CHAPTER 7: GROUND WATER HYDROLOGY

'When the well is dry, we learn the worth of water.'

- Benjamin Franklin

Groundwater hydrology is the science of occurrence; distribution and movement of water below the earth's surface (USNRC, 1991). Groundwater constitutes one portion of the hydrologic cycle and is the most dependable resource throughout the world. Development and management of water resources require appropriate understanding of surface as well as groundwater resources. In this chapter, the author has attempted to investigate the occurrence, distribution and hydro-chemical characterization of groundwater resource in the study area. The author apart from domestic aspects, has also applied various Irrigation Water Quality Indices to evaluate the groundwater quality and established a possible relationship between the existing aquifer types and associated dissolved constituents.

GROUNDWATER OCCURRENCE

To describe the occurrence of groundwater necessitates a review of where and how groundwater exists, that also includes its subsurface distribution in both vertical and aerial extents (Todd, 2011). Groundwater movement and its properties are unique with reference to its place of occurrence (Shivaramakrishnan, 2013). Groundwater occurrence in any given region is a function of various geological and meteorological parameters. Hydro-meteorological parameters contribute as the input to the groundwater system, while its movement, storage and quality are governed by the geological attributes. The groundwater in the Kim River basin shows great variation in terms of its occurrence and distribution due to presence of diverse geological environments that have impacted the quality as well as quantity of the groundwater resources. The hydrogeological information relevant to this aspect is gathered through a detailed well inventory envisaged by the author within the framework of ARDC-III Norms (ARDC, 1982).

Well Inventory and Groundwater Sampling:

A stable, base network of observation wells forms an essential foundation for groundwater studies. Location of well, seasonal behaviour of water level & quality, aquifer – composition & type and its potential in terms of its sustainable yield portray a pivotal role to understand the spatial distribution pattern of groundwater resources occurring in a given area.

To study seasonal water level fluctuations and its hydro-chemical content, author has established an independent network of observation wells. For this, the study area was divided into equal grids of (3x3km) area. The selection of observation well in a particular grid was based on the least seasonal fluctuation in water table; through local infield inquiry and/or adoption of observation well that is being monitored by other state/central groundwater authorities. To maintain uniformity in data collection, the author has used a standard Well Inventory Performa (Annexure D) and correspondingly the

information for each observation well has been collected. The well inventory information was gathered through the following means-

i)   Location and ownership of well in the field.

ii)   Measurement of dimension & depth of well and position of water table.

iii) Nature and composition of aquifer present, observation on thickness of weathered zone and presence of visible geological structures like dykes and hydro fractures, if any.

iv)   Interaction with well owners to gather information about well pumping, yield, irrigated area and crops, etc.

v)   Collection of water samples for determining seasonal change in physico-chemical parameters, if any.

These observation wells, in all 43 in numbers, have served the purpose of groundwater sampling for monitoring the seasonal changes in groundwater quality. The candidate would like to put on record that although efforts were made to maintain grid weightage for an individual observation well; however due to lack of availability of any well at places, the grid space has been compromised, particularly in the lower part of the basin where, canal irrigation predominates.

Further, observation wells located in the upper part of the basin are predominantly fall within rocky and undulatory terrain, therefore aquifers are characterized by limited lateral extent. Thus, at places, weighted area for an observation well is bit reduced. The well inventory and groundwater sampling was carried out for two consecutive years of 2012 and 2013 on seasonal basis. Pre monsoon monitoring was done in the month of May, whereas, the Post-monsoon in the month of October. Also, to appraise on peak withdrawal, winter season monitoring was done in late January/ February month. The information on the positions of the adopted network of observation wells with the prevailing geological regimes is provided in Figure 7.1. The study area has a well-established network of observation wells set up by various government agencies like CGWB, GSGWB and the State Irrigation department. For evaluation of

secular, long term changes in groundwater levels and chemistry, the author has relied on the secondary data maintained by the Ukai-Kakrapar Canal Authority. Detailed information on inventoried observation wells is given in Annexure-E.
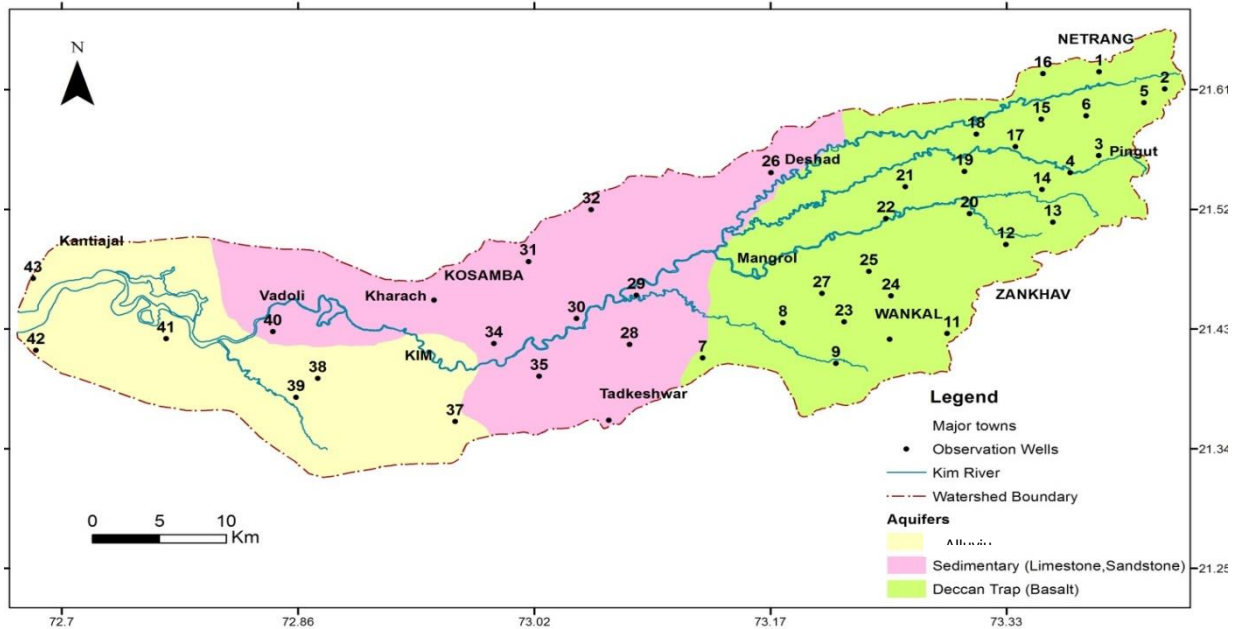

Figure 7. 1 Network of Observation Wells in the Kim River Basin

Hydrogeological Characterization of the Study Area:

The groundwater occurrence and distribution of any region   is strongly governed by the parameters like landform, drainage and litho-structural elements of the area. These parameters coupled with weathering processes creates repository of groundwater. i.e. the aquifer (May & Todd, 2011). As , it has already been elucidated that the Kim River Basin is characterized by 03 definite geological litho-units viz.

i)   *Igneous Rock:* The upper part of the basin predominantly inhabits magmatic rocks of the Deccan traps, i.e. Basalt.

ii)   *Sedimentary Rocks:*   The middle basin part comprises the sedimentary sequence of the Tertiary age. Viz. Sandstone-Shale-Limestone.

iii) *Sedimentary Alluvium:* The lower and partly middle parts of the basin consist of thick pile of alluvium comprising admixtures of sand, silt and clay.

Groundwater occurrence and its potential in the study area is strictly governed by the distribution of the above cited litho-units. Based on the well-inventory data, satellite imageries and available literature; the author has attempted to classify these litho-formations into 03 distinct hydrogeological categories (Davis & DeWeist, 1966), namely;

i) **Consolidated Sediments:**   These are said to be hard rocks or indurated sediments. These rocky aquifers cover about 540 km^2 of upper basinal part of the area. In the study area, they are represented by the basaltic lava flows of various nature and composition. The occurrence of groundwater in basalts of different composition is predominantly confined to weathered and fractured parts of the rocky substratum. Major aquifer systems developed under this category are shallow-unconfined or water-table type. These aquifers are perceived with seasonal fluctuation in groundwater levels. The saturated (aquifer) thickness also tends to vary from area to area due to the change in the thickness of the weathered zone. In terms of aquifers' lateral extent it ranges between 200-800 m (Karanth, 1987).

Other aquifer type observed in the study area is developed along the available fractures. These fractures can be local or regional extent and serves important means of groundwater channelization as well as storage. Fracture capable of transmitting groundwater is said to be a hydro fracture. Hydrofractures are formed depending on the tectonism accentuated local stress in the rock layer, along a potential fracture path. These hydrofractures partly or entirely are the product of internal fluid pressure and can develop at any depth and serve as a consistent source of groundwater in the rocks which lack primary porosity (Gudmundsson, 2002). The aquifers developed along the hydrofractures are narrow, linear, deep and semi confined to confined in nature. In the upper basinal part and in otherwise hard rock terrain; these hydrofractures serves important source of groundwater. A few distinctly visible hydrofractures as seen on satellite image (Plate 7.1) proves their efficacy in terms of its copious yield. Author, as a part of well inventory

and seasonal monitoring of groundwater levels, came across these hydrofractures that are oozing the groundwater in the wells (Plate 7.2)
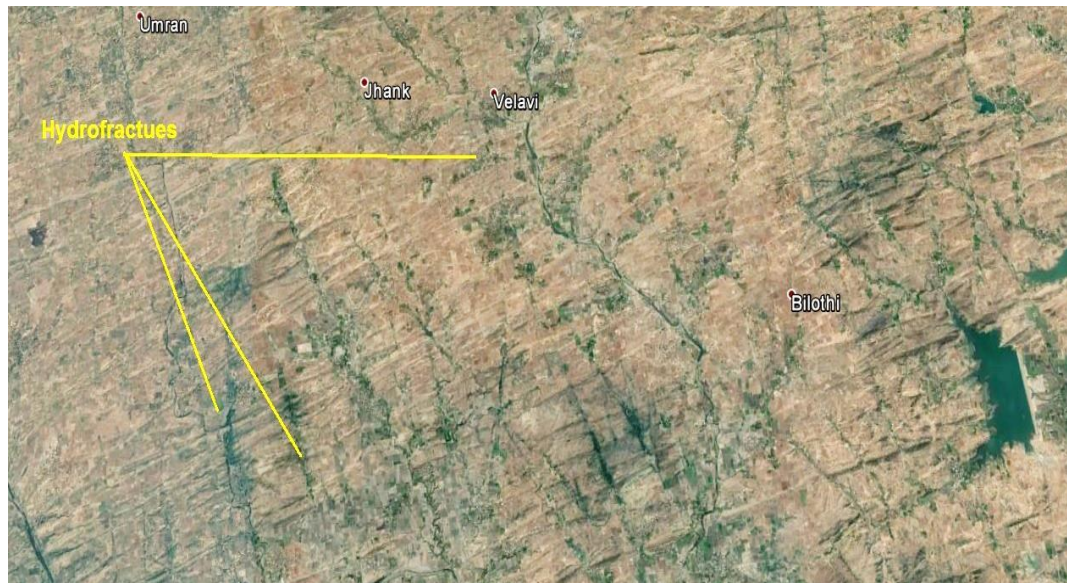
Plate 7. 1 A Satellite View of Hydrofractures in the Upper Parts of the Study Area

Plate 7. 2 Groundwater oozing out under hydraulic pressure from Hydrofractures in a basaltic aquifer (Loc. Chasvad)

As eluded, these unconfined aquifers show marked fluctuation in groundwater levels from post to pre monsoon season i.e. >10m. During post-monsoon, the observation wells witness rise in water table (Plate 7.3a & b) to such an extent that the wells are free flowing. Contrary to this, during the pre-

monsoon period, there has been a sharp decline in groundwater level to an extent that the well is almost dry. Author, in her study area observed that almost 60% of the wells are getting dried up during summer, thereby causing hardship to the local inhabitants to meet their domestic needs. These basaltic aquifers are characterized by low-moderate yield (150-250 lpm).

Plate 7. 1a A View of Open Dugwell showing Near Groundwater Table within the Basaltic aquifer (Loc. Amkhuta)

Plate 7. 3b A View of a Lined Open Dug well of Free Flowing Nature developed within Weathered Basaltic Aquifer in a Pediment Zone(Loc. Tadphalia)

ii) **Semi-Consolidated Sediments:** The middle part of the basin is occupied by the Tertiary sedimentary sequence comprising an intercalated sequence of conglomerate-sandstone-shale and limestones. Aquifers developed within sandstones are ideal source of water due to its appreciable porosity and permeability. The limestone on the contrary, lacks primary porosity but at places secondary porosity is seen very well developed through hydro chemical weathering process. Such aquifers yield large quantities of water (Plate 7.4) but the quality is seldom hard (May & Todd,2011). These sedimentary aquifers are also characterized by a marked seasonal fluctuation in the water table (up to 5m) and are of moderate yield (250-450 lpm). These aquifers cover almost 450km^2 of the study area encompassing one of the most fertile belt of the South Gujarat region. From the total observation wells monitored, about 25% belongs to this category.

Plate 7. 2 A view of an Open Dug well in Limestone Aquifer with a Profused Groundwater Yield (Loc. Pipodra)

iii) **Unconsolidated Sediments:** Aquifers that are developed within the alluvium deposits occur in the middle and lower parts of the basin. The alluvium in the study area represents a thick pile of fluviatile and estuarine sediments comprising a mixture of sand-silt-clay of Holocene-Sub-Recent age. Amongst the flood plain deposits in particular are rich repository of groundwater. The

aquifers are multi layered in nature and of phreatic-confined type. However on approaching towards the coastal plain region, these aquifers turn brackish-saline due to the factors like sediments', inherent salinity, tidal ingression, sea water intrusion and water logging. These aquifers are shallow and are characterized by almost negligible seasonal fluctuation in water table. This may be ascribed to continuous replenishment of water through seepage from the canals and returned irrigation seepage. The aquifer developed within alluvium sediments are of considerable lateral extent and thickness. Due to appreciable range of porosity and permeability, these aquifers are capable of providing high yield (> 500 lpm).

As discussed, the study area comprises of all the three types of aquifers, which are predominantly phreatic in nature and depending on geological environment, show high to negligible fluctuation in the water table, range of groundwater yield and water quality change.

GROUND WATER LEVEL FLUCTUATIONS

Study on groundwater level fluctuation suffice important means for the assessment of groundwater issues relevant to resource estimation, utilization and management. It also facilitates in developing understanding on the concerns apt to groundwater chemistry. Changes in groundwater levels can be placed under three categories viz., seasonal, short time vectoral and long term secular (Todd, 1959). In the present study, the aim is to evaluate study areas' water resource potential; therefore, emphasis has been laid in understanding seasonal and secular changes in groundwater levels.

Seasonal Changes in Groundwater Levels:

A fluctuation in groundwater levels with respect to seasons directly affects the change in the groundwater storage as the rise and fall in the water level is indicative of the net increase and decrease in the groundwater storage respectively. Change in the groundwater storage is a function of processes viz. infiltration & runoff during rainfall and groundwater draft for irrigation, industrial and domestic uses.
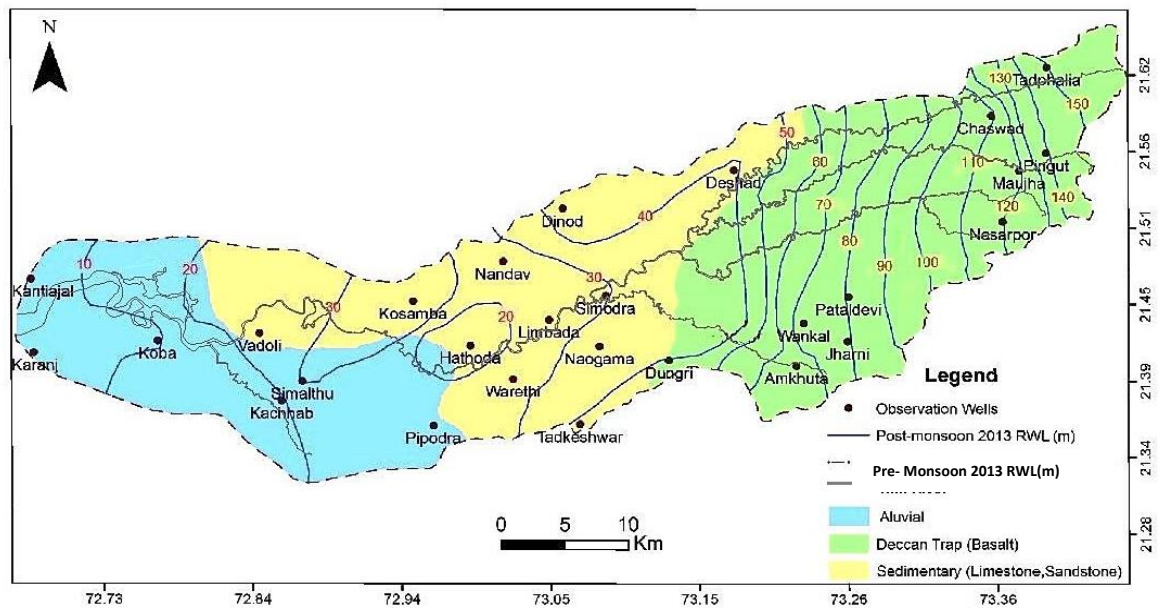
Figure 7.2a Reduced Water level Contour Map of the Kim River Basin (Pre-monsoon, 2013)
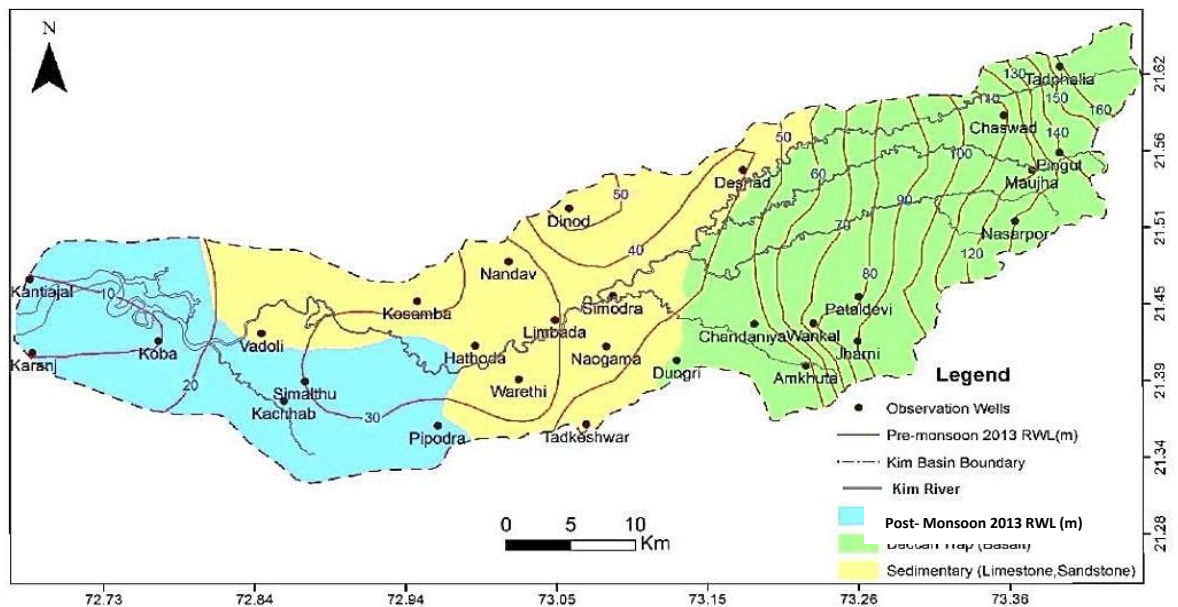
Figure 7. 2b Reduced Water level Contour Map of the Kim River Basin (Post-monsoon, 2013)

It has already been elucidated that to study the seasonal behaviour of groundwater levels and groundwater chemistry in the Kim River Basin; the author has established a network of observation wells (Fig. 7.1). Author has also carried out the seasonal monitoring for the years 2012 and 2013. Based on the gathered data, author has prepared the Reduced Water Level (RWL) contour maps for the pre and post-monsoon seasons (2013) with a 10 m contour interval (Fig 7.2 a & b). Based on the analysis of the RWL contour maps, the following conclusions are drawn:

- The overall groundwater movement and its direction show westerly flow direction indicating strong topographic control. The observed changes in the groundwater flow locally may be ascribed to change in geological environment.

- The groundwater gradient also shows perceptible range viz. in the Deccan Trap dominated upper parts of the basin (1:225); sedimentary rock dominated middle parts of the basin (1:1000); and alluvium dominated lower parts of the basin (1:1600). The observed change in groundwater gradient show strong control of the study area physiography that in fact is governed by contrasting lithologies distributed along the basin.

- The highest RWL observed in the year 2013 for post-monsoon season was 160(Fig. 7.2b) and that in pre- monsoon was 150m AMSL in the eastern highland region. This depletion of 10 m (Fig 7.2a) in RWL may be ascribed to groundwater withdrawal and/or sub-surface run-off contributed to river as base flow.

In order to decipher annual change in groundwater storage in the study area, considering the difference in the pre & post-monsoon RWL, author has developed a map on annual change in groundwater storage (Fig 7.3).
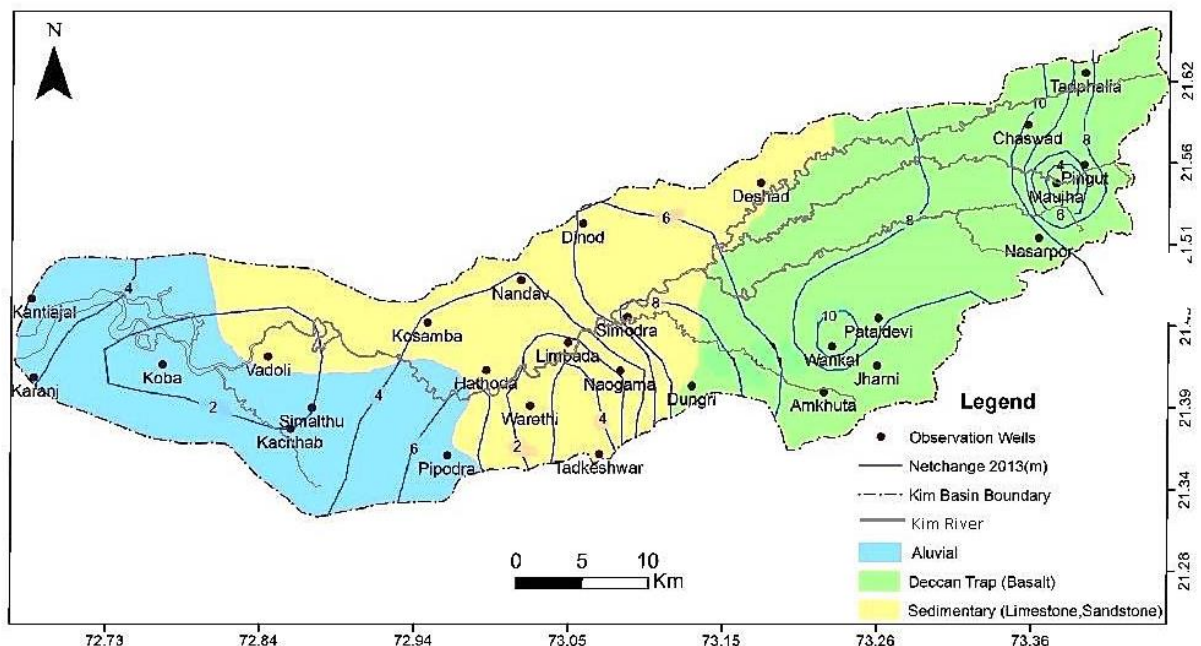
Figure 7. 3 Seasonal Net change in Groundwater Storage (2013)

As clearly visible in Figure 7.3 that the annual change in groundwater storage show a range between 02-10 m; where in higher order change > 6m is by and large observed in upper parts of the basin, which is characterized by rocky phreatic aquifers. However, the depicted minima (4m) around Pingut & Maujha are attributed to area's proximity to Pingut reservoir and its irrigation canal system. The reservoir and canal irrigation facilitates recharge to the aquifers on continual basis thereby; aquifers show least fluctuation in comparison to its peripheral regions.

In the middle and lower parts of the basin observed change in groundwater storage is in the range of 2-6m. As the area display blend of diversity such as large concentration of semi-urban population, mining activity and canal facilitated rich agriculture; the combined effect of these is observed as moderate change in groundwater storage. Similarly, in lower parts of the basin, the observed change in groundwater storage is 2-4 m, ascribed to alluvium aquifer coupled with intensive canal irrigation.

Secular Changes in Groundwater Levels:

Groundwater resource utilization in any region is a manifestation of groundwater draft that is withdrawn from groundwater storage, which is finite and considered to be a replenishable resource. The pace with which the groundwater is withdrawn can be understood through prolonged observations on changes in groundwater levels seasonally. A long term annual time series records of groundwater levels assist in assessing the overall declining and rising trends of groundwater table thereby demarcating the areas of over and under exploitation and water logging (Healy, 2002). This becomes an obvious limitation for the author and therefore secondary data attain greater significance in the assessment of long term behavior of groundwater regime.

As stated earlier that the study area is having a very well established network of observation wells, long term groundwater level monitoring is carried out by the state water authorities with a view to study the impact of agriculture

on groundwater regime. The author would like to put on record that due to intense canal irrigation and its probable impact; long term changes in groundwater regime have been confined to the middle and lower parts of the basin only.

The author has acquired the long term seasonal groundwater level data of 15 years (1998-2013) duration from the Surat Irrigation Circle (SIC). These secondary data were utilized for the construction of well hydrographs to assess-

i) Area specific long term behavioral changes in groundwater levels;

ii) Spatial and secular change in the groundwater levels for 15 years period; and

iii) Assessment of change in groundwater storage attributed to rise and fall in water levels.

Well Hydrographs:

The study of spatial hydrographic profiles is important to evaluate the lateral change in groundwater storage across the study area. For this purpose the author has prepared number of well hydrographs of selected observation wells for the period 1998-2013 considering the pre and post-monsoon SWL in the Central and Lower parts of the Kim Basin only (Fig 7.4). The upper highland region of the basin has been excluded from this study as it has a very restricted canal irrigation and its impact on groundwater regime is negligible owing to presence of hard rock aquifers and steep groundwater gradient.
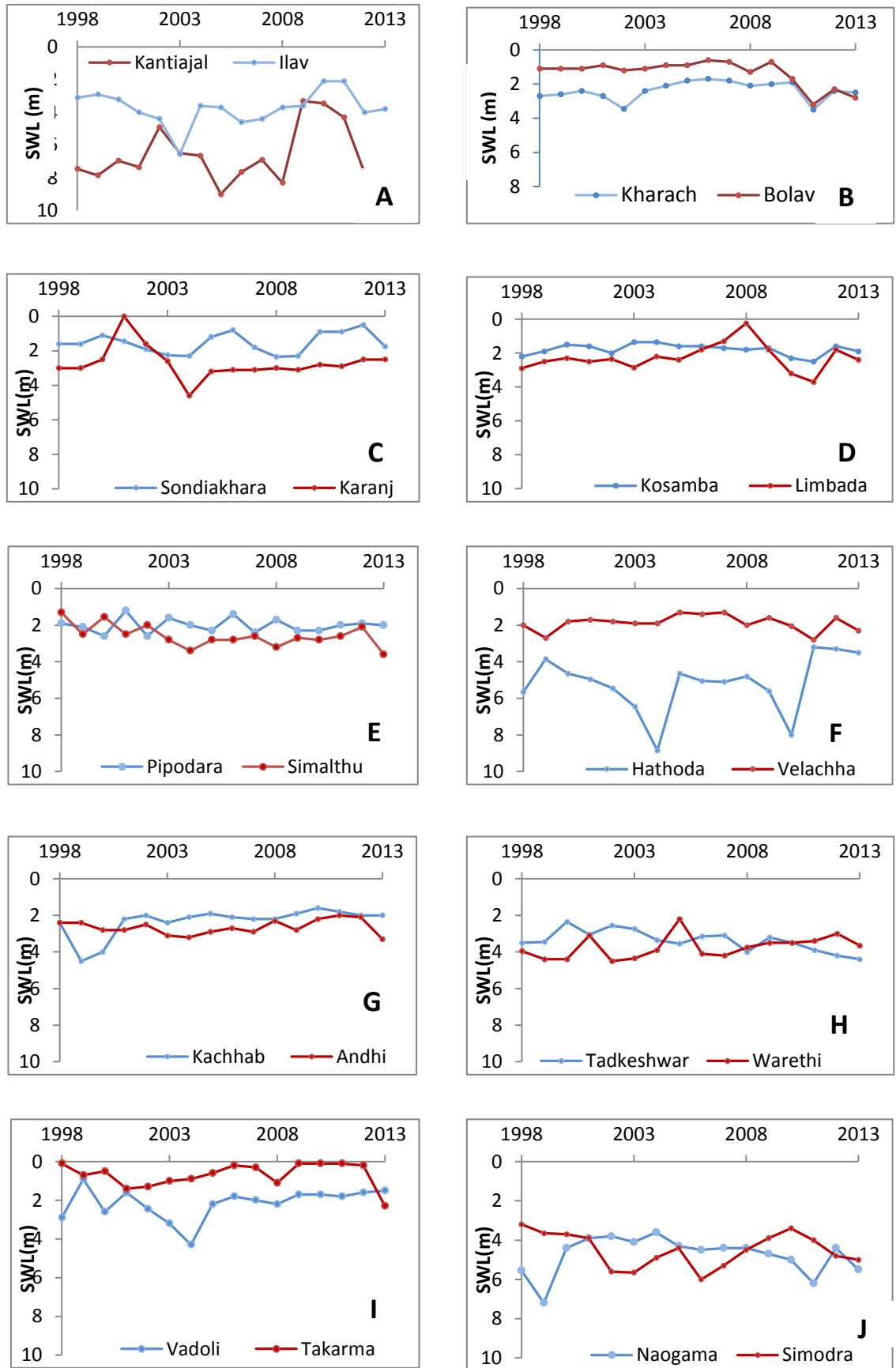
Figure 7. 4 Well Hydrographs Showing Secular Behaviour of Groundwater Table of Selected Observation Wells in the Study Area

A careful study of the presented well hydrographs leads to the following conclusions-

- There has been a perceptible rise in the groundwater levels due to canal irrigation prior to 1998. (i.e. 1976 to 1997).

- There has been no significant change in the groundwater table over the period of 15 years (1998-2013).

- The only observation wells viz. Kantiajal (Fig 7.4A) and Hathoda (7.4F) show water table depth below 06 m. Hence, indicating free from water logging hazards.

- The well hydrographs viz. Limbada (Fig 7.4D) and Simodra (7.4 J) show initial rise in groundwater levels and then a bit progressive decline.

- The well hydrographs viz. Pipodra and Simalthu (Fig 7.4 E) although fall within the water-logged category shows slight decline in groundwater levels.

- Majority of observation wells fall within the categories of severely water logged (< 1.5 m); water logged (1.5 t0 3.0 m); and prone to waterlogged (3.0 – 6.0 m), encompassing aquifers developed in alluvium and rudimentary rock unit.

Net Change:

Considering the data of Pre-monsoon (1998) and Pre-monsoon (2013), on water table depths, the candidate has computed the net change in groundwater levels as positive or negative (Table 7.1). Since, rainfall is the only input for groundwater recharge; the author has considered only the pre monsoon water level records to evaluate secular changes in the groundwater regime (Davis & De Wiest, 1967)

Well No	Village Name	Pre-monsoon Static Water Level (m)		Net Change (m)
		1998	2013	
85	Andhi	2.4	3.3	-0.9
301	Bolav	1.1	2.8	-1.7
133	Hathisa	0.9	3.0	-2.1
380	Hathoda	5.7	3.5	2.2
321	Ilav	3.1	3.8	-0.7
65	Kachhab	2.4	2.0	0.4
317	Kantiajal	7.5	8.0	-0.6
126	Karanj	3.0	2.5	0.5
51	Kathodra	6.9	8.8	-1.9
336	Kharach	2.7	2.5	0.2
263	Kosamba	2.2	1.9	0.3
353	Limbada	2.9	2.4	0.5
177	Limodara	0.8	0.6	0.2
74	Molavan	3.4	3.1	0.3
368	Naogama	5.6	5.5	0.0
148	Pipodara	1.9	2.0	-0.1
59	Sarsana	2.7	2.8	-0.2
67	Simalthu	1.3	3.6	-2.3
362	Simodra	3.2	5.0	-1.8
81	Sondiakhara	1.6	1.8	-0.2
401 A	Tadkeshwar	3.5	4.4	-0.9
60	Takarma	0.1	2.3	-2.2
27	Vadoli	2.9	1.5	1.4
377	Velachha	2.0	2.3	-0.3
76	Warethi	4.0	3.7	0.3

*Source: Surat Irrigation Circle

Table 7. 1 Secular Net Change in Static Water Levels (1998 and 2013)

It is evident that there is no major change in the groundwater storage in the last 15 years in spite of fluctuating rainfall. In the central and lower alluvium plain region (Fig7.5), around villages' viz. Simodra, Tadkeshwar, Simalthu, Ilav and Bhatgam; the change in groundwater level is negative (up to -2 m); whereas, area around villages viz. Sethi, Kusad and Hathoda, the change in groundwater storage is positive (up to +2m). The remaining area shows practically negligible change in groundwater levels (Fig 7.5).
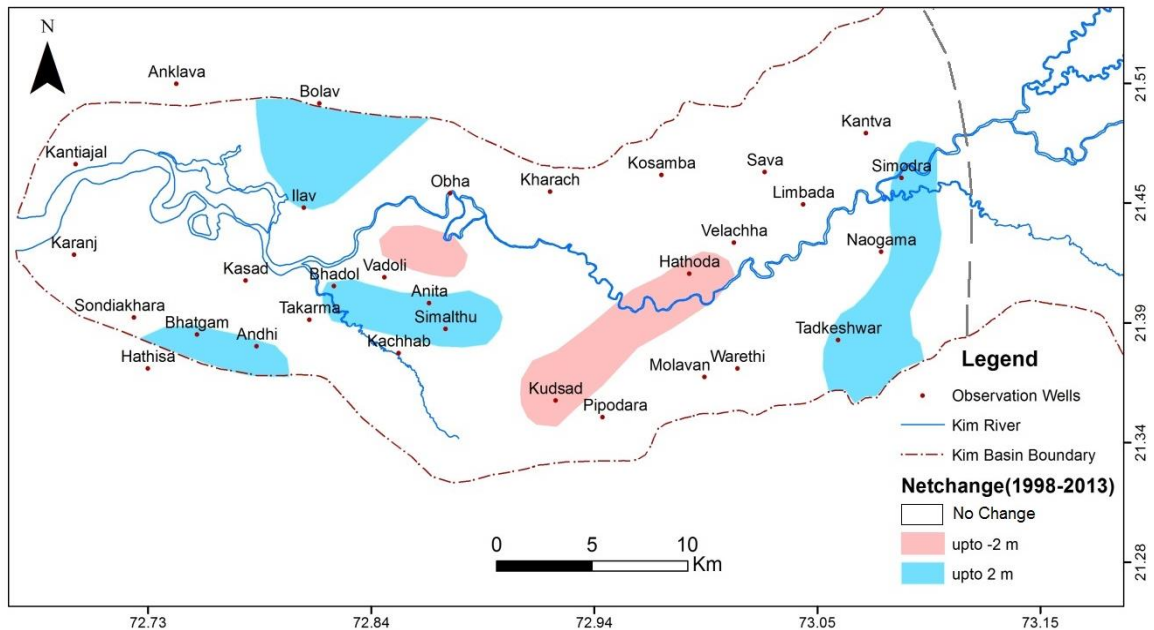
Figure 7. 5 Secular Changes in the Groundwater Storage in the Study Area (1998 -2013)

The chemical composition of natural water is affected by soluble constituents of weathered and decomposed rocks. Due to the rock-water interaction generally higher concentration of the dissolved constituents are found in groundwater than in surface water (Davis & De Weist, 1967). Therefore, chemical characterization of groundwater in terms of its quality holds prime importance for water resource development and planning.

Amongst the groundwater quality indices, Total Dissolved Solids (TDS) is considered to be the most basic measure. This represents all major cations and anions in dissolved form available in groundwater. These major constituents constitute the bulk of the mineral matter contributing to total dissolved solids. Therefore the author has considered TDS as an important physical parameter to assess the long term changes in the chemical characteristics of groundwater system.

Secular change in TDS has been studied in accordance with the water table showing rising and falling trends. For this the author has developed hydro iso-bath maps (7.6 and & 7.7) depicting TDS concentrations observed during Pre-monsoon season for the years 1998 and 2013 respectively.
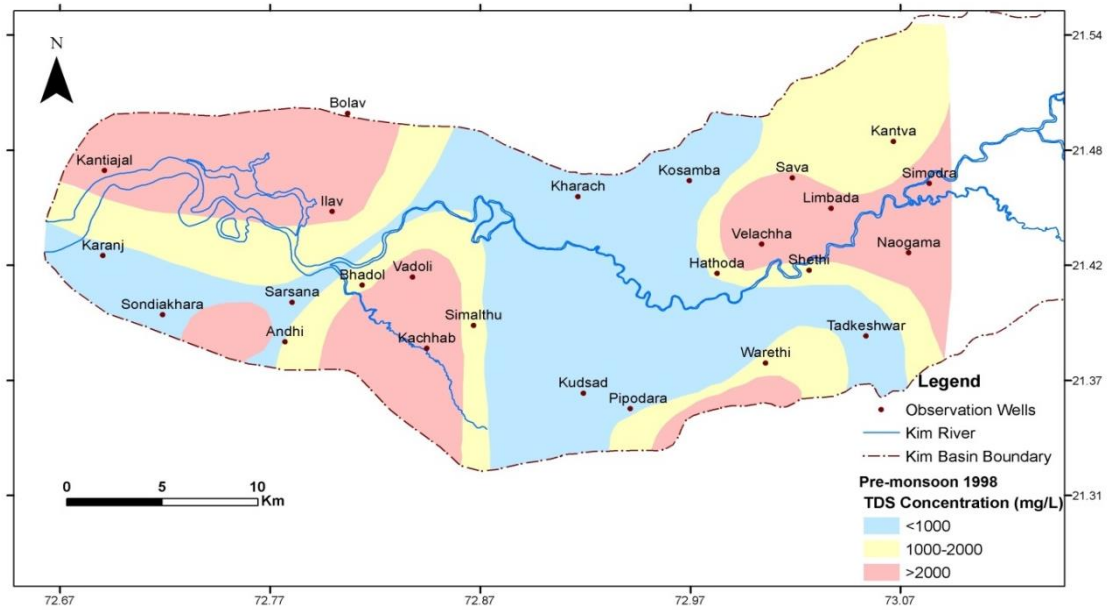
Figure 7. 6 Hydro-isobath of TDS (mg/l) in the Central and Lower Parts of the Study Area (Pre-monsoon 1998)
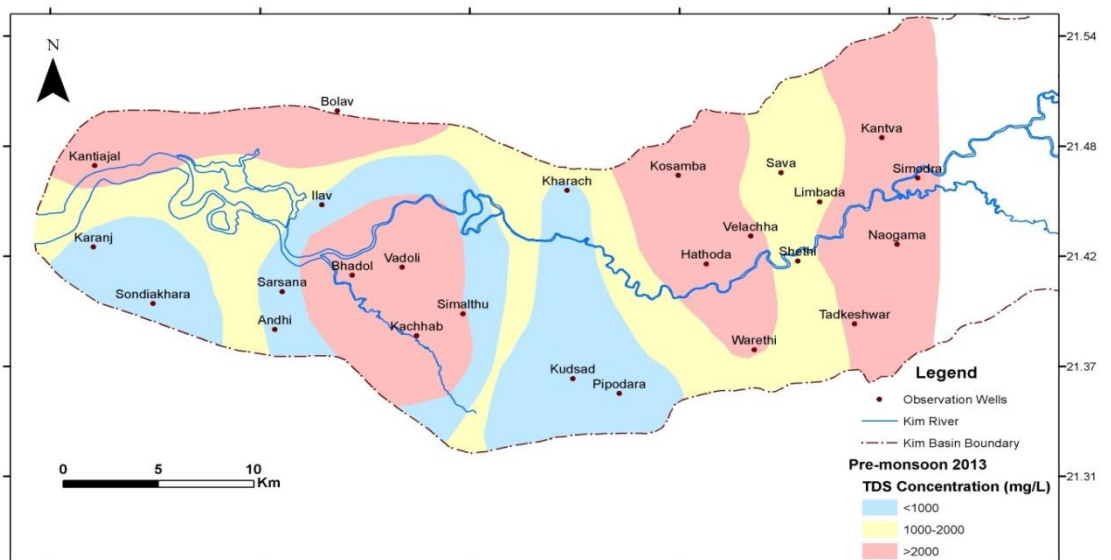

Figure 7. 7 Hydro-isobath of TDS (mg/l) in the Central and Lower Parts of the Study Area (Pre-monsoon 1998)

Year	TDS Concentration (mg/l)					
	<1000		1000-2000		>2000	
	Area (km^2)	% of area	Area (km^2)	% of area	Area (km^2)	% of area
1998	264	39	195	29	214	32
2013	174	26	205	30	295	44

Table 7. 2 Quantitative Assessment of hydro- isobaths of TDS in the Middle and Lower Parts of the Study Area

From the quantitative assessment (Table 7.2), it is evident that during the past 15 years' time (1998-2013), the groundwater quality in terms of its TDS concentration has enriched and over quality of groundwater is deteriorated. There has been a perceptible change in TDS Iso-bath categories show progressive increase in the area from suitable water category (<1000) to unsuitable water category (> 2000) under irrigation water quality norms. This is suggestive of considerable impact over groundwater quality and on the land use. As in the middle and lower parts of the basin area, canal irrigation pre-dominates; the cropping pattern & over irrigation could be ascribed as major causative factors for the increase in TDS concentration.

Impact of Irrigation on Groundwater Regime:

It has already been stated that, agriculture is the major occupation in the study area and almost 55% of the land-use in the study area is occupied by agricultural land. Further, large network of canals cater the needs of water in agriculture. Thus irrigated agriculture is the major consumer of freshwater in the study area. Since the inception of canals (1974), cultivation of water intensive crops like sugarcane and rice round the year embedded less dependency on groundwater for irrigation. Thus, recharge to aquifers due to return irrigation seepage and rainfall together account for increase in the groundwater storage without any significant withdrawal. As a result, the irrigated regions are witnessing the problem of water logging. Extensive work has been carried on the impact of irrigation canals on land and agricultural production throughout the world. Noteworthy contribution on the management and mitigation practices on irrigation water logged regions have been made by Hammad, 1959; Yaron,

1981; Bhatnagar, 1986; Bowonder et al, 1987; 1996; Gupta & Tyagi,1996; Gajja et al, 1998 & 2006; Upadhyay & Chauhan, 2000; Hussain et al, 2008; Singh 2010; Bunn et all, 2011.

The most common problem associated with various irrigation schemes is the rise in groundwater table, sometimes up to the root zone (< 1.5m BGL), the area is considered to be severely water-logged. The Central Board for Irrigation and Power has defined waterlogging as –"*An area is said to be waterlogged when the water table rises to an extent that soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon-dioxide*". Water logging does not always led to soil degradation, but is responsible for limiting plant growth. (FAO, 1970)

The phenomenon of water logging based on secular rise in the water table has been categorized in to 04 Classes (FAO, 1970) viz.

Class	Water Table Depth (m)	Area Significance
I	Less than 1.50	Severely Water logged
II	Between 1.5- 3.00	Water logged
III	Between 3.00-6.00	Prone to Water logging
IV	More than 6.00	Free from Water logging

Table 7. 3 Classification of Water Logged Areas (FAO,1970)

It has already been elucidated that the middle and lower parts of the study area are facilitated with intensive irrigation through a canal network falling under the Ukai Right Bank Canal (URBC) and Kakrapar Right Bank Canal (KRBC) command; stipulated Gross Irrigation Command area of 01,16,918 hectare. The planned crop pattern by the project authority to facilitate canal irrigation and the actual existing crop pattern show paradigm shift (Table 7.4) since the inception of canal irrigation, i.e. Year 1974.

Sr. No.	Crop	Area Planned (,000 Hec)	Area Actual (,000)	Change %
1	Sugarcane	46.8	162.4	+ 352
2	Rice	79.8	45.7	-43
3	Wheat	49.2	07.3	-85
4	Cotton	70.9	08.8	-87
5	Pulses	42.9	01.4	-96

(After Gajja et al, 2006)

Table 7. 4 Status of Cropping Pattern in URBC

It is clearly discerned that there has been a 352% increase in the sugarcane sown area which is water intensive. The less water required crops like wheat, cotton and pulses show drastic decline (>85%) in the net sown area. Therefore, the practiced actual cropping pattern can be considered as one of the major factors that have made the area extremely vulnerable to water logging. Author while carrying out the seasonal monitoring of groundwater levels (Years 2012 & 2013), in the study area could able to visualize the problem of water logging, especially in the middle and lower parts of basin. As the effect of water logging is prolonged and slow process; to work out the details, secondary data have been collected from the URBC authority.

Considering the year 1998 as base line, author has developed water logging scenarios at 05 years interval (1998-2013). For this the author has developed the hydro-isobath maps (Fig 7.8 -7.11) and categorized the area in to respective water logging classes.
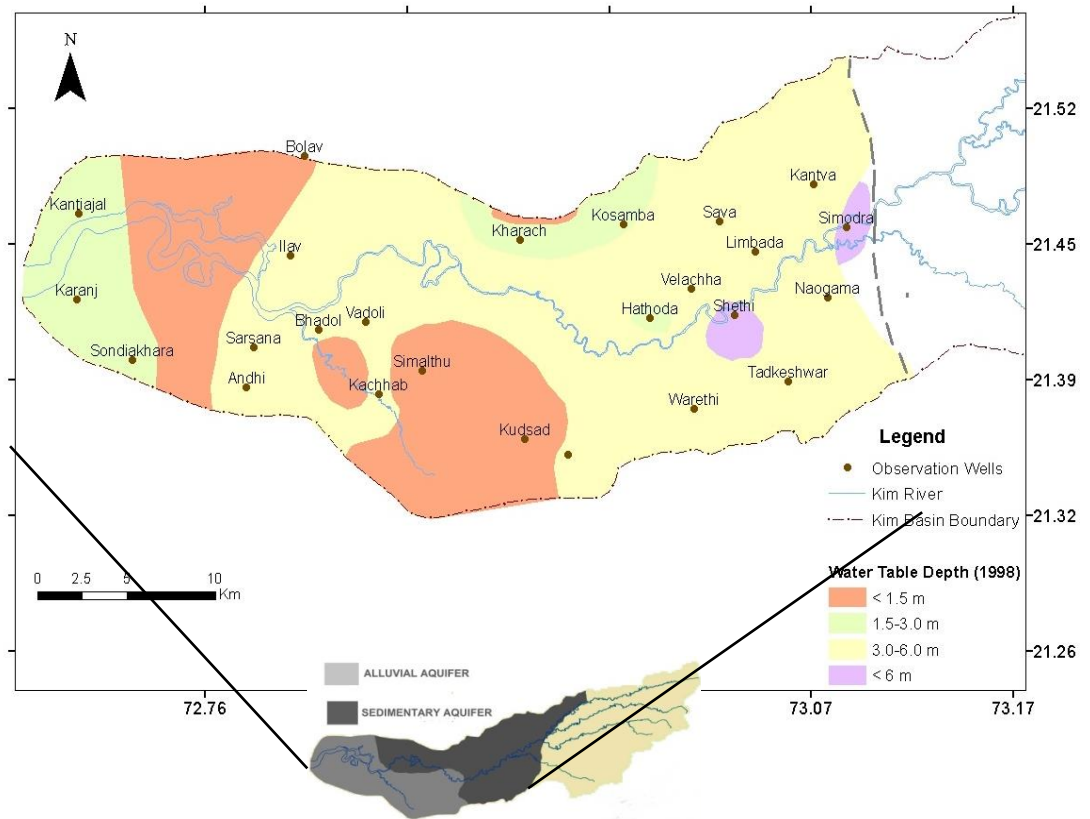
Figure 7.8   Hydro-isobath Map of Central & Lower Parts of the Study Area (Pre-monsoon 1998)
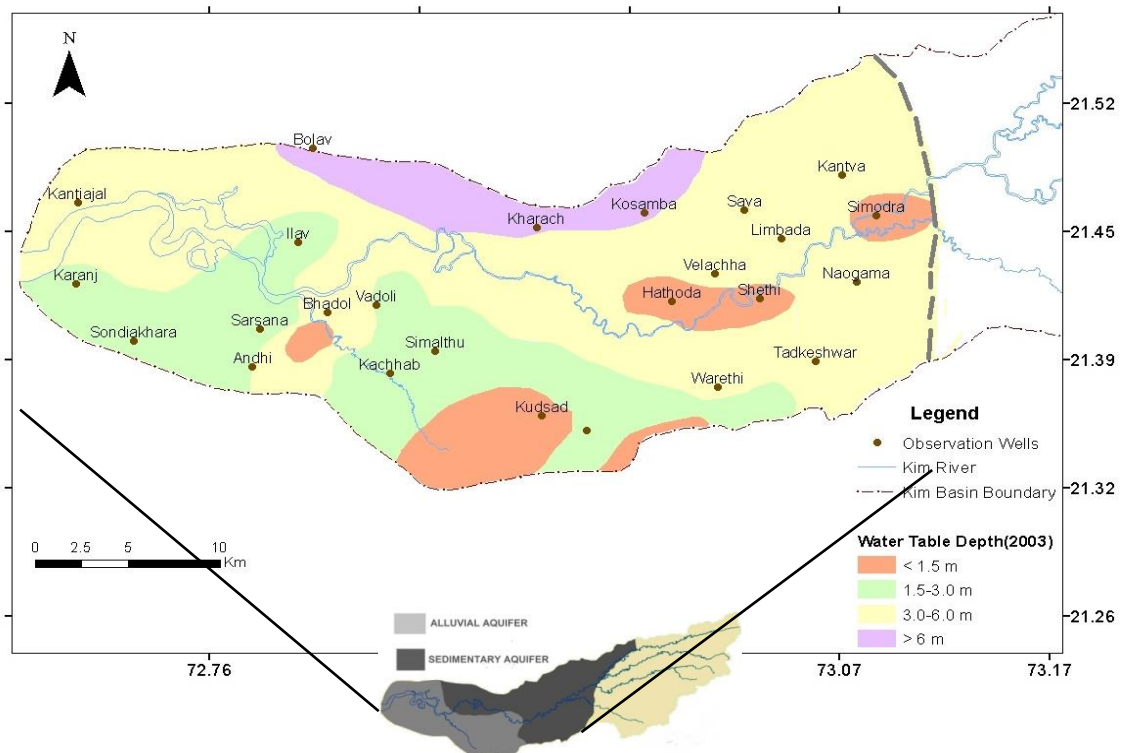

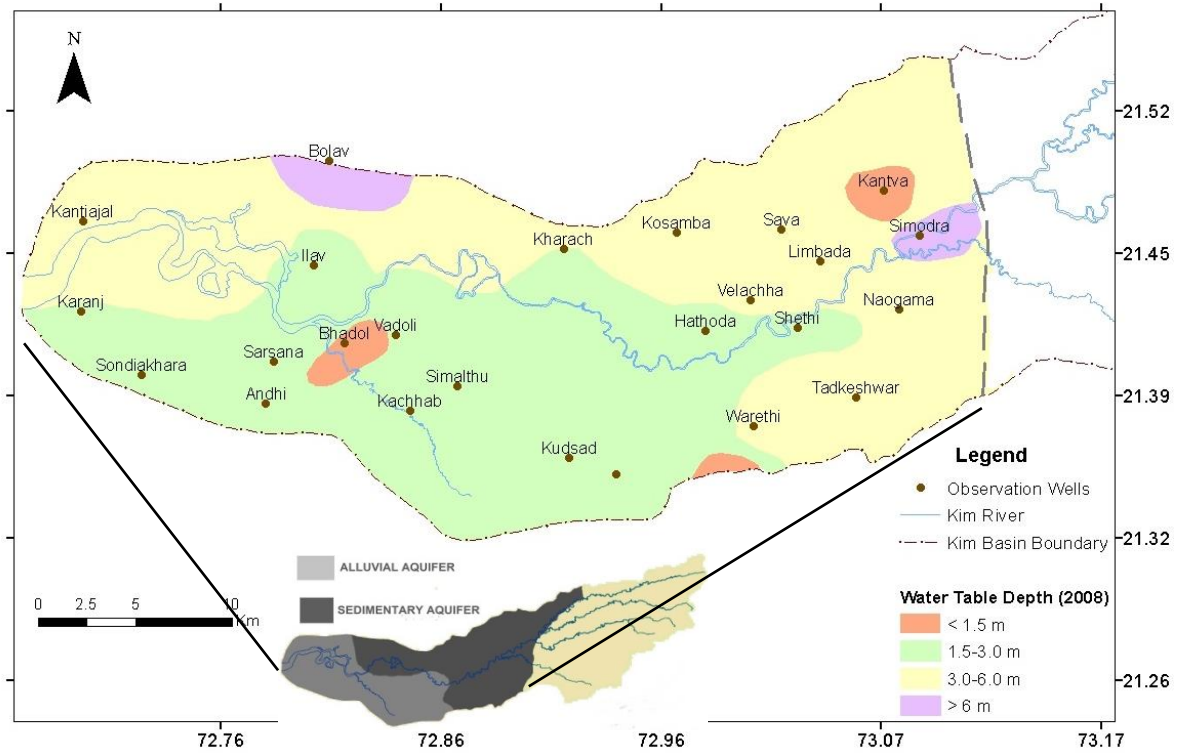**Figure 7.9 Hydro-isobath Map of Central & Lower Parts of the Study Area (Pre-monsoon 2003)**

Figure 7.10 Hydro-isobath Map of Central & Lower Parts of the Study Area (Pre-monsoon 2008)
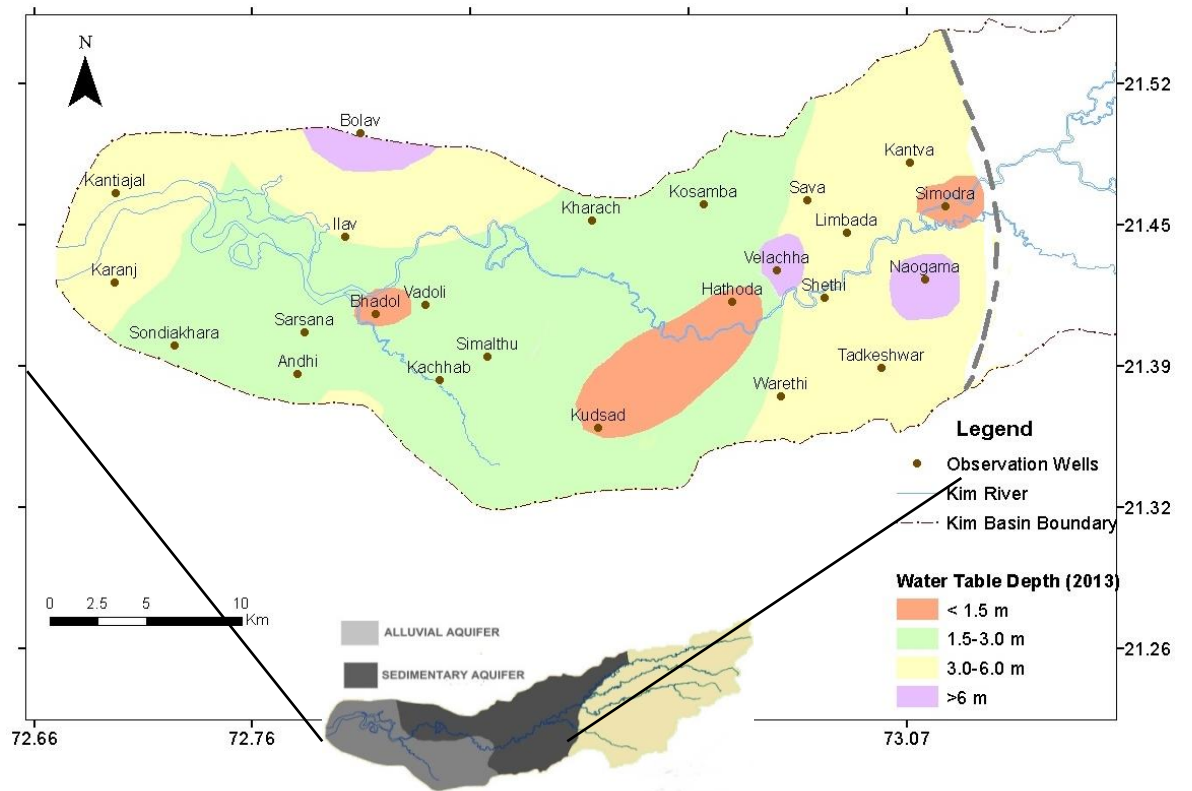
Figure 7.11 Hydro-isobath Map of Central & Lower Parts of the Study Area (Pre-monsoon 2013)

YEAR	Water Table Depth							
	< 1.5 m		1.5 - 3 m		3 - 6 m		> 6 m	
	Severely Water logged		Water logged		Prone to Water logged		Free from Water logging	
	Area (km²)	% of Total Area	Area (km²)	% of Total Area	Area (km²)	% of Total Area	Area (km²)	% of Total Area
1998	190.3	27.0	84.2	12.0	366.4	52.0	64.1	9.0
2003	73.1	10.4	175.4	25.0	407.5	58.0	49.0	6.9
2008	17.7	2.5	321.0	46.0	344.0	49.0	21.3	3.0
2013	53.06	7.5	340.0	47.0	293.0	41.0	24.5	3.5

Table 7. 5Hydro-Iso-Bath Estimates of central and lower Parts of the Kim River Basin

It can be seen from the quantitative assessment (Table 7.5) of hydro-isobath maps developed at 05 years interval; there has been a significant increase in the hydro-isobath classes. Although drastic decline (70%) , the most significant change has been observed in severely water-logged class; the water logged (Class II) category, which show grave rise (35%). The class III (Prone to waterlogging) & class IV (free from waterlogging) does not show any significant change in respective spatial hydro isobath coverage (Table 7.4).The observed drastic decline (~20%) in class I (severely waterlogged) category from 1998 to 2013 may be ascribed to urban and industrial growth in lower parts of the basin that must have led to over exploitation of groundwater to meet the sectorial demands. Therefore, farmers' inclination to grow water intensive crops may be considered as a prime factor in causing the water logging problem.

Realizing this very fact, many measures were taken up by the irrigation department to reduce the watertable by adopting various techniques like conjunctive use of water resources; restricting the release of canal water, encouraging farmers for adopting crop rotations; awareness and education to the farmers' community about water logging problem and adoption of modern irrigation methods like drip irrigation; reducing cultivation of water intensive

crops like sugarcane and paddy with pulses, cotton and cash crops (Navsari Agricultural University,2014) .

As a result the measures for reducing the water table are being adopted at village level, where alternative irrigation practice with groundwater and canal water is adopted. Owing to emerged awareness amongst the farmer community, the net sown area under the paddy and sugarcane cultivation in the study area has also reduced. Now, farmers are taking up water intensive crops on alternate year basis with a sole objectivity to reduce the water consumption and retain soil quality.

Groundwater is a replenishable resource primarily from precipitation. Therefore any change perceived in the groundwater storage is attributed to two important functions viz. recharge to the aquifer with precipitation as a prime source and groundwater draft. In Indian context, on an annual basis, monsoonal recharge is restricted to particular period. Therefore, any change in groundwater storage shall depend on the amount of recharge and groundwater withdrawal. Change in groundwater storage also takes into account all other hydro-climatic processes influencing groundwater storage, including the returned irrigation seepage.

Further, alteration in the groundwater storage is a function of aquifer composition and its hydraulic properties particularly the specific yield. As computation of study area's Water Footprint being one of the prime objectives; groundwater resource potential has been estimated using Water Level Fluctuation/Specific Yield Approach (Walton,1970 and Charlu & Dutt,1982).

Groundwater Resource potential:

The rise in the groundwater levels during the monsoon period leads to the increment in the groundwater storage due to rainfall recharge. The magnitude of rise in water levels is a measure of the recharge to the groundwater system, which is dependent on the specific yield of the formation materials comprising the aquifer (Charlu & Dutt, 1982). The groundwater in the

study area is classified as a dynamic resource and occurs in consolidated (basaltic), semi-consolidated (Limestone & sandstone) and unconsolidated (alluvial) formations at shallow depths. The observed seasonal changes in groundwater levels through a system of observation wells on annual basis leads to develop water table contour maps, and/or facilitate in estimating aquifer specific change by calculating aquifer specific area using Theissen's Polygon method. The groundwater recharge has been calculated using the following equation-

$$R = A \times S_y \times (h_1 - h_2)$$

Where, R = Recharge

A = Area under Evaluation

S_y = Specific yield of the aquifer

h_1 = Post-monsoon water level

h_2 = Pre monsoon water level

The author has considered available standard specific yield values for all the three different aquifers found in the study area (Walton, 1970) and based on the seasonal water level data collected for the years 2012 and 2013, the overall recharge for the basin has been calculated. The details on estimated groundwater recharge in the study area for the year 2012 and 2013 is given in Table 7.6

Aquifer Type	Area (km²)	Specific Yield (%)	Water Level Fluctuation, h_1-h_2 (m)		Change (MCM)		
			2012	2013	2012	2013	Average
Basaltic	540	7	4.5	7.1	170.10	268.38	219.24
Sedimentary	450	10	1.7	3.3	76.50	148.50	112.5
Alluvial	330	15	1.8	3.2	89.10	158.49	123.795
Total	1320		--		335.7	575.37	455.43

Table 7. 6 Groundwater Recharge Estimation for the Kim River Basin

As seen in the above table the annual recharge for 2012 is 335.7 MCM and that for 2013 is computed as 575.37 MCM. The low recharge in the

year 2012 is attributed to less rainfall received by the study area(607mm) during the year 2012.

GROUNDWATER CHEMISTRY

No matter how clear and sparkling may be, natural water is never absolutely pure. Study on regional groundwater quality holds a vital significance in understanding the geo-environmental implications. Chemistry of groundwater is governed by the factors related to chemistry of infiltrating water and the subsequent rock-water interaction within available physico-chemical environment. The suitability of natural water for any particular purpose depends upon the standards of acceptable quality for the respective use. Groundwater chemistry includes study of geologic and hydrologic controls on the chemical characters of groundwater (Beck, 1993). Hydro-chemical investigations are basically carried out to determine groundwater circulation, its sources, concentration, behaviour, and fate of dissolved chemical constituents present. The study of groundwater chemistry for the study area aims to realize –

i. Quantitative assessment of the various chemical parameters on seasonal basis

ii. Understand the mechanism of chemical interactions of groundwater and sediments based on seasonal variations

iii. Qualitative evaluation of groundwater for domestic and irrigation uses.

Groundwater quality is as important as groundwater quantity. The author has contemplated the chemical hydrogeology aspects on seasonal basis for two years (2012 & 2013). Groundwater sampling has been carried out simultaneously along with seasonal monitoring of groundwater levels through a system of observation wells established by the author (Fig 7.1). Few observation wells located in the upper basin were dry during the pre-monsoon season due to lean monsoon, therefore, sampling is ignored.

Groundwater samples collection was done using standard practice, prescribed in the USGS manual. The samples were collected in clean sterile white cans of 1L capacity. The author has determined various physical and

chemical parameters of the groundwater samples through extensive laboratory work using standard methods. The parameters like conductivity, pH and Temperature were measured in-situ while rest of the parameters were analysed in the laboratory. (Table 7.6)

Sr. No.	Parameter	Method/Instrument
1.	pH	pH Meter
2.	Electrical Conductivity	EC meter
3.	TDS	Gravimetric Method
4.	Hardness	EDTA Complexometric Titration
5.	Chlorides	Argentometric Titration
6.	Phosphates	Stannous Chloride Colorimetric Method
7.	Sulphates	Barium Chloride Precipitation Method
8.	Carbonates and Bicarbonates	Sulphuric Acid Titration
9.	Sodium and Potassium	Flame Photometer

Table 7. 6 Methods Adopted for Chemical Analysis of Groundwater Samples

Since the study area is prominent in its agricultural production, the author has also made an attempt to apply standard indices to decide the suitability of the groundwater for irrigation purpose and also for domestic use. Quantitative details on the observed physical and chemical composition of groundwaters in the Kim River Basin for the year 2012 & 2013 are presented in table 7.7 & 7.8.

No.	Village	pH		EC(mS/cm)		TDS		Ca^{+2}		Mg^{+2}		Na$^+$		K$^+$		Cl$^-$	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	Tadphalia	7.3	7.5	681	563	436	360	59	101	32	24	21	17	T	T	53	53
3	Pingut	7.6	7.7	572	340	366	218	50	97	18	12	16	12	T	T	71	62
4	Maujha	7.6	8.2	719	563	460	360	63	126	22	9	28	23	T	T	89	53
7	Dungri	8.2	7.8	1403	1500	898	960	88	134	46	28	160	104	4	1	195	178
8	Chandaniya	7.7	7.6	884	1438	566	920	55	151	25	47	33	33	T	T	107	186
9	Amkhuta	7.9	8.3	747	281	478	180	59	105	25	12	25	22	T	T	107	80
10	Jharni	7.7	7.4	444	1344	284	860	34	67	16	27	14	13	T	T	89	71
13	Nasarpor	8.2	7.7	547	344	350	220	55	55	32	20	26	27	T	T	89	36
15	Chaswad	7.5	8.6	809	1063	518	680	29	143	62	25	32	28	T	T	107	107
23	Wankal	7.2	8.6	1581	2594	1012	1660	88	210	134	77	41	32	T	T	391	231
24	Pataldevi	7.8	7.9	628	781	402	500	29	76	36	27	44	30	T	T	53	71
26	Deshad	7.6	7.6	4534	3781	2902	2420	88	252	177	75	340	154	T	T	781	657
28	Naogama	7.5	7.6	834	1063	534	680	46	256	45	165	77	70	T	T	124	124
29	Simodra	8	8.7	2250	2656	1440	1700	34	172	82	46	370	163	7	7	533	533
30	Limbada	8.5	7.6	7191	6938	4602	4440	176	340	257	90	760	501	63	48	1491	1456
31	Nandav	7.5	8.5	2234	2531	1430	1620	34	260	101	17	270	134	27	13	426	355
32	Dinod	8	8.5	5644	2063	3612	1320	160	130	195	45	330	98	439	163	710	302
33	Kosamba	7.9	7.6	6384	5406	4086	3460	361	365	84	28	560	190	9	3	1331	799
34	Hathoda	8.3	8.2	3691	4438	2362	2840	46	126	120	149	580	436	219	164	888	994
35	Warethi	8	7.6	2231	2219	1428	1420	17	50	34	30	490	194	T	T	515	275
36	Tadkeshwar	7.8	7.5	1072	938	686	600	63	105	35	36	610	51	3	1	178	133
37	Pipodra	8	8.4	1772	2125	1134	1360	21	50	36	45	420	180	2	1	355	293
38	Simalthu	8.3	8.2	1894	1813	1212	1160	17	29	21	36	460	194	9	6	497	391
39	Kachhab	8.6	8.5	3034	3375	1942	2160	42	46	28	38	650	436	20	25	817	577
40	Vadoli	8.3	8.5	7156	6844	4580	4380	122	113	113	184	1100	671	12	8	2396	1500
41	Koba	8.2	8.4	6894	4125	4412	2640	109	118	104	69	1050	626	33	26	2325	1207
42	Karanj	8.4	8.6	5100	2094	3264	1340	38	67	67	61	740	162	95	69	994	160
43	Kantiajal	8.1	-	1522	-	974	-	25	-	67	-	210	-	82	-	337	-

(Note: 1. The TDS and all ionic concentrations are in mg/l   2. *T=Trace, Below Detectable Limit   3. Pre= Pre-monsoon Season, Post =Post-monsoon Season)

Table 7. 7 Seasonal Chemical Composition of Groundwater (2012)

No.	Village	pH		EC (mS/cm)		TDS		Ca^{+2}		Mg^{+2}		Na$^+$		K$^+$		HCO$_3^-$		CO$_3^{-2}$		Cl$^-$	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	Tadphalia	7.8	7.4	500	603	320	386	38	57	67	25	21	12	T	T	122	92	90	Ab	89	43
3	Pingut	7.8	7.7	492	781	315	500	25	79	43	20	18	12	T	T	92	61	60	Ab	53	43
4	Maujha	7.8	7.7	344	431	220	276	29	57	60	14	25	10	T	1	488	214	Ab	Ab	53	28
7	Dungri	7.9	7.9	1281	1338	820	856	46	77	93	42	99	102	6	2	427	61	120	Ab	178	142
8	Chandaniya	7.9	7.8	937	1588	600	1016	21	121	77	59	31	34	T	T	397	275	Ab	Ab	89	213
9	Amkhuta	7.9	7.8	906	1034	580	662	21	106	53	38	27	27	T	T	122	31	60	Ab	71	92
10	Jharni	7.9	7.3	344	619	220	396	34	59	26	25	13	9	T	T	336	92	Ab	Ab	53	36
13	Nasarpor	8.1	7.6	1063	494	680	316	55	57	28	21	20	13	1	T	305	183	Ab	Ab	53	36
15	Chaswad	8	7.7	1781	1088	1140	696	50	87	50	39	60	29	T	T	336	122	Ab	Ab	124	99
23	Wankal	7.8	8.1	2531	1069	1620	684	143	45	71	67	30	21	T	T	397	275	Ab	Ab	373	142
24	Pataldevi	8	7.9	2906	716	1860	458	25	45	41	32	31	24	T	T	336	153	30	Ab	71	43
26	Deshad	7.8	7.5	2031	425	1300	272	126	101	162	138	183	38	1	2	458	366	Ab	Ab	852	36
28	Naogama	7.9	7.3	1250	1122	800	718	143	32	118	68	56	75	T	1	519	427	Ab	Ab	89	128
29	Simodra	8	7.6	3844	2631	2460	1684	147	34	66	123	193	181	21	4	305	214	60	Ab	692	575
30	Limbada	7.9	7.8	6250	3084	4000	1974	235	30	149	162	253	300	45	20	732	641	90	Ab	1207	639
31	Nandav	7.7	7.9	2813	1788	1800	1144	176	44	65	80	143	124	24	22	824	31	Ab	Ab	444	234
32	Dinod	7.8	8	7625	1866	4880	1194	340	102	170	31	178	93	326	141	488	397	Ab	Ab	1118	192
33	Kosamba	7.6	7.8	3813	2231	2440	1428	147	143	122	44	168	114	4	3	214	92	Ab	Ab	692	355
34	Hathoda	7.8	-	3500	-	2240	-	113	-	150	-	293	-	191	-	610	-	90	-	994	-
35	Warethi	8.1	8.4	2656	2216	1700	1418	25	18	45	34	233	76	1	1	427	366	60	120	337	341
36	Tadkeshwar	7.8	7.8	4719	1153	3020	738	29	129	104	23	35	54	1	1	366	336	Ab	Ab	195	163
37	Pipodra	8.3	8.4	2034	2041	1302	1306	84	17	39	46	203	189	4	2	519	366	90	60	337	284
38	Simalthu	8.1	8.2	1625	2506	1040	1604	46	34	11	28	223	710	7	8	275	61	120	Ab	426	568
39	Kachhab	8.3	8.5	3156	3903	2020	2498	50	55	54	75	318	420	34	42	458	427	60	60	799	873
40	Vadoli	8	8	7500	6272	4800	4014	67	67	239	214	443	565	11	9	427	397	30	Ab	1953	1527
41	Koba	7.6	7.7	3469	7738	2220	4952	84	176	34	165	308	505	35	21	1007	854	30	Ab	799	2123
42	Karanj	8.4	8.5	3031	7541	1940	4826	25	27	19	168	253	645	75	123	519	549	150	120	408	1072
43	Kantiajal	8.2	8.3	1250	4428	800	2834	21	60	38	100	87	315	77	64	427	458	90	60	178	781

(Note: 1. The TDS and all ionic concentrations are in mg/l   2. *T=Trace, Below Detectable Limit   3. Pre= Pre-monsoon Season, Post =Post-monsoon Season)

Table 7. 8 Seasonal Chemical Composition of Groundwater (2013)

Parameter*	2012				2013			
	Pre-monsoon		Post-monsoon		Pre-monsoon		Post-monsoon	
pH	7.2	- 8.6	7.4	- 8.6	7.6	- 8.4	7.4	- 8.5
EC (mS/cm)	570	- 7100	280	- 6800	340	- 7630	430	- 7740
TDS	400	- 4600	180	- 4400	220	- 4880	270	- 4950
Calcium	15	- 360	30	- 340	20	- 340	25	- 175
Potassium	Trace	- 440	Trace	- 165	Trace	- 325	Trace	- 140
Magnesium	10	- 250	10	- 185	10	- 240	10	- 210
Sodium	15	- 1100	10	- 670	10	- 440	10	- 640
Bicarbonates		-		-	90	- 1000	30	- 850
Carbonates		-		-	Nil	- 150	Nil	- 120
Chlorides	50	- 2400	50	- 1500	50	- 1950	30	- 2120

All parameters except EC and pH.

Table 7. 9 Seasonal Behaviour of Groundwater Chemistry in the Kim River Basin

Parameter (mg/l)*	AQUIFER TYPE					
	Basaltic		Sedimentary		Alluvium	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
pH	7.5 - 8.2	7.5 - 8.4	7.7- 8.2	7.5 - 8.3	7.9-8.5	8.2-8.6
EC (mS/cm)	400 -1000	400 -1800	1040 - 6700	1050 -3800	1400 -5200	2100 -6500
TDS	250 -1300	250 -1200	660 - 4300	670 -3200	890 -4700	1330 -4200
Calcium	25 -120	50 -120	20 -200	30 -170	20 -100	30 -150
Magnesium	20 -100	10 -70	40 -180	30 -150	10 -180	30 -200
Sodium	10 -130	10 -100	60 -500	50- 400	300 -900	315 -615
Potassium	Trace	Trace	01- 350	01-150	03 -90	10 -100
Bicarbonates	30 -120	Trace	0 - 90	0 -120	30 -120	0 - 120
Carbonates	90 -400	30 -200	210 - 825	30 - 640	275 -1000	60 - 855
Chlorides	60 -190	30 -200	180 -1000	125 -1045	255 -2200	290 -1650

All parameters except EC and pH.

Table 7.10 Aquifer Specific Seasonal Trends in Groundwater Chemistry

A critical appraisal on individual physical and chemical parameters is given as under-

pH:

The pH value of water represents the overall balance of a series of equilibria existing in solution (Hem, 1991). The pH of natural water is largely controlled by chemical reactions and equilibria among the ions in solution. In natural waters the hydrolysis due to carbonate and bicarbonate salts predominates in most instances, due to which pH value is enhanced >7 (Ageno and Valla, 1911). In the study area almost all groundwater samples for both the seasons show pH in the range of 7.2 to 8.6 (Table 7.9), indicating predominance of hydrolysis reaction due to the presence of carbonates and bicarbonates. Also, not much variation is seen in the pH values on the seasonal basis. The pH values are within the permissible limit of (6.5-8.5) of Irrigation Water Quality Standards. (IS: 2296).

Electrical Conductivity:

Electrical Conductivity (EC) measures the amount of total dissolved salts and is considered as a measure of salinity.The Electrical Conductivity (Table 7.9) shows marked seasonal variation ranging from 280 to 7740 mS/cm. EC in the lower basin parts comprising alluvium aquifers is very high indicating saline nature of groundwater (Table 7.10). It is observed that the groundwater samples collected from the wells comprising basaltic aquifers have low EC(400-1000 mS/cm) during the pre-monsoon season while in the post-monsoon season(Table 7.10); there has been a significant rise(up to 1800 mS/cm) . This rise in EC content may be ascribed to dissolution of salts due to weathering of feldspar & amphibole group of rock minerals and subsequent rock-water interaction (May & Todd, 2011). As the aquifers developed within the sedimentary and alluvial aquifers point to lower EC values in post-monsoon seasons; this may be attributed to higher degree of dilution occurred in the groundwater systems. Almost 54% of samples in the pre-monsoon seasons and 68% samples in the post-monsoon seasons were having the EC within the permissible limit of 2250mS/cm for irrigation standards. (IS: 2296).

Total Dissolved Solids:

The amount and type of the dissolved solids depend upon the chemical composition and physical structure of rocks, temperature, residence time and pH (Hem, 1959). The parameter Total Dissolved Solids (TDS) is indicative of an overall suitability of water; excess concentration of TDS restricts the use of water for any purpose. (McKee and Bacon, 1953). Therefore, it serves as an important basis for assessment of water quality. The Kim River Basin exhibits wide range of TDS from as low as 180 to as high as 5000 mg/l (Table 7.9). In order to appraise spatial distribution pattern of TDS and its seasonal behaviour, the author has developed Iso-TDS contour maps for the year 2013. It is evident from the contour map (Fig 7.12 & 7.13) that during the pre-monsoon season, the TDS concentration shows wide range in its quality as well as distribution throughout the study area, whereas, during the post-monsoon season spatial range variation is little.

The spatial distribution pattern through Iso-TDS contour during both the seasons shows development of maxima (>3000 mg/l) in the central part of the basin around Hathoda & Limbada villages. There has been an another maxima (>4000 mg/l) developed around Vadoli in lower part of the basin during pre-monsoon season (Fig 7.12). this suggests that by and large in the middle and lower parts of the basin, the groundwater quality is brackish in character (Hem,1959; May & Todd, 2011). In the upper basin, the TDS distribution shows normal levels, which may be attributed to flushing effect removing the dissolved ions to the lower and middle parts of the basin.
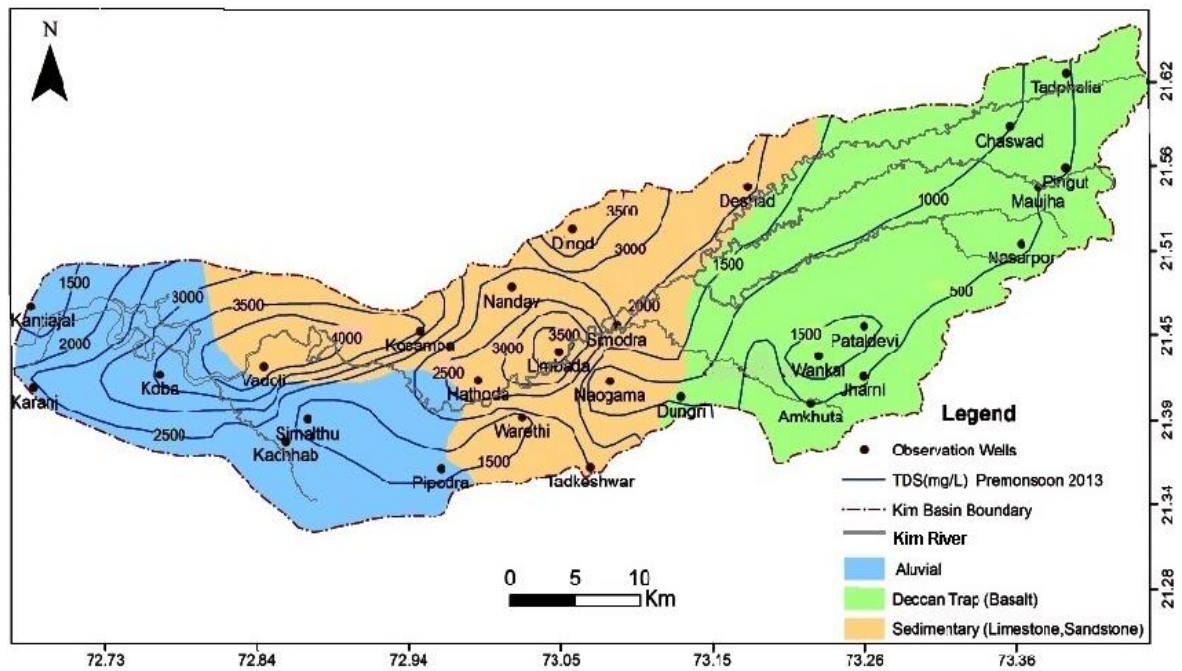
Figure 7. 12 Iso- TDS Contour Map of Kim River Basin (Pre-monsoon 2013)
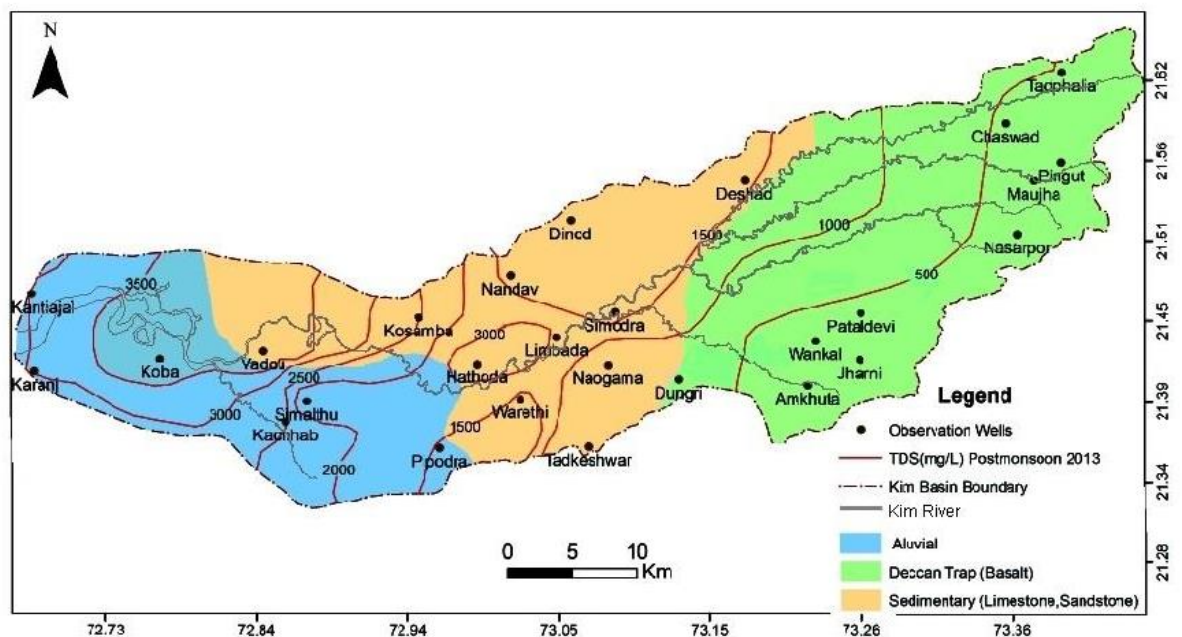

Figure 7. 13 Iso- TDS Contour Map of Kim River Basin (Post-monsoon 2013)

In order to evaluate chemical characteristics of groundwater author has analyzed only major cations viz., Calcium, Magnesium, Sodium and Potassium; and Anions viz., Carbonates, Bi-carbonates and Chloride.

Calcium:

Calcium is one of the most abundant cation, but is never found uncombined state in nature (Sharma and Chawla, 1977). Owing to its wide occurrence in all types of rocks and soils and its ready solubility, calcium is

present in nearly all types of waters (Matthess, 1982). Principal sources of calcium in the groundwater are the silicate minerals belonging to plagioclase feldspar, pyroxene and amphibole groups that are abundantly available in the igneous and metamorphic rocks. In the sedimentary rocks limestone, dolomite and gypsum are the chief sources of calcium (Davis and De Wiest, 1967). The Ca concentration in the groundwater during the pre- monsoon ranges from 20 mg/l to 340 mg/l, whereas during the post- monsoon season, it shows the range between 30 mg/l and 150mg/l. Dissolved calcium concentration is found to be high in the limestone (Sedimentary) aquifer (Table 7.10). As the concentration of calcium in groundwater is lower than sodium, which indicates presence of Base Exchange process in groundwater (Richard. 1968).

Magnesium:

        Magnesium is abundant in nature and forms a normal constituent of dolomite in sedimentary rocks and as a part of composition in biotite, hornblende, and augite minerals in basic igneous rocks like basalt (May & Todd, 2011). Most limestones also contain some magnesium carbonate. In the study area the basalts and limestones are the source of dissolved magnesium in groundwater. Magnesium concentration in the study area varies between 20 mg/l to 240 mg/l in both the seasons and does not show much variation on seasonal basis like other cations (Table 7.9).

Sodium:

        Sodium is considered to be the most important and abundant ion in mineralized groundwater with the exception of gypsiferous and many Ca-HCO$_3$ waters (Davis and De Wiest, 1967). It is considered to be the most injurious cation in irrigation waters (Glover, 2000). It takes part in no important precipitation reactions like calcium and magnesium, because nearly all sodium compounds are readily soluble (Hem, 1991). The sodium ion concentration in groundwater was estimated on seasonal basis and showed wide variation ranging from 15mg/l to 440mg/l and 10mg/l to 550 mg/l during the pre- monsoon and post- monsoon seasons respectively. The lower concentrations are

ascribed to the basaltic aquifers and their concentration tends to increase from upper (basaltic) basin to lower(alluvium) basin (Table 7.10).

Potassium:

The common sources of potassium are the silicate minerals like orthoclase, microcline, nepheline, leucite and biotite from igneous and metamorphic rocks and sylvite and niter from sedimentary rocks (Hem, 1970). Because of lower geochemical mobility in groundwater, potassium is seldom found in higher concentration in natural groundwaters (Matthess, 1982). Potassium is essential in plant nutrition and is removed from soil solution or from exchange media in the soil where plants are growing. The potassium in the plant structure is not returned to the soil, unless the plant is removed (Hem, 1959). In the study area, potassium concentration is found in traces from the basaltic aquifers. The potassium concentration in sedimentary aquifers (sandstone & limestone) and alluvium aquifers is found to be exceptionally high, i.e. pre-monsoon (326mg/l) and post-monsoon (141 mg/l) around Dinod village in limestone aquifers (Table 7.10); whereas in alluvium aquifers, pre-monsoon (up to 75mg/l) and post-monsoon (123mg/l) around Karanj and Kantiajal villages (Table 7.8) is observed. These exceptionally higher values of dissolved K^+ may be attributed to use of chemical fertilizers and /or livestock excreta as a source (Hem, 1970).

The dissolved anionic species (CO_3, HCO_3 & Cl) analysed by the author are given in Table 7.9. The role of anionic species is important from irrigation water quality point of view as with cationic affinity, these anions form salts. Thus, the concentration of these species is utilised by the author as standard indices to evaluate the groundwater for its irrigation suitability.

There exist numerous parameters and indices for evaluating the irrigation water chemistry impact on soil and crop. Irrigation water quality indices like Sodium Absorption Ratio, Soluble Sodium Percentage, Kelly's Ratio, Schoeller's Index and Puri Salt Index are applied to classify the groundwaters from different geological environments. Indices' specific details are given in ensuing   paragraphs.

Well No.	Indices	SAR		Kelly's Ratio		SSP		Schoeller's Index		Puri Salt Index		Permeability Index	
	Village	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	Tadphalia	0.5	0.4	0.14	0.11	12	10	0.52	0.54	-133	-312	28	32
3	Pingut	0.5	0.3	0.17	0.09	14	8	0.57	0.63	-102	-367	35	25
4	Maujha	0.7	0.4	0.20	0.13	17	11	0.41	0.38	-97	-363	52	52
7	Dungri	2.7	2.2	0.63	0.55	38	35	-0.07	0.00	-301	-13	48	46
8	Chandaniya	0.8	0.6	0.24	0.13	19	12	0.50	0.74	-29	-497	44	29
9	Amkhuta	0.7	0.6	0.21	0.15	18	13	0.53	0.57	-68	-392	39	20
10	Jharni	0.4	0.3	0.17	0.09	15	8	0.70	0.66	-98	-252	66	30
13	Nasarpor	0.6	0.6	0.19	0.20	16	16	0.49	0.14	-154	-173	53	45
15	Chaswad	1.1	0.6	0.30	0.15	23	13	0.41	0.58	29	-419	53	30
23	Wankal	0.6	0.5	0.11	0.10	10	9	0.86	0.78	-389	-490	27	35
24	Pataldevi	1.1	0.7	0.36	0.22	26	18	0.04	0.25	48	-162	62	44
26	Deshad	3.7	1.8	0.59	0.33	36	25	0.50	-0.02	749	-390	39	59
28	Naogama	1.4	1.3	0.35	0.28	24	21	0.05	0.12	-137	-347	27	56
29	Simodra	5.6	3.0	1.27	0.61	52	38	0.24	0.52	927	336	50	49
30	Limbada	5.8	7.4	0.77	0.88	42	47	0.42	0.35	1458	1044	41	58
31	Nandav	3.8	2.4	0.80	0.51	42	33	0.22	0.25	492	-111	48	43
32	Dinod	3.0	2.0	0.42	0.47	29	32	0.12	-0.19	20	-101	27	56
33	Kosamba	4.7	2.4	0.69	0.43	39	30	0.49	0.57	533	-495	37	39
34	Hathoda	7.2	6.2	1.37	1.01	54	50	0.08	0.18	1730	1504	51	48
35	Warethi	11.1	3.9	3.93	1.27	76	55	-0.25	0.29	1651	488	84	81
36	Tadkeshwar	8.0	1.1	2.27	0.27	47	22	-1.76	0.45	1339	-313	34	44
37	Pipodra	8.7	4.9	2.85	1.50	68	60	-0.37	0.02	1256	732	72	83
38	Simalthu	12.6	17.6	5.32	4.78	82	77	-0.12	-0.34	1503	2040	92	91
39	Kachhab	13.2	10.4	4.17	2.75	76	72	0.06	0.02	2123	1830	79	77
40	Vadoli	13.0	9.1	2.24	1.28	62	56	0.41	0.37	3769	2560	52	59
41	Koba	15.4	9.5	3.19	1.65	74	60	0.21	0.41	3795	2030	85	58
42	Karanj	13.0	7.8	4.10	1.33	80	55	-0.16	-0.47	2255	1729	95	72
43	Kantiajal	3.8	6.4	1.11	1.20	52	55	-0.15	0.31	607	1235	80	66

(Pre= Pre-monsoon Season, Post =Post-monsoon Season)*

Table 7. 11 Seasonal Level of Irrigation Water Quality Indices

Sodium Absorption Ratio (SAR):

Sodium Absorption Ratio (Richards 1954) indicates the degree to which water tends to enter into cation-exchange reactions in the soil. The sodium or alkali hazard in groundwater is determined by the concentration of cations and is expressed in terms of Sodium Absorption Ratio (SAR). If groundwater used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. Thus, SAR value for a given groundwater provides a useful index of the sodium hazard, affecting an individual soil. The SAR is calculated as-

$$SAR = \frac{Na}{\sqrt{\dfrac{Ca + Mg}{2}}}$$

(all the values are in meq/l)

The U.S. Salinity Laboratory has given a diagram inter-relating the SAR and EC /TDSto find out the degree of suitability of groundwaters in irrigation use and causing salinity and alkalinity hazards to the soil (Richards, 1954).

Salinity Hazard Class	EC (mS/cm)	Hazard Class	Percentage of Samples	
			Pre-monsoon	Post-monsoon
C1	<250	Low	0	0
C2	250-750	Medium	14	21
C3	750-2250	High	39	46
C4	>2250	Very High	26	32

Table 7. 12a: Salinity hazard classification on the basis of EC Values (After Richard, 1954)

Sodium Hazard Class	SAR	Hazard Class	Percentage of Samples	
			Pre-monsoon	Post-monsoon
S1	<10	Low	79	89
S2	10-18	Medium	21	11
S3	18-26	High	0	0
S4	>26	Very High	0	0

(After Richards, 1954)

Table 7.12b: Sodium Hazard Classification on the Basis of SAR Values
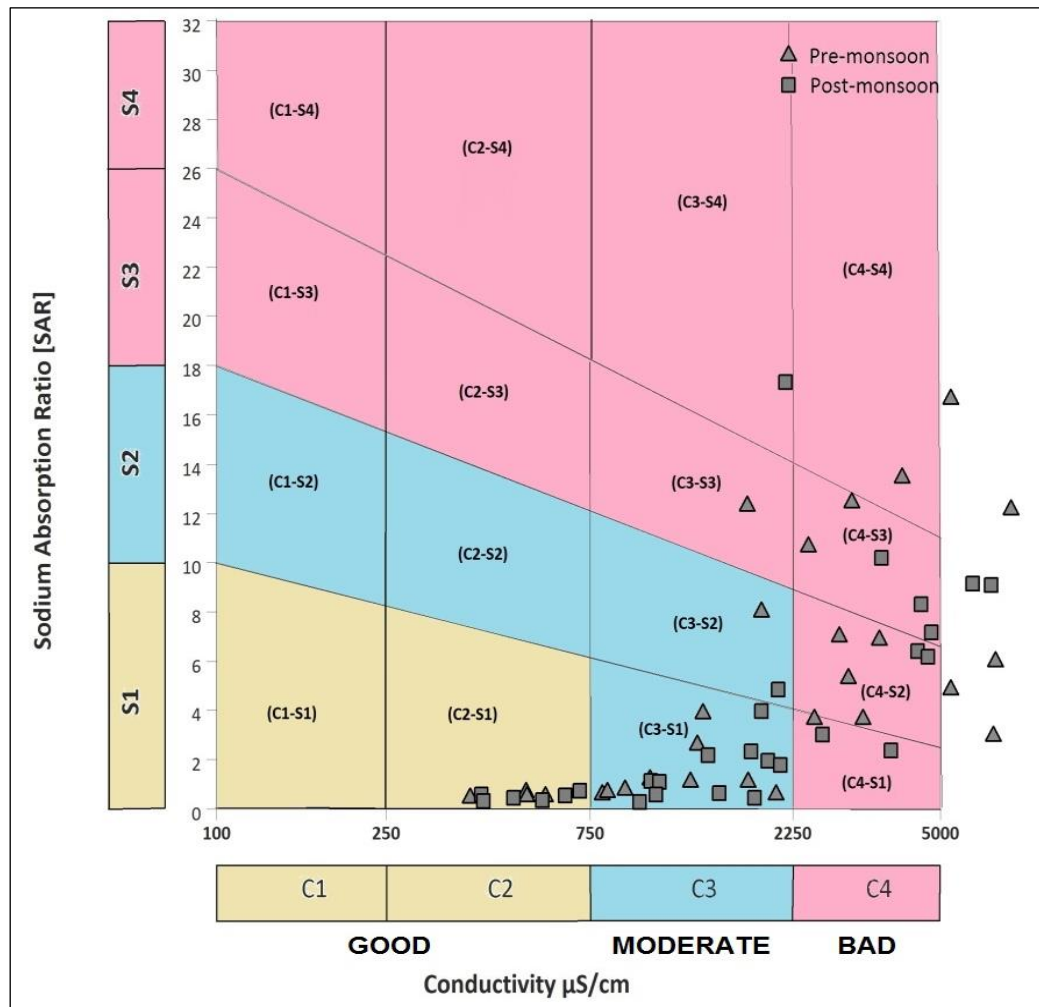
Figure7.14: US Salinity Chart for Classification of Irrigation Water
(After Richards, 1954)

The author's assessment on salinity and sodium hazards (Table 7.12 a & b) in the study area suggests that-

- Overall groundwater quality during post-monsoon season is better than the pre-monsoon period. This may be attributed to dilution effect of rainwater.

- Almost 79% of groundwater samples during pre-monsoon and 89% samples during post-monsoon seasons have SAR<10 which is suitable for irrigation use.

- SAR and EC values plotted in the U.S.Salinity Chart, show, only 14% of groundwater samples during the pre-monsoon and 21% groundwater samples during the post-monsoon season fall in the Class C2-S1 indicating Good water.

- 36% of pre-monsoon and 34% of post-monsoon groundwater samples are categorised as moderate waters belonging to Class C3-S1 and Class C3-S2 respectively for irrigation.

- 50% groundwater samples during pre-monsoon and 29% during the post-monsoon seasons fall in the class of Bad waters which indicates that the waters are unsuitable for irrigation owing too high salinity and alkalinity hazards.(After Richards,1954)

Soluble Sodium Percentage (SSP):

Soluble Sodium-Percentage determines the ratio of sodium to total cations viz., sodium, calcium and magnesium present in the water. Wilcox (1955) used Percentage Sodium and Electrical Conductance to determine the suitability of water for irrigation purpose.[10] SSP is calculated as-

$$SSP = \frac{Na}{Ca + Mg + Na} \times 100$$

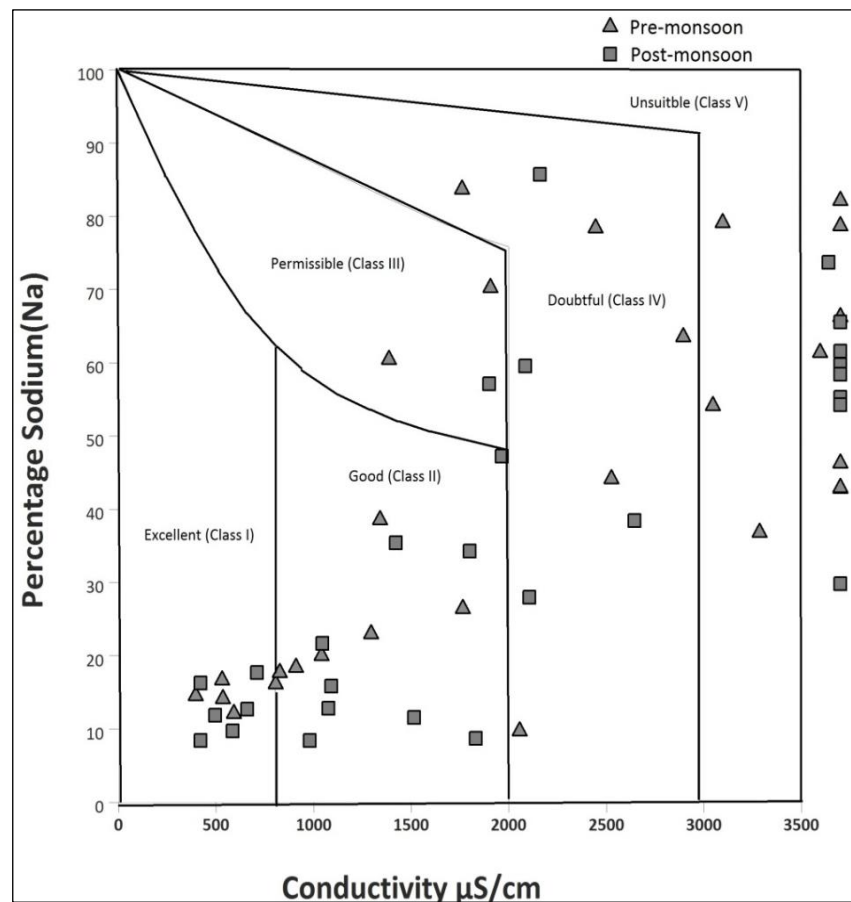*(all the values are in meq/l)*

Figure7.15: Wilcox Diagram for Sodium Percentage (After Wilcox,1955)

Wilcox classified the suitability of irrigation water by a diagrammatic method representing groundwater quality from specific fields (7.16). In this diagram, the % sodium is plotted against EC values to derive the groundwater quality class from five distinct categories of water, suggested as under-

Class	Category of Irrigation Water	% Samples	
		Pre monsoon	Post-monsoon
I	Excellent	18	21
II	Good	21	32
III	Permissible	07	03
IV	Doubtful	18	14
V	Unsuitable	36	29

(After Wilcox, 1955)

Table 7. 10: Classification of Irrigation Water Based on Soluble Sodium Percentage

From, Wilcox diagram (Fig. 7.15), it can be discerned that the groundwater quality during post-monsoon season is more suitable for irrigation as compared to pre monsoon season. It can be further summarized that almost 46% of pre monsoon samples and 56% of post-monsoon samples point to Suitability of groundwater for irrigation purpose; and the remaining belongs to Categories of Doubtful to Unsuitable groundwater that can pose threat to crops if used for irrigation. Most of the waters of the basaltic aquifers located in the upper basin parts fall in the Suitable Category of waters for irrigation. The groundwater quality gets deteriorated in the middle and lower basin parts. This deterioration in quality may be ascribed to over-irrigation, leading to enrichment of salts in the alluvium aquifers and extensive use of chemical fertilizers.

Kelly's Ratio (KR):

Suitability of water for irrigation purpose can also be assessed by calculating Kelly's Ratio (Kelly et al.,1951), which proposes that the potential sodium problems in irrigation water can be evaluated on the basis of following formula-

$$KR = \frac{Na}{Ca + Mg}$$
(all the values are in meq/l)

This ratio reflects the alkali hazards of groundwater. A Kelly's Ratio (KR) of more than one indicates an excess level of sodium in waters. Hence, waters with a Kelly's Ratio < 1 are suitable for irrigation, while those with a ratio >1 are unsuitable for irrigation. The obtained KR Values suggests that 61% (pre-monsoon) and 68% (post-monsoon) groundwater samples had Kelly's Ratio <1. Most of these groundwater samples were from the basaltic and sedimentary aquifers. Remaining samples show KI (>1) that belong to the alluvial aquifers in the lower parts of the basin.

Schoeller's Index (SI):

Schoeller (1959) used an index to determine the probable ion exchange reactions occurring in groundwater. The value of the index changes as the groundwater quality varies. The Schoeller's Index is given by-

$$SI = \frac{Cl - (Na + K)}{Cl}$$

(all the values are in meq/l)

The positive value of the SI indicates direct Base Exchange reaction in the groundwater, i.e. (Na + K) is exchanged with Ca and Mg, while the negative value of SI is indicative of indirect cation-anion exchange. In the study area, almost 75% groundwater samples (pre-monsoon) and 90% groundwater samples (post-monsoon) showed (Table 7.11) that the Schoeller's Index was positive indicating predominance of direct base exchange reactions while 25% groundwater samples (pre-monsoon) and 10% groundwater samples (post-monsoon)showed negative value of SI pointing to indirect cation-anion reactions . Groundwaters in the basaltic aquifers point to direct Base Exchange reactions in all the seasons. The SI (-) particularly in limestone and alluvial aquifers may be attributed to chloro-alkali disequilibrium within the groundwater regime (Schoeller,1959).

Puri's Salt Index (PSI):

It is also used for predicting sodium hazards. It represents the relation between Na^+, Ca^{2+}, and $CaCO_3$ available in irrigation water. Puri's Salt Index is calculated by the following formula-

PSI = (Total Na) - (total Ca-Ca in CaCO₃) x 4.85

(All the values are in mg/l)

PSI is negative for all good water and positive for those unsuitable for irrigation. 46% of pre-monsoon and 61% of post-monsoon groundwater samples indicate PSI (-) therefore belong to good water category. The spatial distribution of Puri Salt Index clearly shows that all the groundwaters from the basaltic aquifer along with few samples from sedimentary aquifers are groundwater suitable for irrigation purpose irrespective of the seasonal variation. Samples from the alluvial aquifers and few samples from sedimentary aquifers show PSI (+) indicating non-suitability of groundwaters for irrigation purpose.

As revealed by various physico-chemical indices (Table 7.11), the study area is characterized by varied groundwater quality. This heterogeneity offered in chemistry predominantly governed by geological environment and anthropogenic factors. The consolidated, partially weathered basaltic aquifers in the upper basin possess good quality water suitable for irrigation. The semi- consolidated sedimentary aquifers in the central part of the basin although are all year round source of water; however groundwater quality is not acceptable for irrigation due to solution weathering (May & Todd, 2011). The unconsolidated alluvium aquifers distributed in the central and lower parts of the basin have high potential of groundwater but quality wise is Unsuitable for irrigation due to high enrichment in various cations and anions. As such, the region being part of irrigation canal command undergoes extensive agricultural practice throughout the year therefore the groundwater use is extremely restricted. Extensive flood irrigation causes greater returned irrigation seepage allowing slow and steady rise in groundwater levels as well as deterioration in groundwater quality due to enrichment in salts. Many regions are facing serious problem of waterlogging which has faded the soil as well as groundwater quality particularly in the lower reaches of the study area.