	Winter, 09	Pre Monsoon, 09	Post monsoon, 09	Winter, 10	Pre Monsoon, 10
23	H4a	Bagda	62.0	54	52.0	57.2	57	55.2	56.9	57	55.8
24	H4b	Mokha	37.0	29	24.8	----	----	----	----	----	----
25	H4c	Ratadiya	42.0	27	17.6	25.1	22	17.3	19.4	14	13.7
26	H5a	Vovar	35.0	26	26.0	30.0	30	30.4	30.5	30	26.8
27	H5b	Bharudiya	23.0	9	----	----	12	12.9	10.8	10	----
28	H6a	Hatadi	19.0	16	15.0	----	11	13.5	14.3	14	----
29	H6b	Kuvai	9.0	6	5.5	6.5	3	1.9	4.8	4	3.5
30	I1a	Khakhar Moti	30.0	-5	-9.6	-15.7	----	-15.7	-11.7	-17	-23.0
31	I1b	Shiracha	19.0	-26	-27.5	-19.1	-41	-44.3	-28.2	-42	-49.2
32	I2a	Moti Bhujpur	29.0	-21	-31.9	-24.2	-77	-85.0	-68.4	-74	-87.8
33	I2b	Pratappar	16.0	-38	-47.5	-43.8	-60	-73.1	-47.2	-56	-58.1
34	I3a	Baraya	38.0	----	----	----	----	-23.0	-7.0	-22	----
35	I3b	Mota kapaya	26.0	-16	-28.9	-16.7	-34	-41.1	-25.0	-47	----
36	I3c	Mundra	13.0	-20	-25.1	-14.3	-18	-25.1	-18.2	-27	-32.7
37	I4a	Ragha	20.0	2	-0.3	3.2	3	2.0	4.8	4	3.2
38	I4b	Goyersama	12.0	-14	-18.5	-12.5	-25	-12.4	-9.3	-14	-24.6
39	I5	Bhadreshwar	10.0	-2	3.0	2.4	-1	-6.8	-6.0	-9	-11.0
40	I6	Kukadasar	8.0	5	0.8	2.5	3	2.0	4.1	3	3.5
41	J1	Tunda	10.0	-38	-40.5	-28.1	-40	-54.5	-35.0	-34	-38.8
42	J2	Navinal	9.0	-29	-42.1	-29.1	-26	-29.1	-26.1	-29	-29.1
43	J3a	Dharub	6.0	-55	-61.1	-42.0	-42	-48.9	-36.0	-48	-50.3
44	J3b	Mundra	5.0	-13	-14.0	-13.3	-19	-40.7	-31.6	-32	-31.6

ANNEXURE 7.1

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Winter 2008)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	7.67	6380	4090	124	125	1088	1066	240	458	337	720	1130
2	F2	Sujapar	7.92	3874	2483	100	134	520	576	120	458	160	360	830
3	F3a	Sanosara	8.29	819	525	48	158	0	77	210	427	284	230	240
4	F3b	Reha nana	8.33	2646	1696	68	334	0	106	90	336	195	270	510
5	F4	Varali	7.70	2586	1658	88	0	495	624	60	305	177	230	570
6	F5	Wada	7.57	1308	838	60	324	0	326	150	183	160	300	350
7	G1a	Chunadi	7.09	2067	1325	60	130	159	509	390	0	603	260	490
8	G1b	Tumbadi Moti	7.40	1657	1062	12	46	281	250	240	183	744	190	220
9	G2a	Kera	7.69	1667	1069	44	178	0	490	420	122	248	500	420
10	G2b	Babiya	8.02	6699	4294	160	118	1134	1123	600	671	248	160	1110
11	G3a	Kanajra	8.02	1508	966	48	89	122	269	210	458	355	450	280
12	G3b	Bandra Nana	8.17	2057	1318	56	113	193	365	150	305	284	450	330
13	G4a	Bhalot	7.82	7099	4550	120	72	1359	1469	240	244	266	460	1430
14	G4b	Vagura	7.92	2895	1856	52	89	437	470	180	366	301	450	470
15	G5	Mathada	7.54	4952	3174	128	322	377	758	150	366	124	370	780
16	G6	Mindiyana	7.83	2566	1645	68	226	81	384	180	397	230	370	400
17	H1a	Ramaniya	8.40	1937	1242	36	180	60	163	390	366	266	560	170
18	H1b	Depa	7.54	3215	2061	64	98	478	413	270	336	727	430	450
19	H2a	Bocha	7.77	5591	3584	36	77	1099	336	240	519	408	630	280
20	H2b	Gelda	7.54	2925	1875	36	101	439	269	330	458	195	560	280
21	H3a	Vanki	8.42	2167	1389	32	190	99	125	150	244	479	330	230
22	H3b	Kandagara Nana	7.18	5401	3462	192	98	835	1085	180	397	160	390	1090

ANNEXURE 7.1

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
23	H4a	Bagda	7.17	4093	2624	100	82	672	787	210	427	284	490	800
24	H4b	Mokha	7.94	429	275	48	158	0	163	210	153	0	190	120
25	H4c	Ratadiya	7.89	4533	2906	32	74	865	192	120	824	408	650	270
26	H5a	Vovar	8.30	2386	1530	20	70	393	154	90	702	230	590	150
27	H5b	Bharudiya	7.77	2067	1325	24	86	283	202	180	640	319	630	170
28	H6a	Hatadi	8.90	3434	2202	20	82	612	192	150	702	355	710	150
29	H6b	Kuvai	7.56	4333	2778	24	190	607	403	270	549	248	620	360
30	I1a	Khakhar Moti	8.19	3135	2010	12	266	198	173	180	671	425	680	170
31	I1b	Shiracha	8.00	2786	1786	8	58	522	134	360	366	284	510	120
32	I2a	Moti Bhujpur	8.19	2766	1773	36	101	403	144	270	427	319	500	180
33	I2b	Pratappar	8.39	3784	2426	20	101	656	100	300	580	408	670	20
34	I3a	Baraya	7.90	4093	2624	40	281	359	307	210	549	319	660	350
35	I3b	Mota kapaya	8.10	1408	902	28	96	108	202	210	336	124	310	180
36	I3c	Mundra	8.24	1068	685	20	38	150	48	120	397	160	420	0
37	I4a	Ragha	8.41	4732	3034	44	194	667	480	360	0	1152	610	520
38	I4b	Goyersama	8.08	3385	2170	44	206	334	384	210	214	869	460	310
39	I5	Bhadreshwar	8.09	4413	2829	28	127	741	355	300	305	301	460	350
40	I6	Kukadasar	8.79	2855	1830	16	151	350	211	240	488	461	500	180
41	J1	Tunda	8.05	5581	3578	48	106	1028	1267	540	336	1436	620	1410
42	J2	Navinal	7.72	12650	8109	96	156	2505	1373	270	244	496	380	1520
43	J3a	Dharub	8.40	3285	2106	24	154	435	173	120	519	549	500	150
44	J3b	Mundra	8.23	4413	2829	24	41	911	240	210	641	549	570	220

ANNEXURE 7.2

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Pre Monsoon, 2008)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	F^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	6.86	5460	3500	140	163	757	812	150	305	1106	1.5	350	1170
2	F2	Sujapar	6.97	4183	2682	104	74	702	720	160	214	621	1.5	330	800
3	F3a	Sanosara	7.00	769	493	44	60	0	134	90	183	177	0.5	170	180
4	F3b	Reha nana	6.33	2835	1818	96	242	78	456	90	266	532	1	350	670
5	F4	Varali	6.91	2855	1830	88	48	465	557	90	152	509	1.5	260	590
6	F5	Wada	7.16	3095	1984	96	41	524	499	150	153	511	0.5	240	580
7	G1a	Chunadi	7.66	2147	1376	72	221	0	240	90	305	461	1.5	280	400
8	G1b	Tumbadi Moti	7.11	1734	1112	40	142	82	202	90	336	301	0.5	330	200
9	G2a	Kera	7.10	1850	1186	88	122	90	221	150	153	407	0.5	280	230
10	G2b	Babiya	7.24	4912	3149	120	70	860	787	150	397	726	2	450	820
11	G3b	Bandra Nana	7.40	2532	1623	64	40	433	360	120	380	301	1	320	330
12	G4a	Bhalot	6.63	6130	3930	108	50	1191	1008	150	396	868	2	340	1030
13	G4b	Vagura	7.56	3155	2022	68	60	534	355	150	244	602	1	350	400
14	G5	Mathada	7.01	5371	3443	96	112	912	710	150	244	1165	1	290	730
15	H1a	Ramaniya	7.21	2235	1433	28	24	436	154	270	275	301	0.5	540	100
16	H1b	Depa	7.56	3724	2387	68	70	646	450	180	305	736	1	370	600
17	H2a	Bocha	7.12	5960	3821	64	24	1254	269	210	549	1276	0	620	290
18	H2b	Gelda	7.43	3005	1926	40	69	514	307	210	336	520	0.5	540	290
19	H3a	Vanki	7.21	2326	1491	88	86	269	192	160	266	502	0	380	380
20	H3b	Kandagara Nana	7.09	5930	3802	340	0	975	1056	60	244	1077	2.5	260	1170
21	H4a	Bagda	6.74	4812	3085	392	0	658	520	150	560	890	0	650	940
22	H4b	Mokha	6.89	11631	7456	272	149	2082	2112	150	427	2131	1.5	410	2210

ANNEXURE 7.2

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	F^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
23	H4c	Ratadiya	7.85	4123	2643	16	19	895	173	210	366	886	1	440	160
24	H5a	Vovar	7.49	3085	1978	24	154	389	211	210	458	539	1	560	210
25	H5b	Bharudiya	7.47	2877	1844	28	48	451	134	240	397	408	2	550	140
26	H6a	Hatadi	7.71	3654	2342	20	48	727	220	150	702	510	2.5	650	190
27	H6b	Kuvai	7.11	4233	2714	28	125	704	192	150	610	869	>2	630	200
28	I1a	Khakhar Moti	7.17	3115	1997	12	120	474	173	180	671	425	2	640	120
29	I1b	Shiracha	7.18	2626	1683	48	34	485	173	180	335	502	2.5	500	110
30	I2a	Moti Bhujpur	7.29	2556	1638	44	72	400	190	210	336	479	0	490	320
31	I2b	Pratappar	7.10	3395	2176	32	199	363	134	120	580	740	0	570	190
32	I3a	Baraya	6.96	4343	2784	80	60	640	355	180	457	1058	2	560	350
33	I3b	Mota kapaya	7.37	1538	986	56	0	290	154	240	244	461	2	350	150
34	I3c	Mundra	7.84	1987	1274	16	130	191	125	180	336	390	2.5	500	90
35	I4a	Ragha	6.41	8287	5312	68	415	1035	710	90	519	2534	1.5	570	1000
36	I4b	Goyersama	7.85	5117	3280	40	134	875	298	150	275	1285	0.5	370	300
37	I5	Bhadreshwar	7.21	5901	3782	68	38	1208	595	150	366	1418	>2	470	570
38	I6	Kukadasar	8.90	2915	1869	12	0	658	115	180	397	585	2	410	60
39	J1	Tunda	7.24	3974	2547	28	113	667	125	180	580	939	1	620	240
40	J2	Navinal	7.47	10643	6822	128	252	1822	970	180	458	3100	0.5	310	1430
41	J3a	Dharub	7.62	6090	3904	28	353	695	570	60	427	1550	2	420	170
42	J3b	Mundra	7.47	6755	4330	32	331	884	630	120	458	1593	2	390	220

ANNEXURE 7.3

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Post Monsoon, 2008)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	7.50	9105	5837	200	86	1702	998	90	397	1783	140	1070
2	F2	Sujapar	7.61	6420	4115	16	46	1373	662	60	336	922	140	800
3	F3a	Sanosara	7.93	1131	725	32	91	49	144	30	183	230	70	140
4	F3b	Reha nana	8.10	4573	2931	124	46	823	643	120	305	532	190	640
5	F4	Varali	7.98	4323	2771	80	38	830	490	90	183	727	70	550
6	F5	Wada	8.00	2496	1600	60	46	419	355	30	122	372	90	360
7	G1a	Chunadi	8.30	2476	1587	44	34	455	269	150	244	727	100	310
8	G1b	Tumbadi Moti	8.66	2726	1747	36	36	518	307	90	244	355	110	270
9	G2a	Kera	8.06	2546	1632	44	38	462	336	60	336	337	160	300
11	G3a	Kanajra	8.23	2356	1510	80	17	419	182	120	336	266	200	210
12	G3b	Bandra Nana	8.19	3095	1984	48	0	658	278	270	214	443	130	270
13	G4a	Bhalot	7.43	13399	8589	164	118	2673	1651	120	183	2428	150	1720
14	G4b	Vagura	7.60	6969	4467	88	38	1431	624	120	427	833	220	700
15	G5	Mathada	7.10	8516	5459	108	36	1769	672	90	458	1947	130	750
16	G6	Mindiyana	8.68	2995	1920	40	24	598	221	120	366	408	180	230
17	H1a	Ramaniya	8.12	4113	2637	40	48	810	317	180	366	479	180	320
18	H1b	Depa	8.26	5821	3731	20	26	1267	192	90	488	1374	200	210
19	H2a	Bocha	8.25	9046	5798	56	300	1444	355	150	519	1223	240	400
20	H2b	Gelda	8.23	4822	3091	44	34	996	336	90	549	903	210	330
21	H3a	Vanki	8.65	3444	2208	40	38	674	480	90	305	372	200	440
22	H3b	Kandagara Nana	7.65	7877	5050	156	50	1539	728	60	366	1547	180	550
23	H4a	Bagda	8.27	8077	5178	60	38	1718	1747	90	427	1241	160	1770

ANNEXURE 7.3

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
24	H4b	Mokha	7.81	14197	9101	188	103	2857	2250	120	488	2482	190	240
25	H4c	Ratadiya	8.65	7218	4627	156	44	1399	739	90	488	1275	210	650
26	H5a	Vovar	8.03	9874	6330	40	43	2146	336	60	641	815	270	300
27	H5b	Bharudiya	8.56	7618	4883	32	0	1718	384	120	549	1243	240	300
28	H6a	Hatadi	8.16	6410	4109	36	50	1339	230	120	610	1151	300	220
29	H6b	Kuvai	8.83	6470	4147	56	0	1426	288	90	671	1115	280	260
30	I1a	Khakhar Moti	8.26	4513	2893	28	0	1007	192	90	763	479	330	140
31	I1b	Shiracha	8.85	5022	3219	32	0	1120	134	120	396	762	210	120
32	I2a	Moti Bhujpur	8.32	4423	2835	28	31	927	230	90	366	709	200	230
33	I2b	Pratappar	8.32	6360	4077	40	0	1419	192	150	549	939	260	190
34	I3a	Baraya	8.65	6210	3981	52	53	1270	317	60	610	967	260	340
35	I3b	Mota kapaya	8.83	2316	1485	32	0	497	230	60	366	266	140	170
36	I3c	Mundra	8.66	1787	1146	20	0	389	134	150	305	213	140	110
37	I4a	Ragha	6.37	4555	2920	80	106	755	902	60	336	773	190	970
38	I4b	Goyersama	6.41	2371	1520	28	50	417	29	120	213	646	170	330
39	I5	Bhadreshwar	8.14	7488	4800	48	50	1573	365	90	397	1617	200	390
40	I6	Kukadasar	8.30	4682	3002	32	26	991	211	150	397	620	200	160
41	J1	Tunda	8.65	8706	5581	20	46	1895	403	60	671	1947	210	370
42	J2	Navinal	6.19	9500	6090	96	202	1692	269	90	275	3191	150	500
43	J3a	Dharub	8.73	5282	3386	24	0	1189	125	90	610	815	190	150
44	J3b	Mundra	8.87	7009	4493	44	0	1564	125	120	396	1599	230	220

ANNEXURE 7.4

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Winter, 2009)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	6.98	3198	2050	100	79	470	1027	90	366	1081	150	1100
2	F2	Sujapar	7.00	3120	2000	104	36	530	835	60	305	798	150	810
3	F3a	Sanosara	7.63	562	360	32	0	93	259	90	122	124	80	200
4	F4	Varali	6.98	2075	1330	60	60	294	547	90	153	532	110	490
5	F5	Wada	7.24	1841	1180	44	19	337	250	60	153	408	80	280
6	G1a	Chunadi	7.39	1560	1000	60	24	244	403	60	396	443	110	410
7	G1b	Tumbadi Moti	7.60	1529	980	40	24	260	394	90	214	425	120	360
8	G2a	Kera	7.29	1810	1160	60	34	283	269	120	305	390	160	350
9	G3a	Kanajra	7.63	1092	700	28	178	0	278	60	366	230	160	230
10	G3b	Bandra Nana	7.42	1622	1040	40	14	300	269	90	275	319	120	250
11	G4a	Bhalot	6.77	5928	3800	224	91	933	1680	120	244	2517	120	1810
12	G4b	Vagura	7.07	2714	1740	60	26	506	442	90	396	869	170	520
13	G5	Mathada	6.96	3432	2200	112	31	602	768	30	366	1117	160	780
14	G6	Mindiyana	7.10	1856	1190	60	26	308	336	90	305	461	160	400
15	H1a	Ramaniya	7.11	2527	1620	56	26	252	499	90	336	656	150	460
16	H1b	Depa	7.12	7176	4600	72	67	1442	941	90	549	2251	210	910
17	H2a	Bocha	7.04	4992	3200	52	24	1044	278	90	518	284	230	280
18	H2b	Gelda	7.26	2402	1540	28	46	434	288	120	427	1223	190	300
19	H3a	Vanki	7.04	2153	1380	64	31	363	576	60	366	532	150	600

ANNEXURE 7.4

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
20	H3b	Kandagara Nana	6.79	3276	2100	124	36	543	931	60	336	1170	150	920
21	H4a	Bagda	7.03	3432	2200	56	46	639	518	120	366	1117	170	590
22	H4c	Ratadiya	7.27	3588	2300	28	48	702	336	90	519	1046	230	260
23	H5a	Vovar	7.16	3089	1980	24	34	620	365	30	610	656	290	290
24	H5b	Bharudiya	7.08	1903	1220	20	22	374	202	120	458	319	230	130
25	H6a	Hatadi	7.78	2839	1820	12	94	461	163	150	458	656	240	130
26	H6b	Kuvai	7.50	3058	1960	36	19	626	326	60	549	709	250	240
27	I1a	Khakhar Moti	7.77	2215	1420	24	0	483	230	90	732	496	270	140
28	I1b	Shiracha	7.37	2262	1450	28	0	489	163	120	488	656	200	90
29	I2a	Moti Bhujpur	7.32	2293	1470	24	48	409	240	90	519	514	160	190
30	I2b	Pratappar	7.29	2995	1920	24	19	626	250	30	580	691	240	210
31	I3b	Mota kapaya	7.44	920	590	24	17	152	192	90	336	390	130	140
32	I3c	Mundra	7.67	1622	1040	116	132	-13	221	30	519	301	210	90
33	I4a	Ragha	6.90	6084	3900	120	72	1126	1085	120	366	195	190	1190
34	I4b	Goyersama	7.35	2558	1640	28	26	507	365	120	305	727	60	280
35	I5	Bhadreshwar	7.14	4836	3100	40	48	976	595	60	397	1542	180	580
36	J1	Tunda	7.06	3432	2200	32	26	703	374	150	580	1064	240	250
37	J2	Navinal	7.00	8736	5600	20	0	1990	1046	30	366	3687	120	1100
38	J3a	Dharub	7.22	2621	1680	28	185	217	240	60	488	638	160	150
39	J3b	Mundra	7.14	3136	2010	32	19	649	250	120	427	957	360	260

ANNEXURE 7.5

Groundwater Chemistry of Observation Wells of Watershed Region (Pre Monsoon, 2009)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	F^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	7.70	4836	3100	116	290	424	912	60	397	1023	2	160	1100
2	F2	Sujapar	7.30	4212	2700	92	113	648	840	60	287	760	2	150	810
3	F3a	Sanosara	8.20	702	450	32	67	0	259	30	183	124	2	80	230
4	F3b	Reha nana	7.50	2746	1760	68	82	398	496	30	214	532	2	130	620
5	F4	Varali	7.90	2465	1580	72	26	434	509	60	244	532	2	150	540
6	F5	Wada	7.00	2496	1600	68	36	428	346	30	153	337	2	80	360
7	G1a	Chunadi	7.70	2012	1290	68	112	171	214	60	234	432	2	120	440
8	G1b	Tumbadi Moti	8.10	2028	1300	40	24	375	306	60	280	461	1	80	380
9	G2a	Kera	7.90	2652	1700	56	118	320	396	30	244	603	2	220	440
10	G2b	Babiya	7.40	3744	2400	60	26	743	346	60	488	798	2	230	420
11	G3a	Kanajra	8.3	1451	930	44	36	215	86	60	306	244	2	170	240
12	G4a	Bhalot	7.70	8580	5500	176	158	1471	1242	90	275	2162	2	100	1700
13	G4b	Vagura	7.60	4056	2600	68	24	810	442	90	397	869	2	170	550
14	G5	Mathada	7.70	5304	3400	96	117	887	796	60	336	1189	2	170	850
15	G6	Mindiyana	7.7	2044	1310	96	67	232	298	60	287	324	1	170	250
16	H1a	Ramaniya	7.60	2980	1910	76	24	553	396	60	256	662	2	190	510
17	H1b	Depa	8.20	3572	2290	24	55	690	230	90	427	390	2	170	150
18	H2a	Bocha	7.50	5928	3800	115	96	1049	326	60	519	1329	2	210	260
19	H2b	Gelda	8.00	2777	1780	44	101	396	346	90	315	532	0	210	310
20	H3a	Vanki	7.30	3900	2500	88	68	325	528	60	366	744	0	160	500

ANNEXURE 7.5

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	F^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
21	H3b	Kandagara Nana	7.30	5304	3400	148	120	822	1056	360	336	1471	2	150	1100
22	H4a	Bagda	7.40	4524	2900	68	52	703	557	90	397	1034	2	70	490
23	H4c	Ratadiya	7.70	4836	3100	36	24	1027	317	90	641	970	2	230	330
24	H5a	Vovar	7.40	3588	2300	40	384	45	326	90	671	674	1	200	270
25	H5b	Bharudiya	7.90	2246	1440	32	22	439	182	30	318	461	2	200	160
26	H6a	Hatadi	9.20	3900	2500	24	46	783	192	180	593	744	2	380	80
27	H6b	Kuvai	8.00	3744	2400	72	142	508	96	30	580	762	2	260	100
28	I1a	Khakhar Moti	8.20	2683	1720	44	252	85	269	30	632	425	2	290	130
29	I1b	Shiracha	8.20	2933	1880	40	264	124	221	120	366	603	2	200	120
30	I2a	Moti Bhujpur	8.40	2761	1770	28	223	176	202	60	488	603	2	200	190
31	I2b	Pratappar	8.20	3900	2500	36	295	291	240	60	305	674	2	130	170
32	I3a	Baraya	7.50	3744	2400	72	103	582	365	120	580	691	2	280	340
33	I3b	Mota kapaya	8.00	1373	880	28	24	238	211	90	305	355	2	440	140
34	I3c	Mundra	8.10	2122	1360	44	12	415	242	60	325	355	.---.	240	220
35	I4a	Ragha	7.80	7800	5000	84	380	972	942	30	519	2345	.---.	220	1200
36	I4b	Goyersama	8.00	3276	2100	28	36	653	693	60	397	939	.---.	140	910
37	I5	Bhadreshwar	8.10	4836	3100	40	36	999	451	60	366	1241	2	180	400
38	I6	Kukadasar	8.30	2886	1850	40	24	573	307	60	312	585	2	220	200
39	J1	Tunda	7.50	4836	3100	40	41	990	288	90	519	1241	2	260	320
40	J2	Navinal	7.20	7488	4800	100	155	1313	269	90	275	2393	.---.	150	230
41	J3a	Dharub	7.90	3276	2100	32	209	318	134	90	478	904	2	150	170
42	J3b	Mundra	7.40	4368	2800	36	74	822	202	60	549	975	.---.	200	270

ANNEXURE 7.6

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Post Monsoon, 2009)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	6.4	5148	3300	100	91	896	950	150	488	723	570	1090
2	F2	Sujapar	6.6	4212	2700	136	24	768	576	60	610	408	430	690
3	F3a	Sanosara	7.1	702	450	40	19	79	336	30	183	106	230	210
4	F3b	Reha nana	6.9	2886	1850	88	48	472	678	0	380	266	400	700
5	F4	Varali	6.4	2480	1590	64	24	452	434	60	305	310	260	510
6	F5	Wada	6.8	1700	1090	100	0	277	330	30	122	266	80	460
7	G1a	Chunadi	7.4	2324	1490	76	29	393	440	90	244	310	360	490
8	G1b	Tumbadi Moti	8.3	1154	740	20	5	234	221	150	366	195	300	140
9	G2a	Kera	7.4	1529	980	48	24	251	234	60	207	213	380	260
10	G2b	Babiya	6.8	9360	6000	1924	0	0	2179	0	671	284	470	2210
11	G3a	Kanajra	7.3	1248	800	48	0	232	346	150	519	195	440	240
12	G3b	Bandra Nana	7.6	1763	1130	44	14	328	280	30	297	201	340	230
13	G4a	Bhalot	6.9	8892	5700	356	34	1575	2006	60	427	1084	350	1990
14	G4b	Vagura	7.3	1997	1280	48	0	405	394	60	271	355	560	260
15	G5	Mathada	7	5460	3500	108	43	1051	845	0	580	810	450	810
16	G6	Mindiyana	7.8	1903	1220	44	36	319	234	60	327	266	450	230
17	H1a	Ramaniya	6.9	4524	2900	108	41	840	874	0	549	337	350	820
18	H1b	Depa	7.2	8580	5500	124	17	1802	566	0	824	925	690	670
19	H2a	Bocha	7.2	5928	3800	48	17	1278	288	0	763	479	640	190
20	H2b	Gelada	6.9	2870	1840	40	12	592	374	60	540	319	570	310
21	H3a	Vanki	7.4	1326	850	36	14	238	180	0	240	195	380	160

ANNEXURE 7.6

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
22	H3b	Kandagara Nana	7.5	4992	3200	148	34	915	979	60	488	554	430	950
23	H4a	Bagada	7.1	2465	1580	36	14	499	314	0	493	301	620	260
24	H4c	Ratadiya	7.4	4992	3200	36	17	1076	413	90	763	714	700	310
25	H5a	Vovar	6.9	4368	2800	32	24	923	317	0	1037	549	810	270
26	H5b	Bharudiya	7.4	2246	1440	28	14	458	288	0	402	301	610	150
27	H6a	Hatadi	7.2	3744	2400	32	14	798	288	60	854	230	780	210
28	H6b	Kuvai	7.3	4212	2700	32	17	901	384	120	732	319	750	270
29	I1a	Khakhar Moti	7.5	2652	1700	20	7	574	173	60	546	230	830	90
30	I1b	Siracha	7.5	2839	1820	28	0	622	221	90	378	496	630	100
31	I2a	Moti Bhujpur	7.3	2917	1870	28	19	603	355	30	402	520	600	230
32	I3a	Baraya	6.9	3744	2400	44	10	794	307	90	732	390	570	280
33	I3b	Mota Kapaya	7.9	1310	840	32	2	260	374	30	397	319	300	300
34	I3c	Mundra	7.3	1170	750	16	0	251	134	60	180	213	570	30
35	I4a	Ragha	7	2761	1770	36	36	526	269	60	610	230	550	190
36	I4b	Goyersama	6.8	3588	2300	48	22	730	317	60	549	567	540	360
37	I5	Bhadreshwar	7.3	5304	3400	60	29	1098	499	30	519	837	500	460
38	I6	Kukadasar	7.3	2855	1830	32	12	598	230	0	482	532	600	170
39	J1	Tunda	6.9	4680	3000	36	12	1014	250	90	732	709	700	150
40	J2	Navinal	7.4	9360	6000	140	60	1880	1171	90	427	2201	480	1200
41	J3a	Dhrab	7.2	3089	1980	20	12	666	230	60	448	620	540	140
42	J3b	Mundra	6.9	4524	2900	36	12	978	298	90	702	762	670	190

ANNEXURE 7.7

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Winter, 2010)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	7.10	5148	3300	204	22	910	1152	60	519	230	270	1120
2	F2	Sujapar	6.90	4056	2600	100	43	737	950	30	549	301	260	910
3	F3a	Sanosara	7.70	655	420	48	7	82	250	60	275	177	310	220
4	F3b	Reha nana	6.80	2792	1790	88	24	496	413	30	458	355	130	720
5	F4	Varali	6.80	2418	1550	100	29	387	173	60	305	443	90	220
6	F5	Wada	6.90	1217	780	48	14	198	298	90	214	177	190	280
7	G1a	Chunadi	7.70	2044	1310	60	22	360	374	90	305	408	230	450
8	G1b	Tumbadi Moti	8.20	1232	790	28	12	229	125	90	336	284	220	210
9	G2a	Kera	6.80	1638	1050	52	17	285	163	30	458	284	360	340
10	G2b	Babiya	6.90	6240	4000	216	14	1162	979	60	702	479	290	1140
11	G3a	Kanajra	7.30	1716	1100	48	12	317	106	60	610	284	160	280
12	G3b	Bandra Nana	6.90	2621	1680	80	17	480	346	30	488	514	180	470
13	G4a	Bhalot	7.20	7909	5070	636	0	1091	2045	30	275	443	280	2070
14	G4b	Vagura	7.40	2418	1550	44	19	470	336	30	671	355	250	280
15	G5	Mathada	6.80	4727	3030	168	7	882	806	60	458	248	270	760
16	G6	Mindiyana	6.60	1981	1270	44	38	332	326	330	244	301	260	290
17	H1a	Ramaniya	6.80	4524	2900	176	22	798	941	60	397	390	260	910
18	H1b	Depa	7.30	8268	5300	60	5	1826	317	90	701	479	380	310
19	H2a	Bocha	7.20	6240	4000	56	50	1277	595	60	701	674	350	650
20	H2b	Gelda	7.00	2933	1880	44	22	584	307	60	763	567	400	290

ANNEXURE 7.7

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
21	H3a	Vanki	7.20	2512	1610	60	24	464	403	30	610	408	330	470
22	H3b	Kandagara Nana	7.20	4696	3010	140	38	847	998	90	488	390	260	1010
23	H4a	Bagda	7.20	3136	2010	36	19	644	355	90	488	443	360	400
24	H4c	Ratadiya	7.10	4758	3050	52	22	995	326	60	640	408	400	330
25	H5a	Vovar	6.90	3136	2010	24	22	653	240	60	763	496	430	240
26	H5b	Bharudiya	7.20	2324	1490	64	29	407	163	90	824	372	340	160
27	H6a	Hatadi	7.40	3214	2060	60	0	671	240	90	671	355	440	240
28	H6b	Kuvai	7.40	3198	2050	28	19	668	298	120	824	496	400	230
29	I1a	Khakhar Moti	7.60	2668	1710	32	0	578	202	60	763	461	500	150
30	I1b	Shiracha	7.70	2855	1830	24	0	630	67	90	1037	390	320	90
31	I2a	Moti Bhujpur	7.70	2886	1850	40	17	587	125	60	610	479	310	190
32	I3a	Baraya	7.20	3588	2300	52	19	730	288	90	610	620	380	320
33	I3b	Mota kapaya	7.90	1310	840	32	10	247	-19	90	763	284	190	120
34	I3c	Mundra	7.90	1045	670	32	7	190	154	150	580	284	240	60
35	I4a	Ragha	7.40	3432	2200	40	14	717	173	90	549	461	180	160
36	I4b	Goyersama	7.30	3089	1980	28	22	638	269	90	458	514	240	270
37	I5	Bhadreshwar	6.90	6240	4000	40	29	1336	288	90	427	160	250	470
38	I6	Kukadasar	7.70	2855	1830	28	12	602	77	120	458	160	360	170
39	J1	Tunda	7.20	5148	3300	60	7	1103	288	60	793	443	340	320
40	J2	Navinal	7.10	9984	6400	140	84	1978	1267	60	396	230	180	1410
41	J3a	Dharub	7.50	3276	2100	32	14	690	211	90	610	177	100	200
42	J3b	Mundra	7.00	4368	2800	24	24	933	182	120	641	727	280	250

ANNEXURE 7.8

(1 of 2)

Groundwater Chemistry of Observation Wells of Watershed Region (Pre Monsoon, 2010)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	F^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
1	F1	Meghpar	7.3	4524	2900	92	112	722	750	60	266	1050	1.5	200	1000
2	F2	Sujapar	7.6	3588	2300	64	41	675	710	60	211	680	1.5	150	820
3	F3a	Sanosara	7.9	562	360	28	12	74	154	30	153	160	1.6	100	110
4	F3b	Reha nana	7.3	2621	1680	72	31	461	443	60	214	480	1.6	200	660
5	F4	Varali	7.4	2278	1460	64	91	276	365	30	305	337	1.6	130	500
6	F5	Wada	7.2	2418	1550	36	14	229	154	30	153	355	1.6	110	60
7	G1a	Chunadi	7.2	1856	1190	48	10	354	310	60	188	310	1.6	170	420
8	G1b	Tumbadi Moti	8.0	1872	1200	16	10	394	211	60	210	372	1.5	200	150
9	G2a	Kera	7.6	2605	1670	48	7	531	269	60	305	301	1.6	230	230
10	G2b	Babiya	6.9	4212	2700	36	41	851	470	120	449	900	1.5	280	490
11	G3a	Kanajra	7.6	1030	660	20	7	200	250	90	397	230	1.5	220	250
12	G3b	Bandra Nana	7.5	1576	1010	28	10	312	198	60	216	266	1.6	210	210
13	G4a	Bhalot	7.2	7800	5000	220	48	1452	1208	60	305	2000	1.5	280	2300
14	G4b	Vagura	7.5	2590	1660	52	5	528	244	30	366	514	1.5	160	300
15	G5	Mathada	7.1	4056	2600	88	105	632	560	30	288	1050	1.5	160	690
16	G6	Mindiyana	6.9	2012	1290	32	10	408	240	30	305	350	1.5	220	220
17	H1a	Ramaniya	7.0	3900	2500	76	36	742	739	30	397	630	1.5	180	820
18	H1b	Depa	7.0	6396	4100	52	24	1368	518	60	580	1060	1.5	300	520
19	H2a	Bocha	7.3	5616	3600	40	22	1206	336	60	732	1350	1.5	330	270
20	H2b	Gelda	7.5	2886	1850	32	67	499	269	90	419	514	1.5	300	230
21	H3a	Vanki	7.2	2808	1800	44	29	541	528	30	315	425	1.5	210	490
22	H4a	Bagda	7.3	2808	1800	28	7	601	192	90	324	620	1.5	260	160

ANNEXURE 7.8

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	F^{-} mg/l	Total Alkalinity as CaCO3 mg/l	Total Hardness as CaCO3 mg/l
23	H4c	Ratadiya	7.5	4524	2900	32	42	925	240	60	610	1120	1.5	650	210
24	H5a	Vovar	7.1	3073	1970	32	0	671	192	120	471	567	1.5	390	140
25	H5b	Bharudiya	7.2	3432	2200	32	24	708	317	30	458	549	1.5	210	310
26	H6a	Hatadi	8.2	4524	2900	28	12	987	202	60	915	744	1.5	450	160
27	H6b	Kuvai	7.3	3588	2300	24	10	781	250	60	578	709	1.5	360	200
28	I1a	Khakhar Moti	7.5	2012	1290	24	0	436	192	60	854	408	1.5	440	110
29	I1b	Shiracha	7.6	3042	1950	16	0	682	86	60	610	443	1.5	300	60
30	I2a	Moti Bhujpur	7.3	2527	1620	20	5	550	202	30	434	479	1.5	300	160
31	I3a	Baraya	7.6	2886	1850	12	7	587	173	30	671	443	1.5	320	190
32	I3b	Mota kapaya	7.4	1529	980	28	12	297	182	60	335	266	1.5	180	150
33	I3c	Mundra	8.1	1498	960	20	0	322	182	30	310	160	1.5	260	70
34	I4a	Ragha	7.1	6240	4000	44	66	1260	374	30	514	1860	1.6	210	300
35	I4b	Goyersama	7.5	2855	1830	8	12	625	221	60	397	730	1.5	370	180
36	I5	Bhadreshwar	7.7	4368	2800	40	14	933	346	60	342	1200	1.5	140	370
37	I6	Kukadasar	7.5	4212	2700	36	17	897	278	30	641	680	1.5	350	290
38	J1	Tunda	7.2	4524	2900	56	62	859	288	90	641	833	1.5	340	280
39	J2	Navinal	7.1	8736	5600	152	166	1520	976	30	336	2450	1.6	200	1330
40	J3a	Dharub	7.4	4368	2800	20	24	937	278	60	427	980	1.5	120	220
41	J3b	Mundra	7.6	4836	3100	28	32	1021	211	60	580	1050	1.5	330	160

ANNEXURE 7.9

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Winter, 2008)

Sr. No.	Code	Village	PH	Ec µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	8.12	3055	1958	40	41	580	374	150	275	1134	380
2	A2	Gelada	8.76	3375	2163	48	31	662	336	150	458	922	290
3	A5	Baraya Nana	8.39	1328	851	24	163	0	163	90	580	479	120
4	A6	Pragpar	9.06	2356	1510	16	192	156	106	300	580	1205	0
5	A7	Toda	7.96	5411	3469	152	113	856	1046	180	153	1489	1030
6	A8	Bhorara	8.28	2266	1453	48	293	0	307	240	244	532	250
7	A9	Gundala	8.87	3904	2502	28	31	807	202	240	519	620	180
8	A11	Ragha	7.83	11102	7117	64	43	2401	835	330	275	355	940
9	B1	Desalpar	7.9	2426	1555	48	134	246	250	240	275	425	240
10	B2	Bhujpur Moti	8.06	2526	1619	60	132	260	355	210	244	798	370
11	B3	Bhujpur Moti	7.9	2516	1613	24	38	478	173	330	458	833	140
12	B4	Samagogha	8.72	2905	1862	24	46	554	0	270	519	780	0
13	B5	Samagogha	8.28	2776	1779	36	82	442	211	600	30	1542	210
14	B6	Kapaya Mota	7.78	3704	2374	24	79	674	115	180	915	1258	80
15	B7	Bhorara	7.68	1208	774	60	302	0	355	240	214	443	310
16	B8	Bhorara	8.32	2845	1824	32	142	347	278	210	458	1152	200
17	B9	Gundala	9.02	4722	3027	24	192	692	154	270	458	2411	130
18	B10	Ragha	8.1	6120	3923	104	233	844	355	210	641	1595	420
19	B11	Ragha	8.41	4732	3034	44	194	667	480	360	0	1152	520
20	B12	Luni	8.86	2067	1325	24	115	228	134	150	640	177	170
21	C1	Bhujpur Moti	8.44	3015	1933	24	36	598	115	630	31	620	100
22	C2	Bhujpur Moti	8.27	3235	2074	24	65	593	278	480	0	1471	240
23	C3	Bhujpur Nani	7.75	4063	2605	28	58	794	307	270	366	922	310

ANNEXURE 7.9

Sr. No.	Code	Village	PH	Ec µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Hardness as CaCO3 mg/l
24	C4	Pratappar	8.5	2706	1734	20	384	0	96	360	793	390	20
25	C5	Samagogha	8.89	2766	1773	24	122	375	19	330	458	780	0
26	C6	Kapaya Mota	8.63	2566	1645	32	156	255	48	300	641	408	0
27	C7	Mangra	8.42	909	582	64	108	0	202	300	275	195	140
28	C8	Mangra	8.13	1717	1101	56	0	331	365	210	275	461	310
29	C9	Sadau	8.92	2127	1363	60	0	421	202	240	519	372	140
30	C11	Luni	8.68	3365	2157	8	250	288	67	180	488	869	140
31	C12	Luni	8.82	1697	1088	24	70	230	202	210	458	319	150
32	D1	Navinal	8.55	3125	2003	32	24	637	86	630	0	620	150
33	D2	Zarpara	8.23	3714	2381	36	60	699	278	390	397	975	250
34	D3	Zarpara	8.22	5182	3322	44	444	292	182	270	366	1329	170
35	D4	Zarpara	8.24	5491	3520	36	82	1067	422	330	458	1400	420
36	D5	Dhrab	8.39	5781	3706	48	46	1189	298	210	366	1595	250
37	D6	Kapaya Nana	8.22	3934	2522	40	122	626	221	330	610	727	150
38	D7	Mundra	8.24	1068	685	20	38	150	100	120	397	160	0
39	D8	Baroi	8.66	1707	1094	36	0	352	211	330	213	372	200
40	D9	Goyarsama	8.08	3385	2170	44	206	334	384	210	214	869	310
41	E1	Navinal	7.72	12650	8109	96	156	2505	1373	270	244	496	1520
42	E2	Navinal	8.67	3225	2067	24	31	656	259	180	305	691	220
43	E3	Zarpara	7.66	18261	11706	392	84	3595	2678	240	153	6930	2810
44	E4	Zarpara	7.94	12989	8326	160	96	2624	1498	1380	214	4059	1570
45	E5	Dhrab	7.97	4702	3014	48	218	610	144	360	244	1170	260
46	E6	Dhrab	8.7	4373	2803	84	444	60	154	150	519	5087	140
47	E7	Mundra	8.23	4413	2829	24	41	911	240	210	641	549	220

ANNEXURE 7.10

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Pre Monsoon, 2008)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	7.14	4571	2930	56	350	317	384	90	397	691	400
2	A2	Gelada	7.23	5632	3610	92	468	295	317	150	488	904	350
3	A5	Baraya Nana	7.84	1732	1110	28	0	367	144	240	488	266	130
4	A6	Pragpar	7.34	3900	2500	36	62	737	278	150	366	632	290
5	A7	Toda	6.81	7972	5110	140	180	1330	1171	120	275	1436	1130
6	A8	Bhorara	7.53	3604	2310	44	0	780	365	150	305	425	290
7	A9	Gundala	7.53	6271	4020	36	526	396	250	330	549	833	200
8	A11	Ragha	7.25	14087	9030	64	144	2896	985	120	641	2664	620
9	B1	Desalpar	7.15	4727	3030	52	125	790	154	180	275	927	250
10	B2	Bhujpur Moti	7.25	4118	2640	40	50	806	355	330	153	649	360
11	B3	Bhujpur Moti	7.83	3962	2540	144	134	490	202	180	640	519	160
12	B4	Samagogha	7.77	4571	2930	56	65	864	58	240	793	708	60
13	B5	Samagogha	7.81	4633	2970	104	314	345	154	150	244	874	210
14	B6	Kapaya Mota	7.96	6006	3850	48	29	1273	125	210	884	1032	130
15	B7	Bhorara	7.35	1763	1130	68	223	0	298	90	305	177	290
16	B8	Bhorara	7.83	4696	3010	40	0	1036	211	240	488	732	180
17	B9	Gundala	7.92	7254	4650	60	434	769	301	60	671	1257	190
18	B10	Ragha	7.39	9688	6210	56	216	1753	384	30	701	2507	410
19	B11	Ragha	6.41	8287	5312	68	415	1035	710	90	519	2534	1000
20	B12	Luni	7.8	3432	2200	20	420	0	288	150	519	355	210
21	C1	Bhujpur Moti	7.75	4930	3160	36	521	96	178	120	427	949	90
22	C2	Bhujpur Moti	7.64	5242	3360	40	504	196	202	270	336	1014	200
23	C3	Bhujpur Nani	7.67	6583	4220	64	634	229	278	150	366	1010	310

ANNEXURE 7.10

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	Total Hardness as CaCO3 mg/l
24	C4	Pratappar	7.5	4384	2810	140	70	715	192	150	824	319	130
25	C5	Samagogha	7.52	1980	1269	48	190	37	125	180	397	265	170
26	C6	Kapaya Mota	8.04	4274	2740	20	144	686	240	240	641	443	150
27	C7	Mangra	8.99	1440	923	16	226	0	0	330	122	124	120
28	C8	Mangra	7.24	2757	1767	48	348	0	259	150	305	443	190
29	C9	Sadau	8.06	3494	2240	32	413	0	106	150	519	572	150
30	C11	Luni	7.56	6599	4230	20	122	1263	202	180	488	1157	160
31	C12	Luni	7.14	2585	1657	16	132	324	163	150	350	574	180
32	D1	Navinal	7.87	5132	3290	8	210	709	202	210	418	1614	150
33	D2	Zarpara	7.14	4976	3190	28	230	673	269	150	366	1097	270
34	D3	Zarpara	7.2	7223	4630	64	216	1176	528	240	275	1188	640
35	D4	Zarpara	7.72	9064	5810	52	276	1499	310	180	580	1500	310
36	D5	Dhrab	7.93	8798	5640	28	127	1751	365	150	275	1713	320
37	D6	Kapaya Nana	8.23	6318	4050	40	384	673	230	210	580	1093	140
38	D7	Mundra	7.84	1987	1274	16	130	191	125	180	336	390	90
39	D8	Baroi	7.73	2822	1809	32	425	0	288	510	0	355	280
40	D9	Goyarsama	7.85	5117	3280	40	134	875	298	150	275	1285	300
41	E1	Navinal	7.47	10643	6822	128	252	1822	970	180	458	3100	1430
42	E2	Navinal	7.89	5132	3290	28	403	377	259	300	244	1262	240
43	E3	Zarpara	6.87	16244	10413	436	209	2540	2454	180	183	4868	4640
44	E4	Zarpara	7.16	11142	7142	176	194	1890	1026	300	0	3780	1600
45	E5	Dhrab	7.67	7051	4520	40	0	1578	398	300	244	1481	300
46	E6	Dhrab	7.79	6630	4250	28	0	1495	350	90	549	1346	250
47	E7	Mundra	7.47	6755	4330	32	331	884	630	120	458	1593	220

ANNEXURE 7.11

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Post Monsoon, 2008)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	$NO3^{-}$ mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	6.53	2106	1350	136	50	232	162	180	214	410	0.02	420
2	A2	Gelada	6.34	2590	1660	56	65	408	250	180	244	570	0.01	380
3	A5	Baraya Nana	6.69	2652	1700	24	48	491	202	90	244	522	0.01	240
4	A6	Pragpar	7.04	1934	1240	28	29	358	67	120	180	367	0.00	270
5	A7	Toda	6.78	4914	3150	172	163	621	317	240	336	1332	0.02	1230
7	A9	Gundala	7.20	2902	1860	84	48	480	115	150	393	651	0.20	150
8	A11	Ragha	6.91	7160	4590	24	77	1475	613	120	488	1750	0.41	500
9	B1	Desalpar	6.50	2543	1630	68	34	443	240	240	110	313	0.02	340
10	B2	Bhujpur Moti	9.70	2184	1400	12	53	388	210	120	180	480	0.06	490
11	B3	Bhujpur Moti	7.22	1981	1270	44	24	360	134	180	210	410	0.48	160
12	B4	Samagogha	6.83	1919	1230	12	24	382	48	260	210	361	4.22	60
13	B5	Samagogha	6.99	1981	1270	28	22	383	144	60	244	442	5.30	200
14	B6	Kapaya Mota	6.91	2652	1700	16	24	547	77	120	430	510	5.51	90
15	B7	Bhorara	5.52	807	517	16	46	80	96	60	61	180	4.14	260
16	B8	Bhorara	6.48	2044	1310	20	48	356	192	120	210	320	5.90	240
17	B9	Gundala	7.49	3214	2060	12	17	694	106	150	305	864	8.35	180
18	B10	Ragha	6.68	4165	2670	44	53	808	307	60	519	940	5.35	430
19	B11	Ragha	6.37	4555	2920	80	106	755	902	60	336	773	5.22	970
20	B12	Luni	7.04	983	630	16	17	176	90	60	120	180	3.98	230
21	C1	Bhujpur Moti	7.15	2168	1390	20	29	421	134	180	210	456	5.99	170
22	C2	Bhujpur Moti	7.04	2293	1470	92	34	358	240	30	260	510	5.86	440

ANNEXURE 7.11

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	$NO3^{-}$ mg/l	Total Hardness as CaCO3 mg/l
23	C3	Bhujpur Nani	7.27	3245	2080	60	96	495	260	160	275	828	3.93	380
24	C4	Pratappar	7.78	2215	1420	36	22	428	163	180	220	450	2.28	160
25	C5	Samagogha	7.35	2044	1310	28	22	397	178	90	250	428	1.86	260
26	C6	Kapaya Mota	6.99	1700	1090	32	24	309	125	210	427	425	2.45	100
27	C7	Mangra	6.59	616	395	20	14	91	0	90	80	120	3.13	90
28	C8	Mangra	6.65	1265	811	44	58	130	150	90	120	250	5.97	360
29	C9	Sadau	6.98	1669	1070	24	68	227	77	90	197	372	4.83	140
30	C11	Luni	7.16	4212	2700	24	26	892	48	60	488	1189	2.52	160
31	C12	Luni	6.91	927	594	16	14	167	110	60	120	130	3.62	160
32	D1	Navinal	7.04	2324	1490	24	43	425	106	180	120	656	4.50	120
33	D2	Zarpara	6.74	2652	1700	24	22	542	154	90	180	775	4.35	300
34	D3	Zarpara	7.05	3682	2360	24	67	692	182	120	260	1080	1.86	410
35	D4	Zarpara	7.51	4259	2730	16	26	912	67	150	275	1260	3.65	240
36	D5	Dhrab	6.62	4181	2680	44	55	807	115	180	183	1284	4.92	370
37	D6	Kapaya Nana	6.62	2933	1880	24	36	579	180	120	210	780	4.94	250
38	D7	Mundra	8.66	1787	1146	20	0	389	134	150	305	213	2.65	110
39	D8	Baroi	5.96	1147	735	32	34	163	125	120	396	496	6.73	260
40	D9	Goyarsama	6.41	2371	1520	28	50	417	29	120	213	646	4.50	330
41	E1	Navinal	6.19	9500	6090	96	202	1692	269	90	275	3191	1.96	500
42	E2	Navinal	6.38	2839	1820	28	60	507	202	150	183	720	1.47	210
43	E3	Zarpara	5.91	7332	4700	432	540	157	1033	90	122	1583	2.22	4300
44	E4	Zarpara	6.10	9906	6350	168	211	1684	1277	270	153	2162	2.40	1730
46	E6	Dhrab	6.26	3947	2530	52	58	739	67	60	397	1205	1.02	350
47	E7	Mundra	8.87	7009	4493	44	0	1564	125	120	396	1599	1.27	220

ANNEXURE 7.12

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Winter, 2009)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	$NO3^{-}$ mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	7.00	2324	1490	44	22	443	326	90	214	620	3.93	370
2	A2	Gelada	6.94	2948	1890	104	0	560	288	150	397	798	4.29	380
3	A5	Baraya Nana	6.90	2948	1890	68	36	532	365	60	92	780	2.83	440
4	A6	Pragpar	6.91	2200	1410	44	19	419	336	90	519	390	1.94	280
5	A7	Toda	6.95	5928	3800	180	46	1071	365	90	122	1773	1.88	310
7	A9	Gundala	7.03	2995	1920	28	22	616	1248	30	580	603	3.94	1270
8	A11	Ragha	7.03	7644	4900	56	36	1628	182	30	580	2552	4.71	150
9	B1	Desalpar	7.12	2636	1690	40	22	520	566	90	305	744	3.57	650
10	B2	Bhujpur Moti	7.08	2652	1700	64	26	487	221	180	214	620	3.03	270
11	B3	Bhujpur Moti	7.26	2683	1720	32	0	581	528	120	488	620	2.58	470
12	B4	Samagogha	7.47	2652	1700	24	0	583	230	120	671	443	2.08	210
13	B5	Samagogha	7.37	2262	1450	28	41	411	250	120	305	620	3.69	110
14	B6	Kapaya Mota	7.76	3026	1940	20	0	674	307	90	793	532	5.75	280
15	B7	Bhorara	7.63	998	640	40	22	143	307	90	275	195	2.30	270
16	B8	Bhorara	7.53	2215	1420	24	24	437	278	180	366	532	9.67	190
17	B9	Gundala	7.15	3588	2300	136	0	670	202	30	671	1365	11.77	150
18	B10	Ragha	7.01	4524	2900	104	72	785	125	60	458	1985	0.43	410
19	B11	Ragha	6.90	6084	3900	120	72	1126	1085	120	366	195	3.88	1190
20	B12	Luni	7.32	1154	740	24	0	238	298	120	458	549	0.30	200
21	C1	Bhujpur Moti	7.71	2340	1500	16	22	479	134	30	427	762	3.51	70
22	C2	Bhujpur Moti	7.23	2683	1720	28	82	430	288	120	275	1046	4.46	280

ANNEXURE 7.12

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	$NO3^{-}$ mg/l	Total Hardness as CaCO3 mg/l
23	C3	Bhujpur Nani	7.07	3588	2300	60	26	707	422	90	701	319	2.04	410
24	C4	Pratappar	7.51	2293	1470	32	14	464	154	120	366	461	1.90	110
25	C5	Samagogha	7.44	2278	1460	12	24	465	230	150	580	355	1.36	150
26	C6	Kapaya Mota	7.63	1966	1260	28	0	421	173	90	366	124	3.89	70
27	C7	Mangra	7.82	702	450	12	0	148	163	60	275	301	1.36	80
28	C8	Mangra	7.46	1498	960	28	46	225	288	120	305	727	9.09	250
29	C9	Sadau	7.54	1732	1110	24	12	348	125	180	336	567	6.11	130
30	C11	Luni	7.32	2902	1860	20	0	645	125	150	275	869	0.87	100
32	D1	Navinal	7.44	2590	1660	20	0	574	182	60	458	691	3.21	130
33	D2	Zarpara	7.50	3073	1970	36	19	630	317	90	305	815	0.33	270
34	D3	Zarpara	7.23	4056	2600	52	38	801	413	120	458	1383		450
35	D4	Zarpara	7.13	4992	3200	48	24	1049	384	90	519	1418	1.67	320
36	D5	Dhrab	7.25	4680	3000	68	29	945	509	90	366	1684	2.72	480
37	D6	Kapaya Nana	7.27	3432	2200	20	31	708	182	60	641	727	8.99	150
38	D7	Mundra	7.67	1622	1040	116	132	0	221	30	519	301	10.93	90
39	D8	Baroi	7.34	1420	910	24	48	207	182	60	336	319	4.02	180
40	D9	Goyarsama	7.35	2558	1640	28	890	0	365	120	305	727	3.37	280
41	E1	Navinal	7.00	8736	5600	20	0	1990	1046	30	366	3687	0.00	1100
42	E2	Navinal	7.28	2512	1610	28	19	510	259	60	366	674	0.00	280
43	E3	Zarpara	6.26	17160	11000	388	197	3130	3994	60	244	8189	1.40	4300
44	E4	Zarpara	6.60	11232	7200	316	34	2160	1718	60	275	4165	1.07	1750
45	E5	Dhrab	7.09	3900	2500	28	43	783	230	90	427	1064	0.78	270
46	E6	Dhrab	7.30	3588	2300	24	31	739	326	90	336	993	0.75	290
47	E7	Mundra	7.42	3136	2010	32	19	649	250	120	427	957	0.82	260

ANNEXURE 7.13

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Pre Monsoon, 2009)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	$NO3^{-}$ mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	7.80	2855	1830	40	170	285	442	90	214	639	3.63	400
3	A5	Baraya Nana	7.80	4680	3000	52	29	963	451	138	458	960	2.78	360
4	A6	Pragpar	7.50	2746	1760	36	29	536	236	60	268	638	2.12	260
5	A7	Toda	7.80	8424	5400	232	36	1605	1517	60	244	1730	0.89	1590
6	A8	Bhorara	8.00	1201	770	20	252	0	230	90	244	408	2.42	250
7	A9	Gundala	7.60	3900	2500	40	144	576	211	60	641	922	4.05	200
8	A11	Ragha	7.30	8736	5600	60	84	1783	595	120	519	1879	4.74	600
9	B1	Desalpar	8.10	3432	2200	40	94	565	384	120	275	740	1.75	300
10	B2	Bhujpur Moti	7.90	2995	1920	56	269	110	376	60	375	681	3.06	500
11	B3	Bhujpur Moti	7.80	2496	1600	20	310	0	192	60	510	549		150
12	B4	Samagogha	8.40	2543	1630	28	103	356	221	30	480	443	1.94	90
13	B5	Samagogha	8.10	2777	1780	44	36	520	336	90	305	510	3.75	250
14	B6	Kapaya Mota	7.90	3744	2400	20	94	660	202	30	610	746	4.20	150
16	B8	Bhorara	8.00	2746	1760	36	55	485	269	90	340	560	4.86	210
17	B9	Gundala	8.10	4680	3000	32	17	1009	269	120	519	1050	10.75	200
18	B10	Ragha	7.80	5616	3600	12	168	958	394	60	641	1361	3.34	380
19	B11	Ragha	7.80	7800	5000	84	380	972	942	30	519	2345		1200
20	B12	Luni	8.20	1466	940	40	0	292	173	60	458	1117	0.83	110
21	C1	Bhujpur Moti	8.00	2933	1880	24	89	478	202	120	410	598	3.26	110
22	C2	Bhujpur Moti	8.10	3104	1990	32	346	16	259	60	427	869	4.14	260
23	C3	Bhujpur Nani	7.80	4212	2700	40	26	874	259	30	488	1050	2.16	300

ANNEXURE 7.13

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	$NO3^{-}$ mg/l	Total Hardness as CaCO3 mg/l
24	C4	Pratappar	8.00	2777	1780	32	0	603	202	90	763	585	2.05	120
25	C5	Samagogha	8.10	2808	1800	20	48	532	182	90	488	520	2.17	90
26	C6	Kapaya Mota	8.20	2621	1680	24	46	489	115	90	440	479	4.52	100
27	C7	Mangra	8.40	858	550	28	0	165	384	60	336	408	2.45	310
28	C8	Mangra	8.20	2075	1330	40	130	184	221	60	366	310	10.14	140
29	C9	Sadau	8.20	2075	1330	24	50	354	384	90	458	532	6.00	350
30	C11	Luni	7.70	6755	4330	36	34	1450	278	90	275	2140	2.17	270
33	D2	Zarpara	7.60	3432	2200	28	41	680	278	120	275	869	1.93	510
34	D3	Zarpara	7.50	5304	3400	56	58	1047	365	60	549	1258	1.09	290
35	D4	Zarpara	7.70	5928	3800	36	173	993	461	60	671	1490	1.48	410
36	D5	Dhrab	7.50	6084	3900	48	60	1231	211	60	366	1773	2.62	140
37	D6	Kapaya Nana	7.80	4368	2800	36	31	905	298	60	763	798	7.89	140
38	D7	Mundra	8.10	2122	1360	44	12	415	242	60	325	355	2.62	220
39	D8	Baroi	8.10	1654	1060	32	194	0	210	90	280	310	8.53	310
40	D9	Goyarsama	8.00	3276	2100	28	36	653	293	60	250	750		910
41	E1	Navinal	7.20	7488	4800	100	155	1313	269	90	275	2393		230
42	E2	Navinal	8.30	3276	2100	28	120	492	307	90	275	656	0.56	480
43	E3	Zarpara	7.00	17160	11000	484	226	2605	2739	90	275	4617	1.21	4590
44	E4	Zarpara	7.10	12480	8000	184	58	2553	1480	90	336	3573	1.23	1730
45	E5	Dhrab	7.80	4524	2900	24	72	877	365	90	366	1205	1.06	260
46	E6	Dhrab	8.10	4352	2790	36	233	515	250	120	336	1099	0.62	260
47	E7	Mundra	7.40	4368	2800	36	74	822	202	60	549	975		270

ANNEXURE 7.14

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Post Monsoon, 2009)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	NO3- mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	6.80	2824	1810	64	14	540	499	90	240	266	1.6	430
2	A2	Gelada	6.80	3276	2100	60	55	569	346	150	519	230	1.5	260
3	A5	Baraya Nana	7.50	2652	1700	72	14	492	380	120	340	319	1.2	400
4	A6	Pragpar	7.20	4212	2700	36	29	860	547	150	519	540	1.1	460
5	A7	Toda	7.00	11304	7246	32	266	2021	2995	60	153	284	1.1	3020
7	A9	Gundala	7.00	3744	2400	200	5	611	365	90	824	230	0.7	240
8	A11	Ragha	6.60	9516	6100	80	144	1824	739	90	763	1779	1.5	690
9	B1	Desalpar	7.20	3432	2200	4	41	697	346	120	397	674	1.7	270
10	B2	Bhujpur Moti	7.00	2746	1760	72	12	518	490	30	310	372	1.4	410
11	B3	Bhujpur Moti	7.10	3276	2100	24	29	661	278	90	402	630	1.5	150
12	B4	Samagogha	7.50	3120	2000	24	38	608	230	120	465	585	1.3	90
13	B5	Samagogha	7.50	2792	1790	20	12	588	307	60	571	230	1.3	210
14	B6	Kapaya Mota	8.60	4056	2600	72	17	806	307	120	546	710	1.5	200
15	B7	Bhorara	7.10	1310	840	60	5	219	140	60	129	266	1.5	270
16	B8	Bhorara	7.20	2808	1800	52	12	555	250	120	310	514	1.3	210
17	B9	Gundala	6.90	4836	3100	40	24	1007	317	90	702	980	1.8	190
18	B10	Ragha	6.70	4524	2900	40	62	877	538	180	549	668	2.8	430
19	B11	Ragha	7.00	2761	1770	36	36	526	269	60	610	230	1.5	190
20	B12	Luni	7.10	2122	1360	20	12	436	146	60	140	479	1.4	230
21	C1	Bhujpur Moti	7.50	2995	1920	16	7	648	259	150	458	479	1.0	110
22	C2	Bhujpur Moti	7.00	3276	2100	24	17	684	310	120	488	510	1.0	300
23	C3	Bhujpur Nani	6.50	4992	3200	52	19	1037	432	150	488	943	1.5	400

ANNEXURE 7.14

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	NO3- mg/l	Total Hardness as CaCO3 mg/l
24	C4	Pratappar	7.40	2558	1640	8	5	563	211	120	368	443	1.2	90
25	C5	Samagogha	7.90	2839	1820	44	7	581	202	120	411	443	1.1	140
26	C6	Kapaya Mota	8.00	2714	1740	12	7	589	163	150	324	520	1.3	60
27	C7	Mangra	7.50	1045	670	24	10	191	221	90	519	266	1.5	90
28	C8	Mangra	6.80	2012	1290	80	10	347	226	90	210	408	1.5	300
29	C9	Sadau	7.30	2153	1380	8	14	452	173	90	340	390	1.8	90
30	C11	Luni	7.60	4836	3100	16	10	1062	269	30	610	956	2.0	140
31	C12	Luni	7.10	2122	1360	36	10	422	224	30	354	380	1.2	200
33	D2	Zarpara	7.20	3744	2400	44	14	772	326	60	395	886	1.6	260
34	D3	Zarpara	7.10	5304	3400	48	19	1113	499	30	510	1090	0.7	440
35	D4	Zarpara	7.90	7020	4500	52	24	1489	365	90	671	1508	1.1	300
36	D5	Dhrab	7.60	6240	4000	60	24	1303	499	90	458	1225	1.0	450
37	D6	Kapaya Nana	7.60	4212	2700	28	12	902	211	150	624	815	1.0	150
38	D7	Mundra	7.30	1170	750	16	0	251	134	60	180	213	1.0	30
39	D8	Baroi	7.00	1763	1130	40	12	331	230	90	458	337	2.2	200
40	D9	Goyarsama	6.80	3588	2300	48	22	730	317	60	549	567	1.0	360
41	E1	Navinal	7.40	9360	6000	140	60	1880	1171	90	427	2201	2.6	1200
42	E2	Navinal	7.60	3276	2100	36	22	661	288	180	340	674	1.6	190
43	E3	Zarpara	6.80	12012	7700	568	580	1002	1602	30	366	2261	1.0	160
44	E4	Zarpara	7.30	9984	6400	210	170	1373	1555	30	427	1714	1.0	1650
45	E5	Dhrab	8.20	4680	3000	40	14	990	317	90	602	1052	1.0	250
46	E6	Dhrab	7.80	4368	2800	40	12	923	384	120	488	820	1.1	320
47	E7	Mundra	6.90	4524	2900	36	12	978	298	90	702	762		190

ANNEXURE 7.15

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Winter, 2010)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	NO3- mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	7.00	3011	1930	52	17	602	298	90	458	248	3.6	350
2	A2	Gelada	7.00	3744	2400	60	17	761	355	60	702	461	1.5	340
3	A5	Baraya Nana	7.40	2714	1740	92	10	501	346	30	610	425	2.5	410
4	A6	Pragpar	7.70	4056	2600	52	19	838	336	60	488	284	1.5	390
5	A7	Toda	7.40	15600	10000	776	43	2619	1459	60	183	266		3490
7	A9	Gundala	7.40	3744	2400	28	5	821	240	60	793	425		200
8	A11	Ragha	7.10	10140	6500	108	65	2088	893	60	519	408	3.1	940
9	B1	Desalpar	7.10	3588	2300	60	26	707	384	90	336	408	4.2	370
10	B2	Bhujpur Moti	7.20	3042	1950	20	12	655	346	90	762	496	2.2	350
11	B3	Bhujpur Moti	7.20	3588	2300	36	24	739	192	90	244	408	2.5	180
12	B4	Samagogha	7.80	2902	1860	24	5	632	134	90	945	355	2.5	60
13	B5	Samagogha	7.70	2761	1770	32	12	576	106	60	427	496	0.6	220
14	B6	Kapaya Mota	7.30	3588	2300	24	0	799	67	90	1251	408	3.2	80
15	B7	Bhorara	7.40	1248	800	40	12	219	173	90	885	762	3.5	230
16	B8	Bhorara	7.40	2699	1730	20	7	585	230	60	702	479	1.8	190
17	B9	Gundala	7.40	5304	3400	40	12	1153	192	120	336	266	4.7	240
18	B10	Ragha	7.60	2902	1860	76	14	553	173	30	701	496	2.0	260
19	B11	Ragha	7.40	3432	2200	40	14	717	173	90	549	461	2.6	160
20	B12	Luni	7.30	2964	1900	40	19	600	211	90	824	355	2.1	270
21	C1	Bhujpur Moti	7.50	3120	2000	20	5	687	144	30	549	425	0.5	130
22	C2	Bhujpur Moti	7.30	3276	2100	36	24	667	211	90	488	372	2.7	290
23	C3	Bhujpur Nani	7.20	4524	2900	48	22	946	374	90	549	585	4.2	390

ANNEXURE 7.15

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	NO3- mg/l	Total Hardness as CaCO3 mg/l
24	C4	Pratappar	7.40	2558	1640	20	10	548	106	120	1098	372	1.6	100
25	C5	Samagogha	7.50	2683	1720	28	7	572	96	150	641	372	1.2	100
26	C6	Kapaya Mota	7.80	2512	1610	32	12	519	96	120	793	425	1.7	90
27	C7	Mangra	7.90	889	570	12	10	173	144	90	488	213	2.6	70
28	C8	Mangra	7.30	2090	1340	72	24	353	365	60	549	390	2.5	430
29	C9	Sadau	7.70	2340	1500	16	10	502	144	120	702	284	9.2	140
30	C11	Luni	7.70	6084	3900	32	22	1323	250	120	884	496	6.1	210
33	D2	Zarpara	7.30	3588	2300	44	22	735	259	60	427	549	2.3	280
34	D3	Zarpara	7.30	4836	3100	68	24	990	480	60	580	425	1.1	480
35	D4	Zarpara	7.70	6864	4400	40	29	1480	365	90	641	479		360
36	D5	Dhrab	7.10	6552	4200	68	2	1427	470	90	366	355	1.2	500
37	D6	Kapaya Nana	7.20	4056	2600	68	12	833	202	120	946	603	0.6	170
38	D7	Mundra	7.90	1045	670	32	7	190	154	150	580	284	0.7	60
39	D8	Baroi	7.30	1716	1100	28	7	349	250	150	305	319	1.9	200
40	D9	Goyarsama	7.30	3089	1980	28	22	638	269	90	458	514	8.4	270
41	E1	Navinal	7.10	9984	6400	140	84	1978	1267	60	396	230	1.0	1410
42	E2	Navinal	7.30	3432	2200	28	10	740	298	120	366	425	8.8	270
43	E3	Zarpara	7.00	15600	10000	496	372	2310	2429	60	244	390	3.2	4900
44	E4	Zarpara	7.00	13104	8400	360	26	2554	1632	120	336	53	0.2	1770
45	E5	Dhrab	7.00	4524	2900	52	17	950	288	60	610	1152	0.1	300
46	E6	Dhrab	7.20	4212	2700	36	17	897	374	90	458	443	0.5	420
47	E7	Mundra	7.00	4368	2800	24	24	933	182	120	641	727	0.4	250

ANNEXURE 7.16

(1 of 2)

Groundwater Chemistry of Observation Wells of Core Area (Pre Monsoon, 2010)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	NO3- mg/l	Boron mg/l	Total Hardness as CaCO3 mg/l
1	A1	Desalpar	6.90	2964	1900	40	53	536	307	30	488	372	3.37	0.2	350
2	A2	Gelada	7.20	2964	1900	16	10	646	269	60	470	514	2.97	2.8	200
3	A5	Baraya Nana	7.60	2543	1630	40	17	508	365	30	460	340	1.49	2	340
4	A6	Pragpar	7.80	2855	1830	24	12	607	240	60	488	470	1.87	0.6	200
7	A9	Gundala	7.90	3588	2300	12	12	790	173	90	610	680	2.71	1.2	90
8	A11	Ragha	7.10	8580	5500	84	14	1852	826	60	580	1632	3.86	1.2	780
9	B1	Desalpar	7.10	3011	1930	36	12	629	317	90	519	461	4.42	0.8	240
10	B2	Bhujpur Moti	7.30	2886	1850	60	19	559	490	30	336	496	3.02	1.8	400
11	B3	Bhujpur Moti	7.40	2839	1820	32	17	585	144	120	480	514	3.00	1	80
12	B4	Samagogha	8.00	2902	1860	28	0	636	211	90	507	450	3.57	0.6	40
13	B5	Samagogha	8.00	2605	1670	32	10	545	278	90	410	410	2.68	0.4	190
14	B6	Kapaya Mota	7.40	3744	2400	24	0	835	163	120	776	479	4.04	1	90
15	B7	Bhorara	7.60	1154	740	20	12	220	178	60	297	213	4.63	0.2	190
16	B8	Bhorara	7.40	2543	1630	36	12	521	250	90	410	443	3.63	0.6	170
17	B9	Gundala	7.50	4212	2700	24	5	934	240	30	763	620	6.21	1	180
18	B10	Ragha	7.50	5772	3700	44	22	1238	413	30	701	1143	3.45	1	360
19	B11	Ragha	7.10	6240	4000	44	66	1260	374	30	514	1860	5.40	2	300
20	B12	Luni	7.50	3588	2300	32	0	790	173	90	518	567	1.32	0.8	100
21	C1	Bhujpur Moti	7.30	2855	1830	28	10	607	278	30	580	372	2.63	0.4	250
22	C2	Bhujpur Moti	7.30	3276	2100	44	31	644	624	30	458	355	2.10	0.5	560
23	C3	Bhujpur Nani	7.40	4212	2700	64	12	874	336	30	610	730	1.37	1.4	290
24	C4	Pratappar	7.40	2496	1600	20	0	552	211	60	460	443	3.76	1.2	130

ANNEXURE 7.16

(2 of 2)

Sr. No.	Code	Village	pH	EC µs/cm	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	$SO4^{-}$ mg/l	$CO3^{-}$ mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	NO3- mg/l	Boron mg/l	Total Hardness as CaCO3 mg/l
25	C5	Samagogha	7.60	2605	1670	16	0	582	221	60	396	284	2.15	0.6	90
26	C6	Kapaya Mota	7.80	2402	1540	24	0	526	173	120	793	408	3.36	0.8	70
27	C7	Mangra	8.10	905	580	28	12	153	288	30	366	390	1.99	0.2	280
28	C8	Mangra	7.30	2012	1290	20	0	441	173	60	390	284	6.64	0.4	70
29	C9	Sadau	7.60	2075	1330	16	7	446	298	90	641	496	3.99	0.8	240
30	C11	Luni	7.50	5772	3700	44	19	1242	432	60	427	532	5.71	1.2	400
33	D2	Zarpara	7.40	4212	2700	24	14	915	221	90	610	743	3.20	1	210
34	D3	Zarpara	7.20	4680	3000	44	17	995	336	30	580	890	1.07	1.4	310
35	D4	Zarpara	7.20	6864	4400	96	12	1448	470	30	732	1366	0.94	1.6	430
36	D5	Dhrab	7.20	6708	4300	80	22	1412	470	60	335	1419	3.03	1	440
37	D6	Kapaya Nana	7.40	4056	2600	48	0	879	240	60	915	479	6.14	1.2	180
38	D7	Mundra	8.10	1498	960	20	0	322	182	30	310	160	2.05	0.6	70
39	D8	Baroi	7.40	1700	1090	28	10	341	210	30	340	240	5.12	0.6	170
40	D9	Goyarsama	7.50	2855	1830	8	12	625	221	60	397	730	3.77	0.4	180
41	E1	Navinal	7.10	8736	5600	152	166	1520	976	30	336	2450	8.57	3.2	1330
42	E2	Navinal	7.60	3276	2100	32	17	686	317	90	397	620	3.93	2.2	270
43	E3	Zarpara	6.80	15600	10000	696	86	2628	1918	60	640	3243	5.53	2.7	4300
44	E4	Zarpara	7.10	12480	8000	220	72	2484	1603	30	560	2884	3.39	2.2	1680
45	E5	Dhrab	7.40	4368	2800	20	7	969	278	60	427	1096	0.95	1.2	220
46	E6	Dhrab	7.40	4056	2600	36	156	594	336	30	410	1061	0.34	1.5	290
47	E7	Mundra	7.60	4836	3100	28	32	1021	211	60	580	1150	0.00	0.4	160

ANNEXURE 7.17
(1 of 2)

Groundwater TDS and Chloride Details of Observation Wells of GWRDC

Sr. No.	Village	Well Code	Total Dissolved Solids (mg/l)						Chloride (mg/l)					
			Pre Monsoon 1995	Post Monsoon 1995	Post Monsoon 2010	Pre Monsoon 2011	Post Monsoon 2011	Pre Monsoon 2012	Pre Monsoon 1995	Post Monsoon 1995	Post Monsoon 2010	Pre Monsoon 2011	Post Monsoon 2011	Pre Monsoon 2012
1	Mathada	KutCD~09	----	----	1160	970	680	1080	----	----	288	360	128	408
2	Naranpar	KutCD~13	----	----	1450	9070	1180	1480	----	----	512	5384	504	632
3	Vaghura	KutCD~15	----	----	1160	1130	830	1240	----	----	248	240	112	192
4	Kanzara	KutCD~16	----	----	1140	1120	640	1050	----	----	208	320	144	272
6	Viravaladia	HLT-033	4920	4220	3300	1010	1210	1960	1960	1960	1520	280	432	840
8	Nagavaladia	HLT-037	4420	4180	1980	3050	680	4360	1640	1800	520	1552	240	2240
9	Hatadi	HLT-040	2360	2300	2280	1980	1940	2250	880	760	560	408	480	640
11	Pavdiyaro	HLT-047	7100	6240	3460	4400	4730	4250	3000	2880	1304	1784	1400	1520
12	Vadala	HLT-052	2040	1660	1450	1490	1550	3170	680	472	304	488	664	1536
13	Ragha	HLT-056	4360	520	2680	3110	4340	3160	1760	104	600	800	1680	1320
14	Goyarsama	HLT-060	1280	5760	3070	1340	2490	1510	336	2440	320	304	640	400
15	Sadau	HLT-062	1200	1080	960	1370	1650	1420	240	256	184	360	384	400
17	Mota Kapaya	HLT-069	1600	1660	1890	1500	790	1420	200	312	424	184	400	496
19	Zarpara	HLT-071	6500		1950	3960	720	2770	2800		312	1864	320	1184
21	Nani Bhujpar	HLT-076	1920	1480	1430	2750	2750	2120	640	520	216	1264	1416	1080
22	Deshalpar	HLT-084	1800	1660	1240	2010	2030	2140	440	368	200	656	760	680
23	Tunda	HLT-087	3580	5000	2300	4920	3050	2690	1200	2160	368	2464	1160	840
24	Kandagara	HLT-093	2880	1080	950	3140	2920	2980	1136	344	248	1432	1320	1496

ANNEXURE 7.17

(2 of 2)

Sr. No .	Village	Well Code	Total Dissolved Solids (mg/l)						Chloride (mg/l)					
			Pre Monsoon 1995	Post Monsoon 1995	Post Monsoon 2010	Pre Monsoon 2011	Post Monsoon 2011	Pre Monsoon 2012	Pre Monsoon 1995	Post Monsoon 1995	Post Monsoon 2010	Pre Monsoon 2011	Post Monsoon 2011	Pre Monsoon 2012
25	Khakhar	HLT-095	880	900	1070	2700	2600	3860	160	152	264	1304	1136	2080
29	Mathak	KC-23	----	----	1130	3460	1710	1340	----	----	488	1872	352	600
30	Vira	KC-24	4480	4800	1240	3650	2100	2770	1840	2168	496	1720	544	1248
31	Chandroda	KC-25	1340	1500	3400	4490	3330	4440	360	440	1840	2400	1600	2024
32	Khambhra	KC-26	960	860	1490	1560	920	1130	280	256	400	544	312	480
33	Bharapar	KC-33	480	480	720	750	930	590	104	96	160	176	280	208
34	Chakar	KC-34	2040	1280	1540	1220	1400	1650	800	410	440	608	680	744
35	Lifra	KC-35	1600	1600	910	800	2520	1110	472	560	200	216	1056	280
36	Patri	KC-36	1340	1720	1700	1860	1630	950	416	560	536	400	520	328
37	Bhadreshvar	KC-37	1540	1760	790	3210	680	720	472	600	192	1560	136	224
38	Gundala	KC-38	----	----	1640	1520	1440	1380	----	----	280	400	304	336
39	Mundra	KC-39	2940	3000	2270	2570	2320	2080	1040	960	784	1120	1072	1064
40	Ramania	KC-42	3840	4200	2440	3220	2510	1200	1600	1640	680	1008	496	304
41	Beraja	KC-43	1600	1500	2490	2620	2130	2460	344	440	960	1136	952	976
42	Asambia	KC-45	----	----	1000	940	1140	980	----	----	448	440	560	416
47	Lakhapar	SHP/203	----	----	2170	2260	2150	2730	----	----	880	1104	864	1320
48	Bhujpur (M)	KC-40	1020	860	1280	1590	1010	1380	280	256	400	504	392	464
51	Meghpar	KCT-11	2760	2560	2570		760	950	1000	900	440		280	424
52	Deshalpar	KCT-12	1600	1280	3270	2130	1490	2580	344	296	440	480	296	1360

ANNEXURE 9.1
(1 of 2)

Observed Water Table Fluctuation (m) in Core Study Area

Sr. No.	Code	Village	Total Depth (m)	RL (m)	Winter, 08	Pre Monsoon, 08	Post monsoon, 08	Winter, 09	Pre Monsoon, 09	Post monsoon, 09	Winter, 10	Pre Monsoon, 10
1	A1	Desalpar	149	38	91.5	91.5	70.1	80.5	81.1	76.2	83.4	85.4
2	A2	Gelada	131	40.5	61.0	76.2	71.5	61.0	76.8	72.4	85.0	85.0
3	A5	Baraya Nana	137	37.5	95.0	97.7	94.5	97.3	98.2	73.2	79.6	82.5
4	A6	Pragpar	63	37.5	.----.	50.3	51.5	53.0	65.5	45.7	50.6	54.9
5	A7	Toda	88	40	45.7	59.5	43.4	50.1	76.2	57.9	--	--
6	A8	Bhorara	84	39	45.7	49.0	21.3	--	--	--	--	--
7	A9	Gundala	76	33	30.5	33.2	21.8	22.9	27.4	20.5	28.4	24.9
8	A11	Ragha	82	26	21.3	22.8	18.6	24.4	24.4	21.3	22.5	24.4
9	B1	Desalpar	146	30	68.6	71.5	67.1	71.0	74.0	61.5	74.4	76.0
10	B2	Bhujpur Moti	137	31.5	106.7	106.7	106.7	106.7	107.3	106.7	106.6	106.8
11	B3	Bhujpur Moti	146	32	39.6	45.7	53.4	--	--	--	--	--
12	B4	Samagogha	107	31.5	53.4	72.4	45.7	76.2	91.5	76.2	76.5	73.2
13	B5	Samagogha	95	35	61.0	64.0	61.0	61.8	68.6	61.0	67.2	70.0
14	B6	Kapaya Mota	91	33	54.9	54.9	58.4	68.0	76.2	67.1	65.9	64.0
15	B7	Bhorara	122	30	51.8	53.3	53.3	79.3	84.1	76.2	76.8	78.8
16	B8	Bhorara	122	26	48.8	53.4	44.2	47.0	48.8	42.7	43.2	48.1
17	B9	Gundala	98	29	45.7	53.3	51.3	67.0	72.0	51.8	48.2	48.8
18	B10	Ragha	70	22	21.3	24.4	21.3	24.4	24.0	22.4	23.0	24.4
19	B11	Ragha	35	19	18.3	20.3	16.8	17.0	18.0	15.2	16.3	16.8
20	B12	Luni	10	17	6.1	7.0	6.3	7.0	9.0	8.5	9.2	9.6
21	C1	Bhujpur Moti	130	22.5	68.6	71.0	56.0	68.6	76.2	--	--	84.0
22	C2	Bhujpur Moti	113	24	96.0	98.8	76.2	83.6	91.5	81.8	84.1	86.4
23	C3	Bhujpur Nani	128	20	83.8	--	--	106.9	--	91.5	--	--

ANNEXURE 9.1

(2 of 2)

Sr. No.	Code	Village	Total Depth (m)	RL m	Winter, 08	Pre Monsoon, 08	Post monsoon, 08	Winter, 09	Pre Monsoon, 09	Post monsoon, 09	Winter, 10	Pre Monsoon, 10
24	C4	Pratappar	61	14	54.9	52.3	45.7	54.0	54.9	45.7	50.2	54.9
25	C5	Samagogha	122	19	54.9	85.4	61.0	67.0	70.5	67.1	67.1	73.8
26	C6	Kapaya Mota	91	23	45.7	45.7	38.1	45.6	--	48.8	--	--
27	C7	Mangra	112	20	30.5	46.0	31.0	41.0	47.1	48.0	67.9	57.9
28	C8	Mangra	91	19.5	48.8	48.8	44.9	45.0	61.0	54.9	59.6	61.0
29	C9	Sadau	91	18	61.0	--	--	--	61.0	--	--	--
30	C11	Luni	46	15	--	15.2	--	16.8	19.8	15.2	16.8	17.8
31	C12	Luni	9	16	5.0	5.5	4.8	--	--	6.0	--	--
32	D1	Navinal	107	15	64.7	--	67.4	71.5	73.2	67.8	68.0	69.8
33	D2	Zarpara	152	12.5	61.0	70.1	68.2	60.5	76.2	67.1	69.0	76.7
34	D3	Zarpara	122	10.5	76.2	83.8	79.3	79.3	79.3	67.1	74.2	81.7
35	D4	Zarpara	128	10.5	48.8	54.9	53.4	50.0	54.9	54.9	57.5	61.0
36	D5	Dhrab	52	9	30.5	33.5	36.6	30.5	36.6	28.7	39.1	44.3
37	D6	Kapaya Nana	99	10	30.0	31.0	33.5	33.5	36.6	30.5	34.8	36.5
38	D7	Mundra	73	15	32.9	38.1	27.3	30.5	38.1	31.2	39.8	45.7
39	D8	Baroi	58	15	33.5	36.6	39.6	39.6	39.6	33.5	37.7	39.6
40	D9	Goyarsama	61	12	25.9	30.5	24.5	36.6	24.4	21.3	26.4	36.6
41	E1	Navinal	110	9	38.1	51.1	38.1	35.1	38.1	35.1	38.1	38.1
42	E2	Navinal	107	9	38.1	38.1	38.1	30.5	39.6	30.5	33.3	42.7
43	E3	Zarpara	107	8	82.3	83.8	65.4	91.5	91.5	76.2	79.3	82.2
44	E4	Zarpara	122	7.5	54.9	70.1	51.8	60.0	71.6	64.0	62.2	74.9
45	E5	Dhrab	107	6	45.7	54.9	48.8	45.7	53.6	45.7	52.3	61.0
46	E6	Dhrab	137	5	42.7	42.8	27.4	51.0	52.3	42.7	42.7	42.7
47	E7	Mundra	107	5	18.4	19.0	18.3	24.0	45.7	36.6	36.6	36.6

ANNEXURE 9.2

(1 of 2)

Computed Reduced Water Level (m) in Core Study Area

Sr. No.	Code	Village	RL m	Winter, 08	Pre Monsoon, 08	Post Monsoon, 08	Winter, 09	Pre Monsoon, 09	Post Monsoon, 09	Winter, 10	Pre Monsoon, 10
1	A1	Desalpar	38	-53.5	-53.5	-32.1	-42.5	-43.1	-38.2	-45.4	-47.4
2	A2	Gelada	40.5	-20.5	-35.7	-31.0	-20.5	-36.3	-31.9	-44.5	-44.5
3	A5	Baraya Nana	37.5	-57.5	-60.2	-57.0	-59.8	-60.7	-35.7	-42.1	-45.0
4	A6	Pragpar	37.5	----	-12.8	-14.0	-15.5	-28.0	-8.2	-13.1	-17.4
5	A7	Toda	40	-5.7	-19.5	-3.4	-10.1	-36.2	-17.9	----	----
6	A8	Bhorara	39	-6.7	-10.0	17.7	----	----	----	----	----
7	A9	Gundala	33	2.5	-0.2	11.2	10.1	5.6	12.5	4.6	8.1
8	A11	Ragha	26	4.7	3.2	7.4	1.6	1.6	4.7	3.5	1.6
9	B1	Desalpar	30	-38.6	-41.5	-37.1	-41.0	-44.0	-31.5	-44.4	-46.0
10	B2	Bhujpur Moti	31.5	-75.2	-75.2	-75.2	-75.2	-75.8	-75.2	-75.1	-75.3
11	B3	Bhujpur Moti	32	-7.6	-13.7	-21.4	----	----	----	----	----
12	B4	Samagogha	31.5	-21.9	-40.9	-14.2	-44.7	-60.0	-44.7	-45.0	-41.7
13	B5	Samagogha	35	-26.0	-29.0	-26.0	-26.8	-33.6	-26.0	-32.2	-35.0
14	B6	Kapaya Mota	33	-21.9	-21.9	-25.4	-35.0	-43.2	-34.1	-32.9	-31.0
15	B7	Bhorara	30	-21.8	-23.3	-23.3	-49.3	-54.1	-46.2	-46.8	-48.8
16	B8	Bhorara	26	-22.8	-27.4	-18.2	-21.0	-22.8	-16.7	-17.2	-22.1
17	B9	Gundala	29	-16.7	-24.3	-22.3	-38.0	-43.0	-22.8	-19.2	-19.8
18	B10	Ragha	22	0.7	-2.4	0.7	-2.4	-2.0	-0.4	-1.0	-2.4
19	B11	Ragha	19	0.7	-1.3	2.2	2.0	1.0	3.8	2.7	2.2
20	B12	Luni	17	10.9	10.0	10.7	10.0	8.0	8.5	7.8	7.4
21	C1	Bhujpur Moti	22.5	-46.1	-48.5	-33.5	-46.1	-53.7	----	----	-61.5
22	C2	Bhujpur Moti	24	-72.0	-74.8	-52.2	-59.6	-67.5	-57.8	-60.1	-62.4
23	C3	Bhujpur Nani	20	-63.8	----	----	-86.9	----	-71.5	----	----

ANNEXURE 9.2

(2 of 2)

Sr. No.	Code	Village	RL m	Winter, 08	Pre Monsoon, 08	Post Monsoon, 08	Winter, 09	Pre Monsoon, 09	Post Monsoon, 09	Winter, 10	Pre Monsoon, 10
24	C4	Pratappar	14	-40.9	-38.3	-31.7	-40.0	-40.9	-31.7	-36.2	-40.9
25	C5	Samagogha	19	-35.9	-66.4	-42.0	-48.0	-51.5	-48.1	-48.1	-54.8
26	C6	Kapaya Mota	23	-22.7	-22.7	-15.1	-22.6	----	-25.8	----	----
27	C7	Mangra	20	-10.5	-26.0	-11.0	-21.0	-27.1	-28.0	-47.9	-37.9
28	C8	Mangra	19.5	-29.3	-29.3	-25.4	-25.5	-41.5	-35.4	-40.1	-41.5
29	C9	Sadau	18	-43.0	----	----	----	-43.0	----	----	----
30	C11	Luni	15	----	-0.2	----	-1.8	-4.8	-0.2	-1.8	-2.8
31	C12	Luni	16	11.0	10.5	11.2	----	----	10.0	----	----
32	D1	Navinal	15	-49.7	----	-52.4	-56.5	-58.2	-52.8	-53.0	-54.8
33	D2	Zarpara	12.5	-48.5	-57.6	-55.7	-48.0	-63.7	-54.6	-56.5	-64.2
34	D3	Zarpara	10.5	-65.7	-73.3	-68.8	-68.8	-68.8	-56.6	-63.7	-71.2
35	D4	Zarpara	10.5	-38.3	-44.4	-42.9	-39.5	-44.4	-44.4	-47.0	-50.5
36	D5	Dhrab	9	-21.5	-24.5	-27.6	-21.5	-27.6	-19.7	-30.1	-35.3
37	D6	Kapaya Nana	10	-20.0	-21.0	-23.5	-23.5	-26.6	-20.5	-24.8	-26.5
38	D7	Mundra	15	-17.9	-23.1	-12.3	-15.5	-23.1	-16.2	-24.8	-30.7
39	D8	Baroi	15	-18.5	-21.6	-24.6	-24.6	-24.6	-18.5	-22.7	-24.6
40	D9	Goyarsama	12	-13.9	-18.5	-12.5	-24.6	-12.4	-9.3	-14.4	-24.6
41	E1	Navinal	9	-29.1	-42.1	-29.1	-26.1	-29.1	-26.1	-29.1	-29.1
42	E2	Navinal	9	-29.1	-29.1	-29.1	-21.5	-30.6	-21.5	-24.3	-33.7
43	E3	Zarpara	8	-74.3	-75.8	-57.4	-83.5	-83.5	-68.2	-71.3	-74.2
44	E4	Zarpara	7.5	-47.4	-62.6	-44.3	-52.5	-64.1	-56.5	-54.7	-67.4
45	E5	Dhrab	6	-39.7	-48.9	-42.8	-39.7	-47.6	-39.7	-46.3	-55.0
46	E6	Dhrab	5	-37.7	-37.8	-22.4	-46.0	-47.3	-37.7	-37.7	-37.7
47	E7	Mundra	5	-13.4	-14.0	-13.3	-19.0	-40.7	-31.6	-31.6	-31.6

ANNEXURE 9.3

(1 of 2)

Village wise Land Allotted for Industrial Development from Various Land Use Categories

Sr. No.	Village	Agriculture m^2	Pasture Land m^2	Cultivable Wasteland m^2	Non Cultivable Waste m^2	Industrial m^2	Total m^2	Total km^2
1	Baraya	94,647	0	67,769	0	0	1,62,416	0.16
2	Baroi	1,55,348	0	6,775	6,82,411	0	8,44,534	0.84
3	Beraja	0	0	19,33,598	0	0	19,33,598	1.93
4	Bhadreshwar	1,31,525	0	8,21,712	4,43,432	139579	15,36,248	1.54
5	Bhorara	27,418	0	0	0	0	27,418	0.03
6	Chhasara	0	0	29,846	0	0	29,846	0.03
7	Dhrab	0	0	0	19,26,355	0	19,26,355	1.93
8	Gelada	0	0	4,24,011	0	0	4,24,011	0.42
9	Goersama	15,479	0	32,171	24,34,874	8592	24,91,116	2.49
10	Gundala	1,66,124	89,638	8,66,608	98,937	0	12,21,307	1.22
11	Jharapara	0	40,22,402	0	67,39,007	0	1,07,61,409	10.76
12	Kandagara Mota	0	3,70,391	25,82,937	36,220	0	29,89,548	2.99
13	Karagogah	16,188	0	5,71,510	0	0	5,87,698	0.59
14	Luni	1,62,078	6,70,657	29,12,168	20,34,433	18717	57,98,053	5.80
15	Mokha	2,01,940	6,376	5,75,669	4,58,728	0	12,42,713	1.24
16	Mota Kapaya	3,03,123	0	1,43,160	16,188	0	4,62,471	0.46
17	Moti Bhujpar	0	0	32,780	9,420	0	42,200	0.04
18	Mundra	0	0	40,470	48,57,513	0	48,97,983	4.90

ANNEXURE 9.3

(2 of 2)

Sr. No.	Village	Agriculture m^2	Pasture Land m^2	Cultivable Wasteland m^2	Non Cultivable Waste m^2	Industrial m^2	Total m^2	Total km^2
19	Nana Kapaya	0	0	92,551	0	0	92,551	0.09
20	Navinal	0	13,42,994	48,259	16,96,874	0	30,88,127	3.09
21	Patri	0	0	63,435	96,000	0	1,59,435	0.16
22	Pawadiyara	2,41,766	0	7,689	66,202	0	3,15,657	0.32
23	Pragpar 1	0	0	4,64,783	0	0	4,64,783	0.46
24	Ragha	0	0	88,930	7,82,384	0	8,71,314	0.87
25	Ratadiya	0	0	2,98,048	0	0	2,98,048	0.30
26	Samagogha	3,65,535	0	3,18,592	47,937	3455	7,35,519	0.74
27	Shekhadiya	40,469	0	17,604	12,82,897	0	13,40,970	1.34
28	Shiracha	4,900	16,086	1,44,069	34,08,646	0	35,73,701	3.57
29	Tunda	0	8,53,891	75,75,910	58,48,536	0	1,42,78,337	14.28
30	Viraniya	0	0	41,986	0	0	41,986	0.04
31	Vovar	0	0	41,075	11,432	0	52,507	0.05
32	Wadala	8,26,267	9,97,771	6,36,398	13,35,678	0	37,96,114	3.80
Total km^2		**2.75**	**8.37**	**20.88**	**34.31**	**0.17**		**66.49**

ANNEXURE 9.4
(1 of 2)

Land Acquired by Various Industries from Various Land Use Categories in the Study Area

Sr. No.	Name of Industry	Village	Agriculture m^2	Pasture Land m^2	Cultivable Wasteland m^2	Non Cultivable Waste m^2	Industrial m^2	Total m^2	Total km^2
1	Aadinath Polifils Pvt. Ltd	Dhrab	Land allotted of account no 416 but covered area not specified						
2	Adani Chemicals Ltd	Dhrab	Land allotted of account no 267 but covered area not specified						
3	Adani Power Ltd	Viraniya	0	0	41,986	0	0	41,986	**0.04**
4	Adani Wilmar Ltd	Pragpar 1, Baroi	1,55,348	0	1,08,048	0	0	2,63,396	**0.26**
5	Agro Crops Exim Ltd	Nana Kapaya	0	0	21,651	0	0	21,651	**0.02**
6	Ashok Alcho Chem Ltd	Baraya	94,647	0		0	0	94,647	**0.09**
7	BSNL	Bhadreshwar	0	0	300	0	0	300	**0.00**
8	Coastal Gujarat Power Ltd	Tunda, Kandagara Mota	0	12,24,282	60,15,010	8,15,274	0	80,54,566	**8.05**
9	Deast industries Pvt Ltd	Vovar	0	0	41,075	11,432	0	52,507	**0.05**
10	Gujarat Adani Port Ltd	Goersama	Land allotted of account no 121 but covered area not specified						
11	Gujarat Energy Transmission Corporation Ltd	Moti Bhujpar, Siracha, Mokha	4,900	0	0	16,520	0	21,420	**0.02**
12	Gujarat State Petronet Ltd	Gundala	0	0	3,600	0	0	3,600	**0.00**
13	HPCL Mittal Pipeline Ltd	Gundala	0	0	1,025	0	0	1,025	**0.00**
14	Indian oil corporation Ltd	Patri, Bhadreshwar	0	0	6,070	1,46,282	0	1,52,352	**0.15**
15	Jindal Sow Ltd	Pragpar 1, Samagogha, Moti Bhujpar	3,65,535	0	7,14,882	47,937	3,455	11,31,809	**1.13**
16	L T C Agro Sels Ltd	Ratadiya	0	0	2,98,048	0	0	2,98,048	**0.30**

ANNEXURE 9.4

(2 of 2)

Sr. No.	Name of Industry	Village	Agriculture m^2	Pasture Land m^2	Cultivable Wasteland m^2	Non Cultivable Waste m^2	Industrial m^2	Total m^2	Total km^2
17	Laxmiwadi Mines and Minerals Pvt. Ltd	Bhorara, Gundala	1,93,542	0	50,688	0	0	2,44,230	**0.24**
18	Ms. Kotak Agro Processing Pvt. Ltd	Baraya	0	0	55,135	0	0	55,135	**0.06**
19	Mundra Port and SEZ Ltd	Entire coastal villages	15,60,247	71,45,924	1,26,46,861	3,32,75,759	27,309	5,46,56,100	**54.66**
20	Mundra Taluka Charm Udhyog	Moti Bhujpar	0	0	0	900	0	900	**0.00**
21	OPG Power Gujarat Ltd	Bhadreshwar	1,31,525	0	6,74,409	0	1,39,579	9,45,513	**0.95**
22	Phillips Carbon Black Ltd	Wadala, Mokha	2,47,063	0	47,551	0	0	2,94,614	**0.29**
23	Rishi Container Station Pvt Ltd	Mota Kapaya	Land allotted of account no 528 but covered area not specified						
24	Shree Amit Marketing Pvt ltd	Patri	0	0	63,435	0	0	63,435	**0.06**
25	Shree Ashapura Mincechem Ltd	Baraya	0	0	12,634	0	0	12,634	**0.01**
26	Shree Sanghvi Movers Ltd	Chhasara	0	0	29,846	0	0	29,846	**0.03**
27	Welspan Power and Steel Ltd	Navinal	0	0	48,259	0	0	48,259	**0.05**
Total km^2			**2.75**	**8.37**	**20.88**	**34.31**	**0.17**	**66.49**	