CHAPTER 3

QUALITATIVE ANALYSIS OF GROUNDWATER IN HYPER ARID REGION

This chapter provides a qualitative assessment of groundwater in Bikaner district, which is a hyper arid region in the State of Rajasthan, India. The objectives of the chapter are to (i) analyze various physicochemical parameters for assessing the groundwater quality in the Bikaner district using multivariate statistical methods, and (ii) assess the groundwater quality using fuzzy multi-criteria decision making tool.

3.1 INTRODUCTION

The groundwater is considered as a blue gold of vital social and economic importance. It affects the human health and agriculture sector severely due to its poor quality. The sustainability of groundwater quality and quantity is essential for its domestic and agricultural uses so that it can be utilized effectively for a long time in an optimal manner without damaging to the environment (Singh 2010). As water is a good solvent, it is highly vulnerable to degrade by its quality due to geological formations, anthropogenic sources of pollution and other developmental actions (Das et al. 2018; Tiwari et al. 2017). With accelerated and uncontrolled development projects such as stock farming, irrigation, urbanization, and industrialization, a large quantity of waste products are being generated and discharged which ultimately contaminate groundwater. Therefore, the hydro-geochemical processes, responsible for quality of groundwater, are a matter of growing interest. Vasanthavigar et al.

(2010) considered hydrogeochemical parameters to ascertain the suitability of groundwater for human needs as well as for irrigation purposes. Li et al. (2016) reported that the variation of regional hydrology and water resources are driven by human activities and natural environmental changes. The dissolved salts in groundwater increase its salinity due to weathering of mineral rocks which when comes in contact with groundwater, results in increased concentration of various cations and anions in the water. The active management of agricultural landscapes is affecting the water quality of the groundwater aquifers. The use of wide variety of fertilizers, manure, excessive phosphorus and nitrogen substances during agricultural production causes the degradation of water quality (Getahun and Keefer 2016). The water quality degradation in case of arid to hyper arid regions occurs due to over exploitation of groundwater and exposure of groundwater to mineral deposits in the aquifer region. Many researchers have carried out groundwater quality assessment in India (Gautam et al. 2015; Kamra et al. 2002; Kumar et al. 2015; Ravindra and Garg 2006; Singh et al. 2002). The studies have found that over exploitation of groundwater results in degradation of water quality and gradual drop of groundwater table up-to 30 meter for most of the wells (Chintalapudi et al. 2017). It increases the content of fluoride, nitrate, iron, and other heavy metals in the groundwater with an increase in salinity of the water (Gautam et al. 2015; Kamra et al. 2002; Singh et al. 2002). The contamination of groundwater once occurred from agricultural residues, fertilizers, and over exploitation can persist for decades as the movement of water inside the aquifer is very slow. Earlier studies carried out to assess the quality of groundwater reveal that the chemistry of groundwater is governed by typical correlations and interactions among a wide range of physicochemical variables (Praveena et al. 2010; Singh and Mukherjee 2015). A study by Singh and Mukherjee (2015) assessed the geochemistry of groundwater in the western part of India, whereas, the study from Praveena et al. (2010) assessed groundwater quality of unconfined aquifers using numerical and hydro-chemical approaches. The chemistry of groundwater can ascertain its use for drinking and agricultural needs. Jasrotia et al. (2018) evaluated the groundwater quality parameters using geochemical plots and various other hydro-chemical analysis methods in order to assess the geochemistry of the groundwater.

Rajasthan is the largest state of India which stands at very critical juncture due to its alarming decrease in ground water levels. As surface water potential is inadequate and rainfall is meager, there is increased dependence on ground water for meeting almost all types of water requirements. Contamination is prone to increase in these regions due to inefficient water pumps and irrigation systems. The excess infiltration of ground water is due to its low prices and believed abundant availability in the aquifers, which is not true for every location (Schmoll et al. 2006).

The present study deals with Bikaner block of Rajasthan, India which comes under the category of hyper-arid zone receiving a few precipitations (100-350 mm) in a year. Number of pumping wells in the region has reached a drastic number for drinking and irrigation purposes in the last decade. The block is facing an acute shortage of groundwater resources with the stage of groundwater development for the study area as high as 146.66 %. Most of the area comprises of alluvial aquifer system and is underlain by highly permeable and well drained sandy to sandy loam soils, which is coarse in texture. The alluvial aquifers become vulnerable to contamination due to their high permeability and shallow characteristics (Singh et al. 2005). Along with this, anthropogenic sources and hydro geochemical processes may be accountable for contaminating the groundwater. Thus, there is a need to carry out extensive investigation on the issues to assess different processes involved in contaminating groundwater (Helena et al. 1999). In recent years, the prevailing ground water situation in the block has become alarming due to incessant falling of water levels in the wells. The aquifer chemistry is severely affected by the anthropogenic and natural activities, thus an attention is required to focus on these activities for sustainable management of the ground water (Subba Rao et al. 2006).

The multivariate methods such as, Hierarchical Cluster Analysis (HCA), Principal Component Analysis (PCA) for understanding the multifaceted data promises a clearer understanding of water quality in the area under consideration (Srinivas et al. 2015). Probable sources that are liable for the variations in ground water quality can be ascertained effectively by applying the above said techniques. These techniques can be considered as an important tool in order to formulate suitable policies for real time and sustainable management of the groundwater assets (Singh et al. 2005; Singh and Ghosh 2003; Singh 2008). In the present study, the groundwater samples have been collected for water year 2016 during both pre-monsoon and post-monsoon period. These samples were analyzed using charge balance error method and statistical z-score were computed. Finally, 14 samples out of 43 samples were found appropriate for further analysis. Different multivariate statistical techniques were applied to extract information about the similarities or dissimilarities between the sampling sites, identification of water quality variables responsible for spatial and temporal variations in groundwater quality, the hidden factors explaining the structure of the database, and the influence of the possible sources (natural and anthropogenic) on the groundwater quality parameters. The major issues addressed in this study are 1) evaluation of the suitability of groundwater in the Bikaner block of Rajasthan, 2) assessment of prevailing association amongst the contributing parameters and/or groundwater occurrence and 3) determination of the utility of multivariate statistical methods in order to achieve sustainable groundwater quality management. Figure 3.1 of the study depict the graphical representation of research work carried out in this study. It explains the major problem and need of the study, research methodology adopted, and findings of the present study.

Major problems of sustainable groundwater management and Need of the study

- Groundwater is the only source of fresh water for both drinking and agricultural use in hyper-arid regions of Rajasthan
- Alarming decrease in groundwater levels and scanty rainfall.
- The region is facing acute shortage of groundwater resources with the stage of development as high as 146%.
- The shallow and highly permeable aquifers in the region are more vulnerable to contamination.
- Data collection and data quality are two main constraints for groundwater quality assessment

Selection of study location	Data Collection	Data Standardization	Statistical Analysis	Results and discussions
▪ Location and extent ▪ Climate and rainfall ▪ Physiography and geo-morphology ▪ Land use ▪ Crops ▪ Soil ▪ Geology	▪ Sampling location identification using GPS ▪ 43 tube-wells sample were collected ▪ Pre-monsoon data collection ▪ Post-monsoon data collection	▪ Ion balance study ▪ Charge imbalance error ▪ Z score computation ▪ 14 well samples found robust for further analysis	▪ Multi variate statistical analysis ▪ Principal component analysis ▪ Hierarchical cluster analysis	▪ Geochemical plotting ▪ Piper plot ▪ Wilcox plot

Major findings

- It is found from the study that the quality of groundwater is not fit for drinking and agriculture purposes.
- The groundwater is mainly affected by alkali and salinity hazard.
- Results thus obtained can be used for selecting index well
- The index well can serve a centre point for the groundwater quality monitoring and devising a suitable policy for sustainable management of groundwater.
- Collection and monitoring of data for only index well can provide groundwater quality of the region.
- Process of groundwater quality monitoring is cost effective and easy.

Figure 3.1 Summarized graphical representation of the present study

The present study focused on the overall groundwater quality in the Bikaner region by analyzing the various groundwater quality parameters. However, the study has not discussed the relation of these parameters according to groundwater uses. Therefore, to visualize the sustainability issues of groundwater quality in the domestic and irrigation uses, another case study has been carried out. The study area for the second work belongs to same region (Bikaner district), but for block level (Dungargarh Block) to cover the domestic and irrigation aspects of groundwater quality. The second case is described in section 3.6.

These studies meticulously contribute to the limited number of groundwater quality studies in the region facing water scarcity and also its applicability to other similar regions. The study presents a novel approach using multi criteria decision making tools and hydro-geochemical plotting to understand the interrelationship among various groundwater quality parameters in a hyper arid region of western Rajasthan supporting decision makers for devising a suitable policy for sustainable groundwater management. It discusses critical issues of groundwater quality and identifies critical physicochemical parameters regulating the groundwater quality in the region, which ultimately creates a mass awareness among the various stakeholders and policy makers as well. Hence, it is expected to yield direct benefits to society and to create awareness among people in a groundwater dependent ecosystem.

3.2 LITERATURE SUMMARY

A detailed literature review has been presented in section 2.2 which indicates that a groundwater quality assessment using hydro-geochemical parameters is a common approach to understand the hydrology and status of groundwater. Some of the studies were found close to the research aim of the current study and towards assessment of groundwater quality in a hyper arid to arid region though they do not belong to chosen study area. Few important observations have been inferred as discussed in Chapter 2 to formulate objectives and scope of this chapter.

3.3 STUDY AREA

3.3.1 Location and Extent

Bikaner is located in the north-western part of the state of Rajasthan and has an international border with Pakistan. It occupies an area of 30381.75 sq km and lies between 27° 11’ and 29° 03’ north latitudes and 71° 54’ and 74° 12’ east longitudes. The district is having five blocks/Panchayat samities viz. Bikaner, Kolayat, Lunkaransar, Sri Dungargarh, and Nokha. The location of study area is shown in Figure 3.2.

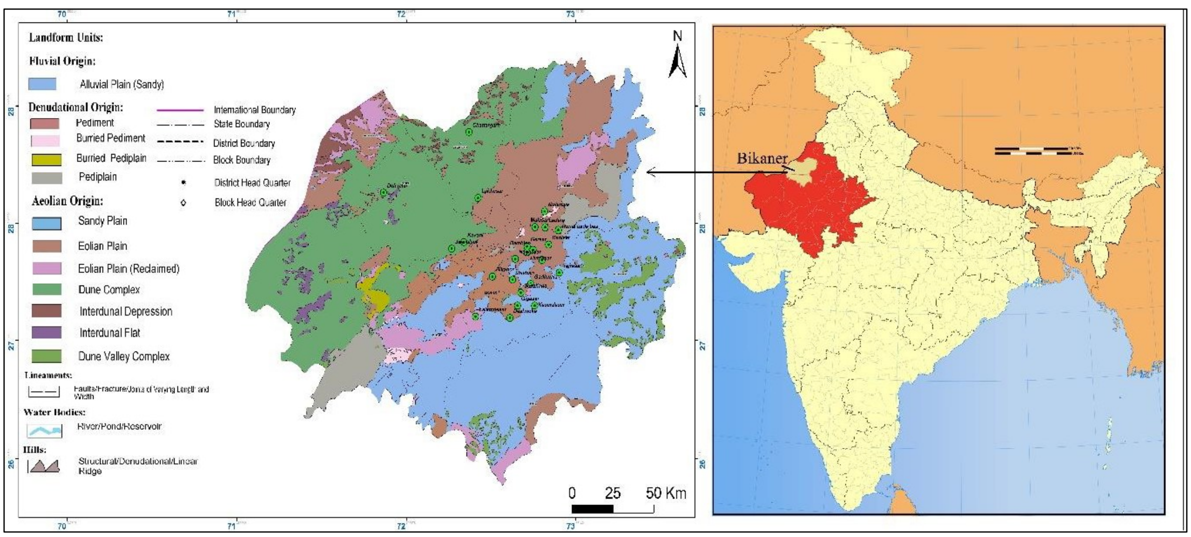


Figure 3.2. Location of the study area

3.3.2 Climate and Rainfall

The climate of the Bikaner block ranges from arid in the east to extremely arid/hyper-arid in the west and is characterized by large extremes of temperature, erratic rainfall and high evaporation. Being situated on the western side of Aravalli hill ranges, the area is characterized as typical rain shadow region resulting in low precipitation. The normal annual average rainfall of the block is 262.11 mm for the last 108 years (1901-2008). The temperature in the winter season is fairly low and there is a probability of frost occurrence once in three years. Wind speeds during the winter season are low with an average value of 4.5 km/hr, the main direction of wind being North-East. High temperatures in the block start from April onwards whereas May and June are the hottest months of the year.

3.3.3 Physiography and Geomorphology

The general regional slope of the block is from SSE to NNW and regional elevation above MSL is about 152 m in the western part and 275 m in the eastern part. The block has no major river. Alluvium, tertiary and paleozoic sandstone are the main water-bearing formations in the block. The depth to water in the block ranges between 5 m to 136 m below ground level (bgl). Based on the history of evolution, slope, erosion and depositional characteristics, size and nature of sediments, drainage system and salinity hazards, the existing landforms of the block can be described as flat and gravelly aggraded older alluvial plains.

3.3.4 Land Use

About 35 percent of the total area of the district is cultivated. However, the area sown varies up to 45 percent depending upon rainfall occurrence in a particular season of the year. The percentage of uncultivable land is about 55 percent depending upon annual rainfall characteristics, nature of geomorphology and non-availability of water sources. The forest and pasture lands of the district are accounted for 2.59 percent and 1.77 percent respectively.

3.3.5 Geology

The rock formations in the block are mainly concealed beneath a thick cover of dune sand. However, a very few isolated rocks are exposed to the surface. On the basis of available literature and lithology of existing dug wells and tube wells in the region, it has been found that the rock units in the block exist from Paleozoic to Quaternary periods. A generalized geologic succession of the rock formations occurring in the block along with their lithological characters is given in Table 3.1.

Table 3.1 Geological succession of Bikaner district

Group	Series	Geological Unit	Lithological Characteristics	Water Bearing Properties
Quaternary	Recent	Wind-blown sand	Very fine to fine, buff to grey sand, well rounded to sorted by wind action.	Generally lies above the zone of saturation.
	Pleistocene	Alluvium	Unconsolidated to loosely consolidated sand, fine to medium, silty clays and kanker with occasional horizons of gravel sand and coarse sand. Sodium salt and gypsum occur at places. Thickness varies from 4 to 70 m.	Yield low to moderate supplies of water. Quality varies from potable to brackish.
Tertiary	Eocene	Sandstone	Coarse and gritty sandstone usually semi unconsolidated, porous with intercalated clays and gravel. Fuller's earth, bentonite and lignite also occur in this sequence. Its thickness varies from 50 to more than 276 m.	Supplies moderate to fair quantity of water to wells. Quality varies from fresh to saline.
Paleozoic	Marwar Super Group	Nagaur Sandstone	Hard, compactly consolidated, reddish sandstone. Thickness varies from 140-250 m. Interbedded with red shales.	Yields low to moderate discharge. Quality of groundwater is fresh to saline.
		Bilara Limestone	Limestone, hard, massive. Grey to blackish in color with occasional cavities. Thickness varies from 115 to 225 m.	Yields low to moderate discharge. Quality is fresh to saline.

3.4 RESEARCH METHODOLOGY

3.4.1 Data Collection and Standardization

Groundwater samples were collected from 43 tube wells that were located in various villages of Bikaner block during the pre-and post-monsoon period in the year 2016. Sampling locations were identified using the Global positioning system (GPS) as shown in Table 3.2 of the study. Samples were collected in polyethene bottles as per the prescribed standard. These were filtered through 0.45 μm membrane filter and split into two portions: one acidified with concentrated HNO_3^- for dissolved cation estimation and the other for rest of the estimations.

Table 3.2 GPS location of the villages in terms of longitude, latitude and average mean sea level

S. No.	Village	GPS location		Mean sea level (m)	S. No.	Village	GPS location		Mean sea level (m)
		Longitude	Latitude				Longitude	Latitude	
1.	Bambloo	73.496	28.033	214	2.	Shivbari	73.383	27.887	214
3.	Bikaner	73.272	27.903	229	4.	Surdhana	73.428	27.816	235
5.	Chattargarh	73.143	28.610	266	6.	Deli talai	72.673	28.311	181
7.	Deshnoke	73.368	27.694	266	8.	Gadhwala	73.483	27.867	228
9.	Gersar	73.463	28.050	210	10.	Gigasar	73.410	27.754	265
11.	Himtasar	73.462	28.021	206	12.	Kavani	73.115	28.071	180
13.	Jaimalsar	73.048	28.039	184	14.	Kesardesar	73.504	27.754	269
15.	Malasar	73.506	28.143	202	16.	Ladera	73.562	28.142	203
17.	Molaniya	73.559	28.219	201	18.	Lakhusar	73.193	28.285	205
19.	Nuarangdesar	73.545	27.984	227	20.	Lalamdesar	73.179	27.701	273
21.	Ranisar	73.581	28.059	215	22.	Naggasar	73.398	27.989	208
23.	Runiabada bas	73.635	28.129	212	24.	Tejrasar	73.640	27.922	172

Electrical conductivity, pH and total dissolved solids were measured in the field with portable meters. Samples were stored at 4°C and alkalinity, chloride, phosphate, nitrate, and sulfate were estimated as per the standard methods (Clesceri et al. 1998).
The accuracy of estimation was verified by analyzing standard reference materials. The data thus obtained were first of all tested for charge imbalance error and only 14 samples were found suitable for further analysis. As far as PCA method is concerned, Bartlett's sphericity test and Kaiser-Mayer-Olkin (KMO) test were conducted to justify the groundwater sample data and its adequacy. The Bartlett's sphericity test carried out on the correlation matrix shows a calculated value of χ^2 (chi-sq.) = 452.706, which is greater than the critical value as specified in the literature χ^2 =146.6 (with Pearson coefficient (P) = 0.05% and degrees of freedom 91°). Thus, PCA method can be applied effectively to achieve a significant reduction of the dimensionality of the original dataset.

The initial step to carry out the PCA and HCA methods is to standardize the dataset of all physicochemical water quality parameters, of all water samples. This hydro-chemical data was analyzed in the following steps. If $x_{i,\dots,}x_p$ denote the P variables, with N number of observations, the j^{th} observation of the i^{th} variable is X_{ij}, where i= 1,…, P and j = 1,…, N. If S and X_m denotes the standard deviation and mean, estimated from the N observations of the i^{th} variable respectively, then the j^{th} observation of the ith variable is expressed in standardized forms as;

$$Z_{ij} = \frac{X_{ij}-X_m}{S_i} \qquad (3.1)$$

where Z_{ij} is the j^{th} value of the standardized variable Z_i. This value of Z_i is called as z-score (Liu et al. 2003). In the present study for PCA and HCA methods, the data were first standardized by computing z-scores from the non-normal condition and ascertaining the normal distribution of the data. The mean and variance of z-score were found to be 'zero' and 'one' respectively for all values. Standardization of data enhances the impact of variables having small variance and decrease the impact of variables with large variance. Further, the standardization of data nullifies the impact of units of measurement and makes the data dimensionless.

3.4.2 Principal Component Analysis

Principal component analysis (PCA) discovers a novel orthogonal co-ordinate system of un-correlated variables to present the original data (chemical). Each principal vector (coordinate direction) is described as a linear combinations of the original variable. Here, the first principal vector, is in the direction of largest variance from the original data. The eigen value associated with each direction is a measure of the variance occurred in that particular direction. Each following principal vector is used to be orthogonal to the previous vectors and it is in the direction of largest variance, which is not accounted for the previous vector(s). The dimension/dimensionality of the data can be decreased by ignoring the vectors associated with small eigen values, which account the lease variance. This process is very useful for identification of variables that are correlated (Mrklas et al., 2006). Consequently, PCA is a useful tool to explicitly deal with the variance occurred in interrelated or closely related variables to reduce the dimensionality in data set (Rao et al. 2020). In this study, PCA method was applied to extract significant principal components (PC's) and the values thus obtained were fed to perform varimax rotation analysis for generating varifactors (VFs). Principal components are linear combinations of the original variables. The aim of PCA is to dimensionally reduce the contribution of the variable of less importance as compared to another variable in the water quality data set. The variance of data obtained in the analysis helps to identify the most contributing variable in the dataset (Shrestha and Kazama 2007). The PC's so obtained lie along the directions of maximum variance. Three principal components were retained, following the criteria which suggest using all the PC's up to and including the first one after the break, with eigenvalues more than unity and describing percent of the variance in the original dataset. Referring to the Eigenvalue of a PC suggest that if the Eigenvalue is more than unity then it provides more useful information about the underlying facts and impact of contribution thus ensuring the reduction in dimensionality (Cattell and Jaspers 1967). Along with obtaining PC's, PCA provides correlation matrix which describes the relationship of each parameter with one another.

3.4.3 Hierarchical Cluster Analysis

Cluster analysis is a tool to classify the right group of data as per their similarity to each other. The Z score of all the variables make it possible to standardized, before they are subjected to cluster analysis. The Euclidean distance implies the higher similarity among the measured objects. In cluster, the different groups may reveal either the collaboration/interaction between the variables or the collaboration/interaction between samples. The cluster analysis methods are of two type - nonhierarchical cluster analysis and hierarchical cluster analysis. Ward's method or clustering process is used in the hierarchical method to find number of clusters. In the present study, a hierarchical cluster analysis (HCA) has been applied to identify the relatively homogenous groups of cases or variables based on their intrinsic properties. In HCA, clusters are generated successively starting with most alike pairs of variables and generating greater clusters progressively. Cluster analysis is the task of combining a set of variables in a way that the variables in the group known as cluster show much more similarity with one another than those variables which lies in other clusters. The outcomes of HCA helps in understanding the data and designating the patterns (Singh et al. 2005). The HCA was applied to the standardized data set by deploying Ward's method using Euclidean distance as a degree of resemblance.

3.5 RESULTS AND DISCUSSION

On the basis of a methodology developed in this study, results were obtained using both PCA and HCA. The subsequent section describes the results obtained from PCA, HCA and geochemical plots.

3.5.1 Principal Component Analysis

In this study, the PCA is carried out to assess the influence of water quality by evaluating the chemical associations as described by the factor loadings. The PCA was carried out using a dataset consisting 14 groundwater samples from Bikaner block.

The first three factors are selected adopting correlation criteria as described in Table 3.3, to represent the prevailing hydro geochemical phenomenon as described in Figure 3.3. a) and b), which have helped in the formation of the present groundwater chemistry without losing the information of interest.

The output of PCA reveals that the first three eigenvalues together account for over 87.149% of the total variability of the combined population for pre-monsoon and 85.497% for post-monsoon as shown in Tables 3.4 and 3.5 respectively.

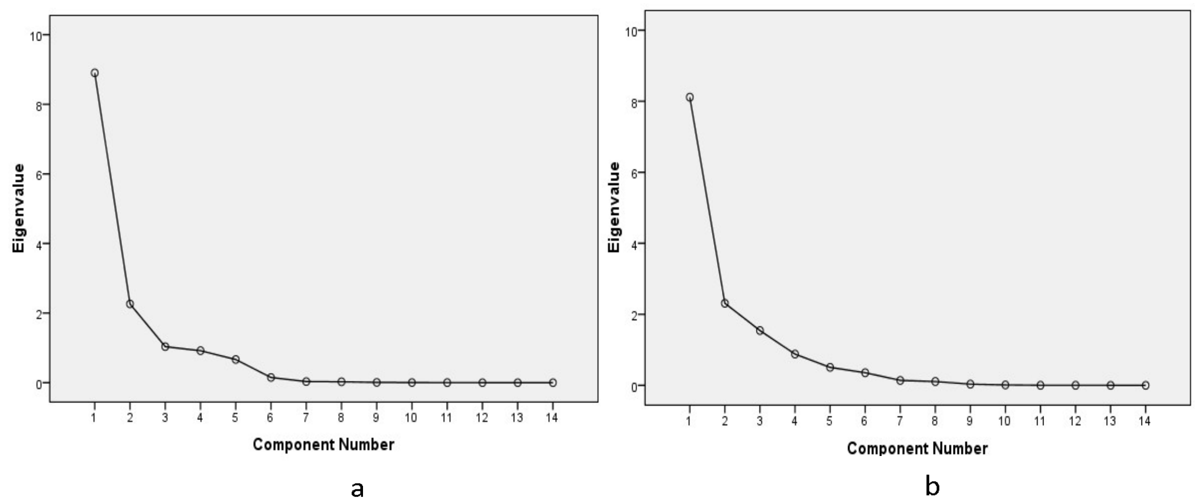


Figure 3.3. Scree plots for a) pre-monsoon and b) post-monsoon

Table 3.3 Correlation criteria

Eigen values	Correlation
0 to 0.29	Negligible
0.3 to 0.49	Low
0.5 to 0.69	Moderate
0.7 to 0.89	High
0.9 to 1.00	Very high

Table 3.4 Pre-monsoon total variance explained

Total variance explained pre-monsoon									
Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
PC 1	8.904	63.596	63.596	8.904	63.596	63.596	7.514	53.673	53.673
PC 2	2.262	16.158	79.755	2.262	16.158	79.755	2.720	19.427	73.100
PC 3	1.035	7.394	87.149	1.035	7.394	87.149	1.967	14.049	87.149

Table 3.5 Post-monsoon total variance explained

Total variance explained post-monsoon									
Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
PC 1	8.115	57.961	57.961	8.115	57.961	57.961	7.588	54.199	54.199
PC 2	2.311	16.509	74.470	2.311	16.509	74.470	2.367	16.907	71.106
PC 3	1.544	11.026	85.497	1.544	11.026	85.497	2.015	14.391	85.497

For pre-monsoon, the first Principal Component (PC 1) after varimax rotation as shown in Table 3.6 (a), which accounts for more than 63% of the total variance, has very high loading on TDS, Na^+, K^+ and NO_3^- and significant/high loadings on EC, Mg^{++}, F^-, and $SO_4^{--}$and TH. Whereas, for post-monsoon, the first Principal Component (PC1) has very high loading on EC, TDS, Na^+, Mg^{++}, Cl^- and TH and significant/high loadings on Ca^{++} and SO_4^{--}as shown in Table 3.6 (b). For pre-monsoon, the second Principal Component (PC2) after Varimax rotation, which accounts for more than 16 % of the total variance, has very high loading on pH and significant/high loadings on Ca^{++}.

For post-monsoon, the second Principal Component (PC2) has significant/high loadings on K^+. For pre-monsoon, the third Principal Component (PC3) after Varimax rotation, which accounts for more than 7% of the total variance, has significant/high loadings on HCO_3^- whereas for post-monsoon, the third Principal Component (PC3) has very high loading on CO_3^- and significant/high loadings on HCO_3^-.

The major contributor of Ca^{++} seems to be gypsum, dolomite, and limestone occurring in the sedimentary basin of the area. Water in contact with gypsum can attain higher calcium contents and solubility of gypsum increases in saline waters. Principal sources of Na^+ could be the precipitate of sodium salts impregnating the soil in shallow water tracts particularly in arid and semi-arid regions.

Table 3.6 Rotated component table for a) Pre-monsoon and b) post-monsoon

a)

Rotated component pre monsoon			
Variable	PC 1	PC 2	PC 3
NO_3	.945	-.115	-.264
TDS	.942	.236	.186
K	.941	-.004	-.217
Na	.927	.131	.203
EC	.889	.256	.302
SO4	.875	.391	.122
F	.794	.178	-.114
Mg	.792	.483	.353
TH	.700	.592	.381
Cl	.622	.397	.577
pH	-.120	-.917	.172
Ca	.529	.717	.399
CO_3	.068	-.535	-.480
HCO_3	.047	.031	-.795

b)

Rotated component post monsoon			
Variable	PC 1	PC 2	PC 3
TDS	.980	.154	-.003
EC	.978	.125	.047
Mg	.950	.058	-.018
Na	.945	.053	-.029
Cl	.927	.054	-.137
TH	.911	.323	-.093
SO4	.894	.354	-.116
Ca	.818	.377	-.019
NO3	.688	-.081	.371
K	-.055	.865	.350
F	.247	.802	.042
pH	-.371	-.580	.481
CO3	-.104	.029	.947
HCO3	.175	.459	.761

Certain clay minerals and zeolites may contribute to the sodium content in groundwater. The primary source of carbonate and bicarbonates in the present samples could be due to higher pH values of the samples ranging in between 4.5-8.2 and above 8.2. Presence of bicarbonate is indicated when pH is between 4.5-8.2 and carbonate if pH above 8.2 (Karanth 1987). The important contributor of sulfate in present samples seems to be gypsum and anhydrite found in the sedimentary rocks of the reason. Local abnormal concentrations of sulfate may be due to traversing of groundwater through lignite, coal, and gypsiferous beds. In sedimentary rocks, dolomite and limestone which contains magnesium carbonates seem to be the major contributor of magnesium in the water samples. A solution of halite and other evaporite deposits in the regions are the primary sources of chloride in present case along with atmospheric sources. Fluoride in the water samples seems to be derived from certain amphiboles, mica, and complex fluoride bearing silicates. By far the greatest contribution of nitrate in groundwater may be from the excessive use of fertilizers and dung of field grazing cattle's such as – cow, sheep, and goat in the study area. As the area comes under hyper-arid zone mineralization and concentration by evaporation may result in higher values of TDS in the samples.

3.5.2 Hierarchical Cluster Analysis

Hierarchical cluster analysis was conducted in order to distinguish spatial similarity among the water sample wells in the region. On the basis of similar hydro-geo-chemical features and sources of natural background, HCA reproduced three clusters in pre-monsoon water samples and four clusters of post-monsoon water samples effectively. The details of the produced cluster are given in Table 3.7 of the study. The nearby locations of the water sample sites primarily fall in the same cluster due to the orderly and appropriate involvement of sampling sites in the development of cluster. The clustering of water samples in both pre and post-monsoon shows that groundwater quality varies smoothly with a few gradual changes over the entire region. This variation may be due to the equally prevailing hydrogeological environment in the area. The dendograms for both pre and post-monsoon are shown in Figure 3.4 and Figure 3.5 respectively. The dendograms show a clear picture of the spatial similarity occurring among the water samples in the area under consideration.

Table 3.7 Distribution of groundwater samples sites in different cluster

Pre-monsoon		Post-monsoon	
Cluster	Sites	**Cluster**	Sites
1	Bikaner, Malasar, Molaniya, Shivbari, Gersar, Ranisar, Runia Bas, Surdhana, Bambloo, Deshnoke, Naurangdesar	**1**	Chattargarh, Kavani
2	Chattargarh	**2**	Tejrasar, Gigasar, Gadwala, KesardesarJatan, Bambloo, Molaniya, Deshnoke, Ladera, Deli talai, Lalamdesar
3	Himtasar, Jaimalsar	**3**	Jaimalsar
		4	Lakhusar, Naggasar

The branching-type nature of the dendogram allows to trace backward or forward to any individual case or cluster at any level.

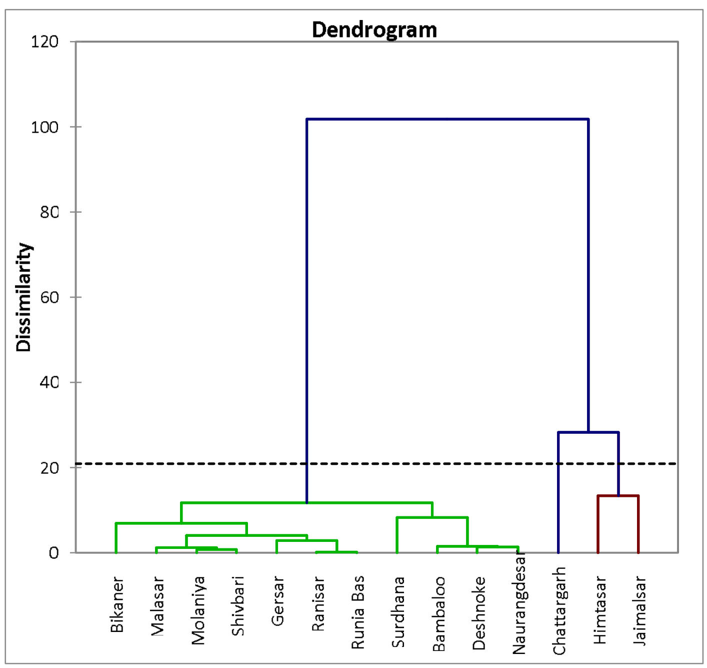


Figure 3.4. Dendogram using Ward's method for pre monsoon

In our case, if we examine the dendogram for pre-monsoon, it is very clear that Bikaner, Malasar, Molaniya, Shivbari, Gersar, Ranisar, Runia Bas, Surdhana, Bambloo, Deshnoke, and

Naurangdesar are very similar and in another cluster, Himtasar and Jaimalsar are very similar. Further, we can extract sub clusters from the picture shown in Figure 3.4. The dendogram for post-monsoon, it is very clear that Chattargarh and Kavani are very similar and in another cluster Tejrasar, Gigasar, Gadwala, Kesardesar Jatan, Bambloo, Molaniya, Deshnoke, Ladera, Deli talai, and Lalamdesar are very similar. Further, we can extract sub clusters from the picture shown in Figure 3.5. To develop an effective groundwater quality monitoring system in the region, the HCA method offers a reliable classification of groundwater by selecting index wells within a cluster which will help us in formulating well-suited policy to monitor the groundwater quality spatially. This will result in reduced number of sampling sites along with reducing monitoring cost significantly.

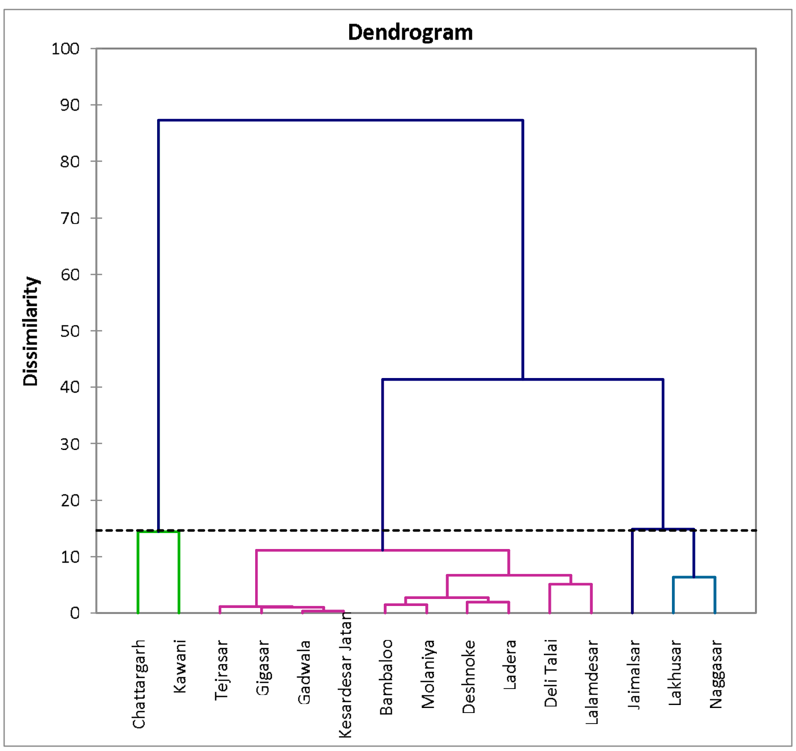


Figure 3.5. Dendogram using Ward's method for post monsoon

3.5.3 Hydro-geochemical Plotting of Water Samples

As groundwater is the only source of water requirement for domestic and agricultural purposes, groundwater quality of the region has also been evaluated by the use of geochemical plots, such as Piper diagram (Piper 1944) and Wilcox plot (Wilcox 1955). The graphical representation of groundwater quality data helps us to visualize the status of the prevailing groundwater quality in the region. Piper diagram basically helps us to conclude several conclusions such as water type, precipitation or solution, mixing, and ion exchange. This diagram given by Piper (1944) is a combination of anion and cation triangle with an intervening diamond. In the lower left triangle values of the three cations *viz.* Ca^{++}, Mg^{++}, Na^{+}; are plotted whereas in the lower right triangle three anions HCO_3^{-}, SO_4^{--}, Cl^{-}; are plotted and the central diamond is used to show the overall chemical character of the water. On the basis of placement of samples near the four corners of the diamond the water can be classified into four basic categories as near the top of the diamond, the sample is high in Ca^{++} + Mg^{++} and Cl^{-} + SO_4^{--}, which illustrates an area of permanent hardness. The water sample placed near the left corner are rich in Ca^{++} + Mg^{++} and HCO_3^{-} and is described as an area of temporary hardness. In the lower corner, water samples are basically comprised of alkali carbonates (Na^{+} + K^{+} and HCO_3^{-} + CO_3^{-}) whereas, in the right side of the diamond, water samples are categorized as saline water types (Na^{+} + K^{+} and Cl^{-} + SO_4^{--}).

The prime use of Wilcox plots is to categorize the water samples for irrigational use and to classify water quality so that the seasonal effects on water quality could be visualized. The Wilcox diagram is plotted between EC as an abscissa and Sodium absorption ratio (SAR) as an ordinate.

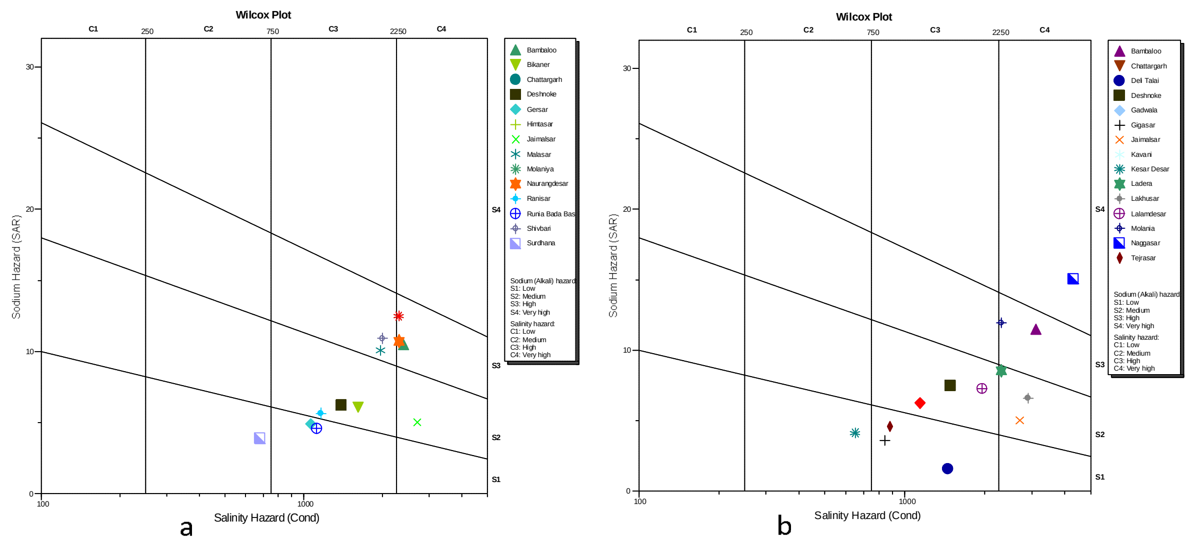


Figure 3.6. Wilcox plots for a) pre-monsoon and b) post-monsoon of water samples

The Wilcox diagram explicitly talks about the two important aspects of water quality named as Salinity hazard and Sodium (Alkali) hazard. The diagram in terms of salinity deduce the water samples as low salinity water (C1), medium salinity (C2), high salinity (C3), and very high salinity (C4). In terms of alkali hazard, the water samples can be deduced as low sodium water (S1), medium sodium (S2), high sodium (S3), and very high sodium (S4).

According to Wilcox (1955), water sample with a SAR value up to 10 and EC up to 250 can be considered as S1 water. If the SAR value lies between 10 -18 and EC value lies in between 250 - 750, then it is considered as S2 water. Further, a SAR value up to 26 and EC value up to 2250 defines S3 water. More than 26 SAR and 2600 EC the water can be defined as an S4 type. The various physicochemical parameters analyzed in this study were plotted using Wilcox (as shown in Figure 3.6 a) pre-monsoon and b) post-monsoon) and Piper (as shown in Figure 3.7 a) pre-monsoon and b) post-monsoon) diagrams and the results are tabulated in Table 3.8.

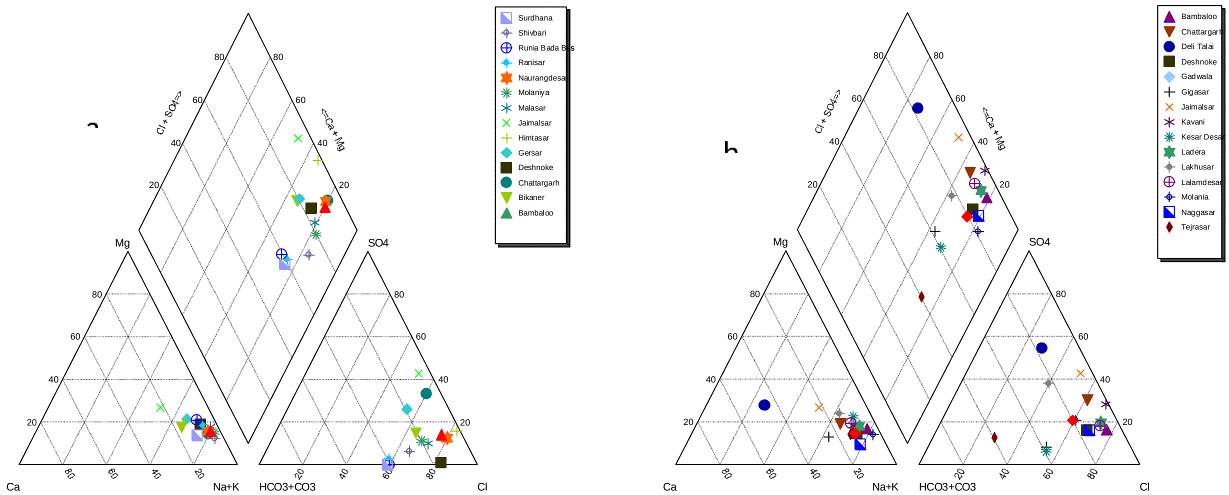


Figure 3.7. Piper plots for a) pre-monsoon and b) post-monsoon of water samples

The Wilcox plot clearly shows high salinity hazard in the region with medium to high alkali hazard in the majority of the region. It is observed that approximately 41.6% of the samples are under very high salinity hazard, 45.83% of the samples are with high salinity hazard, and rest of the samples falls under moderate salinity hazard. In the same manner, 33.4% of the samples are observed with high alkali hazard, 37.5% of the samples with medium alkali hazard and remaining samples were found to be with low alkali hazard.

Table 3.8 Water quality status of the area under consideration

S. No.	Village	Hazard		Water type	S. No.	Village	Hazard		Water type
		Salinity	Alkali				Salinity	Alkali	
1.	Bambloo	Very high	High	Na-Cl		Shivbari	High	High	Na-Cl
2.	Bikaner	High	Medium	Na-Cl	14.	Surdhana	Medium	Low	Na-Cl-CO_3
3.	Chattargarh	Very high	High	Na-Cl-NO_3-SO_4	15.	Deli talai	High	Low	Ca-Mg-Na-SO_4-Cl
4.	Deshnoke	High	Medium	Na-Cl	16.	Gadhwala	High	Medium	Na-Cl

5.	Gersar	High	Low	Na-Mg-Cl-SO_4	17.	Gigasar	High	Low	Na-Ca-Cl-HCO_3
6.	Himtasar	Very high	High	Na-Mg-Cl	18.	Kavani	Very high	Medium	Na-Cl-SO_4
7.	Jaimalsar	Very high	Medium	Na-Mg-Ca-Cl-SO_4	19.	Kesardesar	Medium	Low	Na-Mg-Cl-HCO_3
8.	Malasar	High	High	Na-Cl	20.	Ladera	Very high	Medium	Na-Cl
9.	Molaniya	Very high	High	Na-Cl-NO_3	21.	Lakhusar	Very high	Medium	Na-Mg-Cl-SO_4
10.	Nuarangdesar	Very high	High	Na-Cl	22.	Lalamdesar	High	Medium	Na-Mg-Cl
11.	Ranisar	High	Medium	Na-Cl-HCO_3	23.	Naggasar	Very high	Very high	Na-Cl
12.	Runiabada bas	Low	High	Na-Cl-HCO_3	24.	Tejrasar	High	Low	Na-Cl-HCO_3

Considering the Piper diagram, Na^+, Mg^{++} are the dominant cations, whereas Cl^-, SO_4^{--}, are the dominant anions in the respective left and right triangle of the diagram. The conclusion can be drawn on the basis of the Piper plot that majority of the water samples falls under the category of saline water. Majority of groundwater samples (37.5%) have been found with the water type Na^+-Cl^-, and about (33.4%) of the samples represent with alkali carbonates and rest (29.1%) of the sample shows a mixed type, as shown in Table 3.8, for both pre-and post-monsoons.

3.6 ASSESSMENT USING FUZZY MULTI CRITERIA DECISION MAKING

It is important to realize that management of groundwater does not only mean assessing groundwater quantity and its availability for different purposes but also its quality which have been impacted significantly to be precursor to various water borne epidemics. In arid and semi-arid regions, the problem has indeed become even serious and challenging which are now being recognized as a social and academic imperative by all water sectors. Hence it is necessary to put appropriate efforts in improving quality of groundwater on scientific lines by utilizing these resources in sustainable manner. The vagueness and complexity involved in sustainability not just makes it difficult to define or measure it but also demands to apply concepts of fuzzy logic. Fuzzy logic is not just capable of imitating experts but also gives a systematic approach to express vagueness and impreciseness (Singh and Dubey 2012).

Fuzzy multi-criteria decision making tool can be used to assess the quality of water (Singh et al. 2015). A systematic model can be developed using MATLAB fuzzy logic tool box. The inputs of such a model are the quantitative sustainability objectives and output will be the measure of sustainability. ten Brink (1991) have presented a useful tool for establishing sustainable development. He suggested that a model should (a) give a clear indication as to whether objectives of sustainability are met; (b) express the system as a whole; (c) have a quantitative character; (d) be understandable to non-scientists; and (e) contain parameters which can be used for periods of one or more decades. The focus of the study is to assess the groundwater suitability for Dungargarh block of Bikaner district, Rajasthan which has population about 50,000 (as per 2011 census) for different beneficial uses especially for irrigation and domestic uses. Suitability of groundwater has been evaluated with reference to standards prescribed by Bureau of Indian Standards (BIS) (Standard, 1991). Water quality of 15 groundwater wells of this block has been analyzed and sustainability of these wells has been assessed though initially 38 wells were sampled. These wells are located at Bana, Bigga, Biramsar, Dhirdesar chotiya, Dhirdesar purohitan, Dholiya, Dungargarh, Gusainsar, Kitasar, Kotasar, Kunpalsar, Ladhariya, Lakhsar, Punrasa, and Sawantsar villages. Water quality analysis has been performed using by applying concepts of fuzzy logic in MATLAB tool (version 8.0.0.783 (R2012b)) and sustainability of groundwater wells has been assessed corresponding to given beneficial uses so that the water requirements for present generation are met without compromising the needs of the future generations.

3.6.1 RESEARCH APPROACH

The complexity and ambiguity involved in sustainability can be handled effectively using fuzzy logic reasoning (Zimmermann, 2011). A very popular fuzzy inference technique called Mamdani method has been used in this study which consists of four basic steps a) fuzzification of the input variables, b) rule evaluation (inference), c) aggregation of the rule outputs (composition), and d) defuzzification. The process of transforming real data values into linguistic values by performing operations is called fuzzification. The given information or data is represented by IF–THEN linguistic rules. A linguistic rule consists of an IF-THEN statement (IF–part is called the antecedent, while the THEN–part is called the consequent) which is formed with the help of linguistic values of the linguistic variables under expert opinion. In order to obtain a final crisp value, defuzzification methods are applied. An illustration of IF–THEN fuzzy approximate reasoning is the assessment of drinking water quality based on concentration of Total dissolved solids (TDS), pH, Total hardness (TH), Nitrate (NO3-) and Fluoride (F). Choosing TDS, pH, TH, NO3- and F as the primary factors deciding the drinking water quality, the fuzzy rules can be

- IF TDS is ‘excellent’ AND pH is ‘excellent’ AND TH is ‘bad’ AND NO_3^- is ‘excellent’ AND F is ‘excellent’, THEN drinking water quality is ‘satisfactory’.

- IF TDS is ‘excellent’ AND pH is ‘excellent’ AND TH is ‘acceptable’ AND NO_3^- is ‘excellent’ AND F is ‘acceptable’, THEN drinking water quality is ‘good’.

‘Acceptable’, ‘Bad’ and ‘Excellent’ are linguistic values of the linguistic variables TDS, pH, TH, NO_3^- and F; they correspond to the fuzzification of their data value (concentration in mg/l or meq/l). ‘Very bad’, ‘Bad’,

‘Satisfactory’, ‘Good’ and ‘Very good’ corresponds to the linguistic values of drinking water quality. Defuzzification of their linguistic values provides a crisp measurement of drinking water quality. MATLAB based Fuzzy Inference System (FIS) consists of combination of these rules which serve as input to the model being developed. In this way, a mathematical model is developed which not just defines groundwater sustainability as a function of number of various parameters but also gives a numerical value of sustainability.

3.6.1.1 Sampling wells

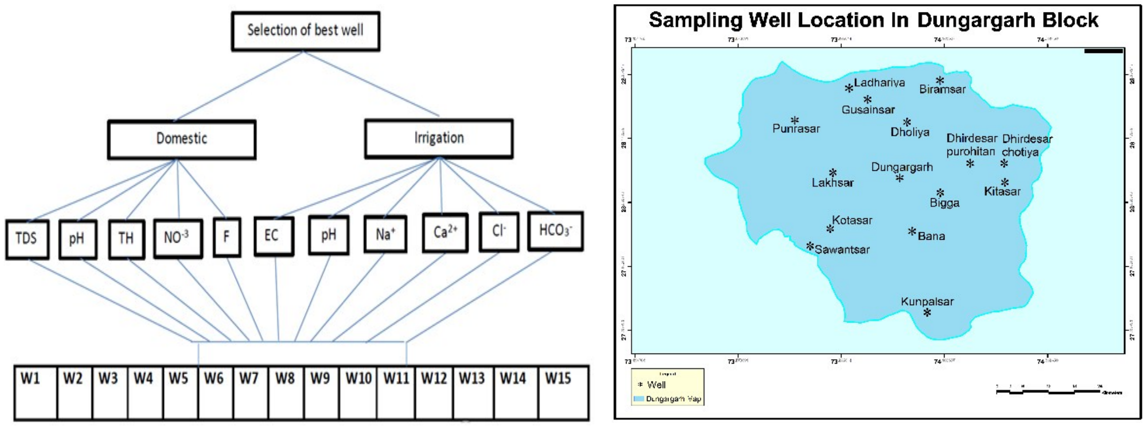
In this study, a total of fifteen important sampling groundwater wells are chosen from the Dungargarh block of Bikaner district of Rajasthan (Figure 3.1b). These wells are located in Bana (W1), Bigga (W2), Biramsar (W3), Dhirdesar chotiya (W4), Dhirdesar purohitan (W5), Dholiya (W6), Dungargarh (W7), Gusainsar (W8), Kitasar (W9), Kotasar (W10), Kunpalsar (W11), Ladhariya (W12), Lakhsar (W13), Punrasa (W14), and Sawantsar (W15). Each groundwater well has been represented as the groundwater system at that location and sustainability of these wells are assessed in context to domestic and irrigation usages using fuzzy logic concepts.

3.6.1.2 Water Quality Parameters Considered for the Study

The quality of water varies with time and space depending on concentration of different water quality parameters. Based on the water quality, user can decide the optimal use of the water at a particular location. Authors have identified appropriate water quality parameters based on the earlier work (CGWB, 2009; Singh and Ghosh, 1999; Singh et al. 2007; Singh et al. 2019) and also on the basis of opinion of the experts on requirements of domestic and agricultural usages. The combined effect of these parameters for a particular beneficial-use has been evaluated to measure sustainability for each groundwater well. The important parameters considered for domestic purposes are total dissolved solids (TDS), pH, total hardness (TH), Nitrate (NO_3^-), and Fluoride (F). Similarly, the water quality parameters for irrigation purpose are considered as electrical conductivity (EC), pH, Sodium (Na^+), Calcium (Ca^{2+}), Chloride (Cl^-), and Bicarbonate (HCO_3).

3.6.1.3 Normalization of Data Values

In this study, sustainability assessment is formulated by decomposing appropriate elements at different hierarchical levels (Figure 3.8 a) for the selected sampling well locations (Figure 3.8 b). The top most level deals with the selection of the groundwater well on the basis of its optimal sustainability for a given designated-use. The intermediate levels correspond to criteria (i.e. domestic and irrigation) and sub-criteria representing the suitable water quality parameters for different beneficial uses. The bottom most level corresponds to fifteen sampling groundwater wells chosen from the study area of Dungargarh block of Bikaner district in Rajasthan.



a) b)

Figure 3.8 a) Hierarchical structure of the objective, criteria, sub-criteria and decision alternatives considered in the study b) Locations of Sampling wells in Dungargarh block, Bikaner

The status of water quality for a given usage have been expressed using linguistic variables. They are bad (=B), acceptable (=A), and excellent (=E). These linguistic variables have been expressed by the membership functions of the input and outputs variables as shown in Figure 3.9 (a) and Figure 3.9 (b). The sustainability of groundwater wells corresponding to domestic and irrigation have been expressed in linguistic terms such as very bad (=VB), bad (=B), satisfactory (=S), good (=G), and very good (=VG). Trapezoidal membership functions are chosen for both input and output variables as they can represent the uncertainties and ambiguities in a much better way (Zimmermann, 2011). In each figure, the horizontal axis represents the normalized scores of sustainability ranging at interval [0, 1], whereas the vertical axis represents membership grades at interval [0, 1]. In the present study, groundwater quality was monitored to assess sustainability effects with respect to irrigation and domestic uses. In order to evaluate overall score at a given sampling well, there is a need to evaluate the rating of all the parameters on the same scale because all parameters associated with assessment of sustainability may have different measurement units. This requires linear normalization of the actual measured values with some standard values. The normalized rating of these parameters can be obtained by introducing a simple linear transformation function (or utility function) as expressed in equation (1). If C_0 is the observed data value of the water quality parameter for a particular usage of a given well and C_{min} and C_{max} be the minimum and maximum values of the parameter, C_t be the target value; then its normalized value C_N is calculated as follows:

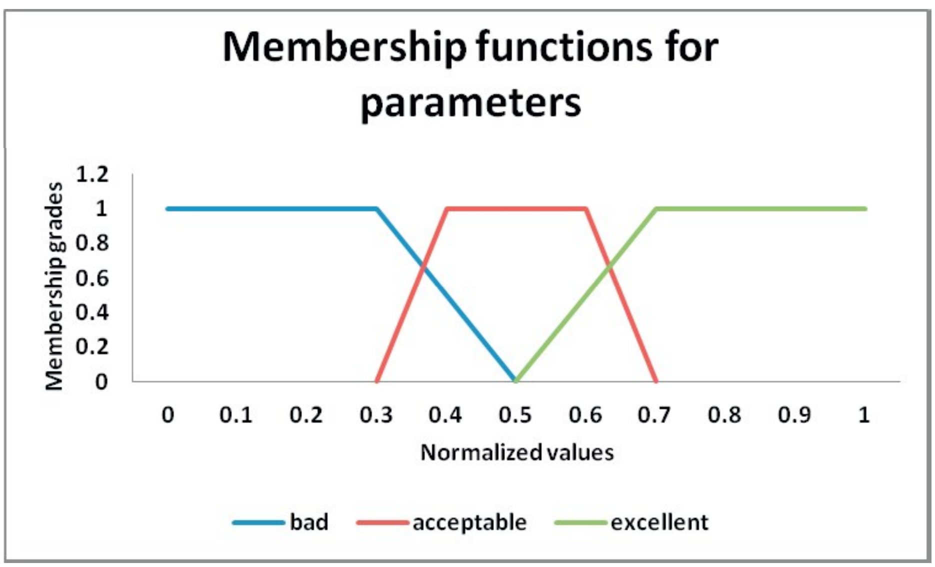
If target value C_t corresponds to an interval [min C_t, max C_t]:

$$C_N = \frac{C_0 - C_{min}}{\min C_t - C_{min}}; for\ C_0 \leq C_t$$

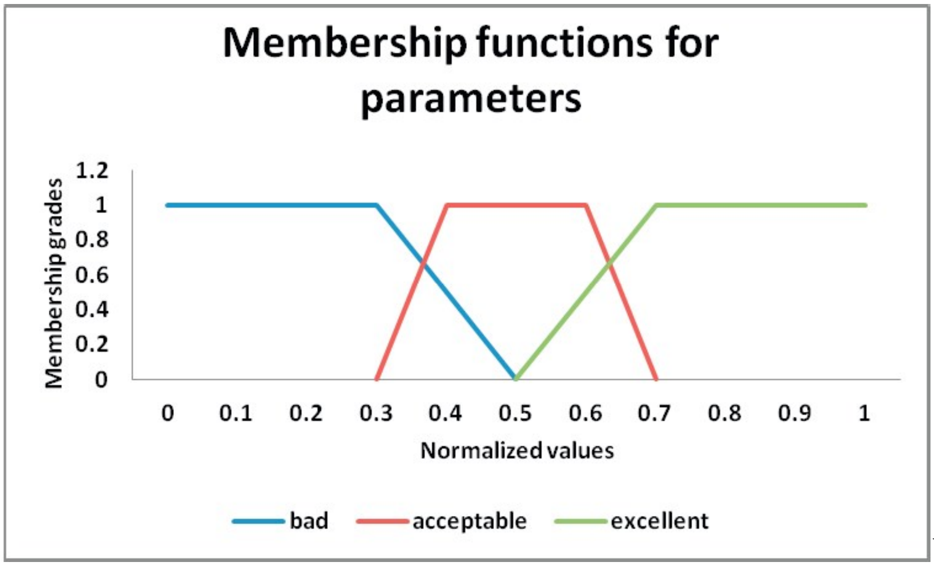
$$C_N = 1; for\ C_0 \in [\min C_t, \max C_t],\ and \qquad (3.2)$$

$$C_N = \frac{C_{max} - C_0}{C_{max} - \max C_t}; otherwise$$

In this chapter, equation (3.2) has been used because target values for each parameters lies within the range of permissible limit.



a)



b)

Figure 3.9 (a) Membership functions for input parameters; (b). Membership functions for output parameters

For example, the permissible range for pH corresponding to domestic purposes varies between 6.5 (min C_t) to 8.5 (max C_t) as shown in Table 3.9. It summarizes the normalized values of all parameters for sampling groundwater well located at Bana. Similarly, normalized values of all other parameters have been calculated at all sampling wells.

Table 3.9. Normalized values of parameters for Bana well

Bana						
Parameters	C_0	C_{max}	C_{min}	Min C_t	Max C_t	C_N
E.C.(x 10^6µ siemens/ cm)	1150.000	7200.000	690.000	250.000	1500.000	1.000
TDS(mg/l)	652.000	4963.000	390.000	500.000	2000.000	1.000
pH	8.600	8.900	7.200	6.500	8.500	0.750
Na^+(meq/l)	7.375	50.511	3.478	0.000	2.174	0.892
Ca^{+2}(meq/l)	1.072	10.792	0.418	1.600	4.800	0.553
Cl^-(meq/l)	5.820	46.516	3.400	1.400	3.944	0.956
HCO^-_3(meq/l)	3.622	9.506	1.911	0.820	1.970	0.781
NO^-_3(meq/l)	1.056	34.702	0.000	0.726	1.613	1.000
F(mg/l)	0.680	2.320	0.000	1.000	1.500	0.680
TH(mg/l)	187.000	995.000	83.000	300.000	600.000	0.479

3.6.1.4 Fuzzy Inference Rules Using Fuzzy Operators

The overall sustainability of the specific well for a particular usage is evaluated using fuzzy inference rules, popularly known as IF-THEN rules. These IF and THEN statements are connected with a fuzzy operator (AND or OR) which is used to obtain a single number for the fuzzy evaluation. These rules are formed after consulting the fuzzy experts using fuzzy logic toolbox of MATLAB. Generally, the maximum number of rules for a given usage (R) can be formulated as R = [number of linguistic variables] $^{\text{(number of parameters)}}$. For example, if there are three linguistic variables (i.e. bad, acceptable and excellent) for 5 input parameters associated with domestic purposes, there will be $3^5 = 243$ rules, which can be formulated to determine the sustainability of a groundwater well. The important rules that are being used in this study with specific reference to domestic purposes are shown in Table 3.10.

3.6.2 Application of MATLAB Based Fuzzy Inference System

The methodology used in this model has been explained in six simple steps as shown in Figure 3.10. For illustration, sustainability measure of the groundwater well located at Bana village with respect to domestic usage has been briefly explained. The same procedure has been applied for remaining groundwater wells. The main steps of the process are as follows: (a) the membership grades for input variables (i.e. water quality parameters) have been defined in MATLAB FIS framework, (b) the membership grades are also defined for the sustainability measure of groundwater well, say at Bana for domestic purposes as the output variable, (c) Fuzzy inference rules are defined using AND operator with the help of experts, (d) Normalized values of all water quality parameters have been derived as shown in Table 3.10 and aggregation values have been evaluated under fuzzy inference rules to get the final measure of sustainability of the well. Thus, the sustainability measure of a well located at Bana for domestic purposes is 0.644 which has been expressed as 64.4 %. It indicates that a well located at Bana demonstrates "good" sustainability condition as can be seen from Figure 3.9 (a-b). Similarly, sustainability measures of all the wells have been evaluated and classified with respect to both domestic and irrigation usages as shown in Tables 3.11 and 3.12.

Table 3.10 Fuzzy inference rules used for domestic purposes

Description	Inputs					Output	Description	Inputs					Output
Operators→	IF	AND	AND	AND	AND	THEN	Operators →	IF	AND	AND	AND	AND	THEN
Parameters→	TDS	pH	TH	NO-3	F	Result	Parameters→	TDS	pH	TH	NO-3	F	Result
Rule 1	E	E	B	E	E	S	Rule 8	E	E	B	B	B	B
Rule 2	E	E	A	E	A	G	Rule 9	E	E	E	E	A	VG
Rule 3	E	B	E	E	B	B	Rule 10	E	E	B	E	A	S
Rule 4	E	B	E	E	A	S	Rule 11	A	E	B	A	A	S
Rule 5	E	E	E	E	B	S	Rule 12	E	B	E	E	E	S
Rule 6	A	E	E	B	E	G	Rule 13	B	E	B	B	E	VB
Rule 7	E	E	B	E	E	S	Rule 14	B	E	B	A	B	VB

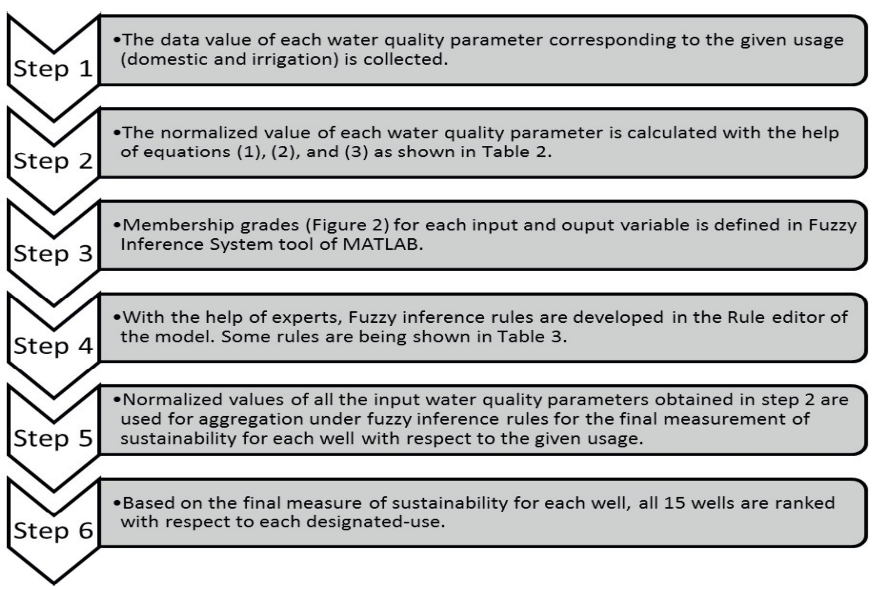
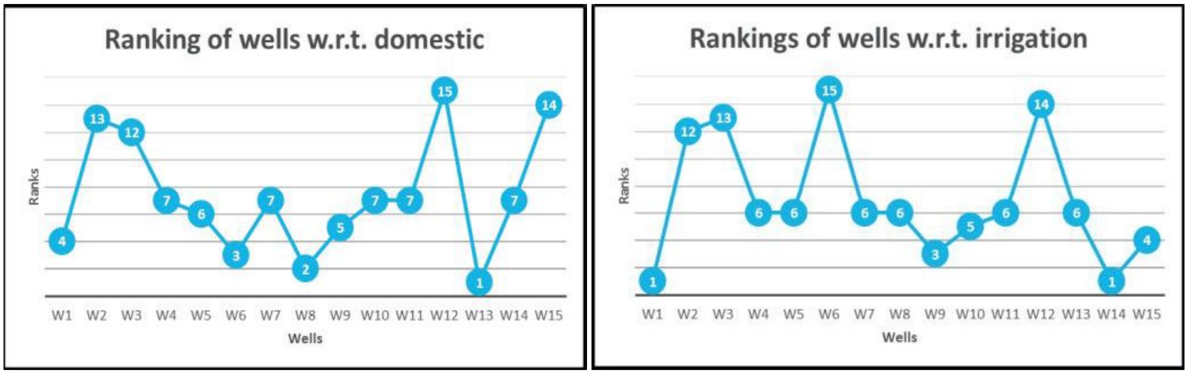


Figure 3.10 Methodology applied to obtain sustainability measure of well



a) b)

Figure 3.11 a) Rankings of wells with respect to domestic usage, b) Rankings of wells with respect to irrigation Usage

3.6.3 Results and Discussions

The scores of all 15 groundwater wells with respect to both the beneficial uses have been shown in Tables 3.12 and 3.13. Figures 3.11(a) and 3.11(b) depict the ranking of these wells according to their sustainability scores for domestic and irrigation purposes. The abscissa (X-axis) of the plot represents the groundwater wells and ordinate (Y-axis) represents the final ranks that are calculated using the proposed methodology.

Table 3.11 Sustainability score at groundwater wells for domestic usage

Domestic															
Parameters	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
TDS	1.000	1.000	0.873	1.000	1.000	0.620	1.000	1.000	0.999	0.645	1.000	0.000	1.000	1.000	0.000
pH	0.750	0.000	0.250	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.250	1.000	1.000	1.000	1.000
TH	0.479	0.770	1.000	1.000	0.286	1.000	0.378	1.000	0.638	0.194	1.000	0.000	1.000	1.000	0.382
NO-3	1.000	1.000	0.951	0.988	0.962	0.430	0.222	1.000	0.917	0.430	0.836	0.000	0.955	1.000	0.585
F	0.680	0.200	0.488	0.200	0.760	1.000	0.680	0.488	0.341	0.680	0.780	0.920	0.680	0.240	0.360
Final Score	0.644	0.250	0.490	0.500	0.587	0.750	0.500	0.869	0.618	0.500	0.500	0.075	0.907	0.500	0.084

As it can be seen from Figure 3.11(a) that well no. 13 (W13) located at Lakhasar secures rank 1 with the highest measure of sustainability i.e. 90.7% corresponding to domestic purposes. This is because data values of all water quality parameters lie in the permissible range of the Target values with TDS, pH, TH and NO_3^- having excellent as their linguistic variable and F has acceptable value. However well no. 12 located at Ladhariya has the least measure of sustainability 7.5 % as most of the important water quality parameters are below permissible range. As far as utilization of these wells for domestic and irrigation purposes is concerned, the wells having sustainability of 50% or above are considered as best. On the basis of the scores, only 40 percent of the wells are considered best for domestic usages. This gives systematic information to the planners to decide which well's quality is best to be used for household purposes and what measures or policies should be obtained to improve the sustainability of the wells securing low ranks. Similarly, from Table 3.12 and Figure 3.11(b) it can be inferred that well no. 14 (W14) located at Punrasar secures rank 1 with the highest measure of sustainability i.e. 92.5% corresponding to irrigation purpose as observed values of all water quality parameters lie within the permissible limit of the target values. However, well no. 6 located at Dholiya has the least measure of sustainability with a sustainability score of just 7.5 % due to the fact that most of the important water quality parameters are below the permissible limit. Only, 33 percent of the wells are considered best for irrigation. Hence, more than 50 percent of the groundwater wells of this region are unfit for both drinking and irrigation. The results indicate that groundwater of this region needs immediate attention from the controlling agencies.

Table 3.12 Sustainability score at groundwater wells for irrigation usage

Irrigation															
Parameters	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
E.C.	1.000	1.000	0.579	1.000	0.972	0.193	1.000	0.789	0.649	1.000	0.877	0.000	0.772	0.965	1.000
pH	0.750	0.000	0.250	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.250	1.000	1.000	1.000	1.000
Na+	0.892	0.856	0.406	0.923	0.750	0.000	0.829	0.622	0.622	0.924	0.748	0.935	0.608	0.803	0.954
Ca+2	0.553	0.682	1.000	0.000	0.000	1.000	0.273	1.000	1.000	0.350	0.814	1.000	1.000	1.000	0.355
Cl-	0.956	0.888	0.364	0.956	0.956	0.000	0.938	0.609	0.508	1.000	0.869	0.383	0.605	0.753	1.000
HCO-3	0.781	0.808	0.687	0.888	0.202	0.800	0.630	0.247	0.908	0.681	1.000	0.380	1.000	0.941	0.861
Final Score	0.925	0.471	0.250	0.500	0.500	0.075	0.500	0.500	0.832	0.603	0.500	0.084	0.500	0.925	0.612

3.7 EVALUATION AND RECOMMENDATION

The methodologies described in this study can assist the research community to include the hydro-geochemical information in the analysis of semi-arid and arid region aquifer systems. The methodology used in this study allows the successful outcomes of each method accommodating all information to generate a robust interpretation by incorporating the strength of various geochemical, statistical, and spatial grouping tools. Therefore, optimal groundwater extraction integrated groundwater management, and checked use of fertilizer and pesticides for crops are desired to ensure acceptable groundwater quality in the region. The race towards the livelihood resilience can explain why groundwater is overexploited by end users. In the last few decades, there are several problems arisen from the evolution of groundwater for irrigation purposes, in developing nations of Asia and Africa (Shah 2005). The contamination of groundwater and its quality degradation affects the farmers in terms of crop choice and availability of potable drinking water (Ranjan 2012). This leads to identifying alternate solutions for drinking water in the area. The filtration system commonly used in households of India are not efficient. They discard 75% of the water supplied for the purification and only 25% is used for drinking purpose (Bhakar et al. 2016). This makes fewer choices available to the end users for satisfying their daily needs of livelihood. Singh (2014) claimed that the conjunctive use of surface water and groundwater can be a better option for sustainable irrigation system. When it comes to hyper-arid regions where, groundwater availability is low to lower, groundwater quality assessment of the aquifer systems can support decision making for developing sustainable groundwater policies. The use of remote sensing in combination with a multivariate statistical tool or artificial intelligence techniques can provide better possibilities to assess and monitor large samples of water quality. It can also work to remove uncertainties in the analysis data (Swain and Sahoo 2017).

3.8 SUMMARY

The various physicochemical parameters from the hydro-chemical data sets were analysed using multivariate statistical methods to identify contributing variables and spatial similarity between the groundwater samples. PCA extracted three significant principal components explaining 87.149 % of the total variability of the combined population for pre-monsoon and 85.497% for post-monsoon of groundwater quality. The major variations are due to the solubility of gypsum, a precipitate of sodium salts impregnating the soil, higher pH values, excessive use of fertilizers, dung of field grazing cattle's, concentration by evaporation and weathering of the rocks. HCA played a key role in identifying the spatial similarity between the groundwater quality samples from the region. The clusters generated can be utilized in order to select index well from the spatially similar clusters to achieve effective groundwater quality monitoring in the area under consideration. It can be concluded from the graphical plots of groundwater quality data, that the groundwater sources in Bikaner block are affected by alkali hazards and salinity, which is not suitable for drinking and irrigation purposes. Overall sustainability of all the wells under the second study is computed using five water quality parameters for domestic usage and six water quality parameters for irrigation purpose. The fuzzy inference rules are developed using MATLAB by fuzzy AND, OR, and IF–THEN operators. The rules are linguistic and express the interdependencies amongst the essential parameters determined for measuring sustainability of a particular groundwater well. To manage issues concerning maximizing sustainability on a small scale like farming in a particular piece of land might be simpler, however, when the scale of assessment goes up to regional level as in this study, management of sustainability becomes difficult and confusing. The outcomes of the two studies can be used by practitioners and policymakers for development and implementation of strict groundwater management policies for sustainable management of this natural resource. The scope of the study covers limited numbers of the well in the assessment due to poor data quality, however, the tools used for the assessment have capabilities to assess large regions/areas. In above discussed concern of low-quality data, use of Remote Sensing and GIS can be a viable solution to visualize the vulnerability of groundwater situation in the region. In future the time series analysis of the data can be carried out to have a wide picture of groundwater quality. Using Remote Sensing technique, assessment of groundwater quality will be the further scope of this study, which has been discussed in next chapter.

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