CHAPTER 4

REMOTE SENSING AND GIS IN GROUNDWATER MANAGEMENT STUDIES

In continuation with the previous chapter, this chapter specifically focuses on the use of Remote Sensing (RS) and GIS Techniques for assessing groundwater suitability. The objectives of this chapter includes: (i) generation of site suitability maps for irrigation and drinking purposes; (ii) development of a methodological framework; and (iii) utilization of the methodological framework to assess potential zones of groundwater, in the Bikaner region in the state of Rajasthan, India.

4.1 INTRODUCTION

The northwest region of India has the most agricultural productivity in India, but it is on the cost of groundwater overexploitation. Groundwater is the key source of livelihood in the western arid region of India. As a result, groundwater has been overexploited by the people in the region to fulfill their basic needs. It has to be utilized judiciously for all beneficial uses including agricultural and domestic uses so that issues of groundwater quality and quantity can be addressed in a sustainable manner (Srinivas et al., 2015). Groundwater resources are utilized for a variety of purposes like drinking, irrigation, industrial, recreational, and various other household activities (Prasanth et al., 2012). The sustainable management of groundwater becomes even more essential for country like India, which has only 4% share in world water with about 16% of total world’s population (IDEI, 2018). Groundwater sustains many ecosystems and is a significant source of fresh water supply for consumptive use both in rural and urban areas (Shakerkhatibi et al., 2019). Thus, it is required to assess groundwater resource accurately with reference to its quantity and quality. The groundwater quality has been quantified using different techniques by different researchers (Jha et al. 2007; Kamra et al. 2002; Kaur and Singh 2011; Kumar et al. 2015). These studies demonstrate how water quality is correlated with a large number of parameters (Praveena et al. 2010; Srinivas et al., 2018; Singh and Mukherjee 2015).

The research community has provided various tools and techniques to assess the groundwater quantity as well as quality. The conventional techniques such as lithologs, non-destructive tests such as VES (Vertical Electrical Sounding, 2D-resistivity imaging etc.), and field surveys require a great time, labour, and cost as compared to the remotely detecting and monitoring techniques like remote sensing and GIS. Contemporary developments in the field of RS and GIS technologies have proven their effectiveness for groundwater studies (Jha et al., 2007; Machiwal and Singh 2015; Oikonomidis et al., 2015). RS and GIS offer highly versatile tools and integration of spatial data with many diligent decision making techniques such as weighted overlay analysis (Senanayake et al., 2016; Singh et al., 2019), Analytical Hierarchy Process (AHP), catastrophe, and entropy methods (Jenifer and Jha, 2017), fuzzy multi-objective optimization (Singh et al., 2007), frequency ratio models (Manap et al. 2014) and fuzzy multiple-attribute decision making techniques (Singh et al., 2017). Over the years, several methods/approaches have been devised by the researchers to describe potential zones of groundwater and mapping of its quality (Naghibi et al. 2018, Senanayake et al. 2016, Iqbal et al. 2015). They have considered a number of factors in order to find best locations for groundwater potential and locations based upon its quality. These factors include Digital Elevation Model (DEM), drainage, soil strata, Land use and Land cover (LULC), rainfall, and spatial distribution of various parameters considered in assessing quality of groundwater. A sustainable groundwater management plan needs a continuous monitoring and assessment of groundwater quality and quantity so that this important natural resource can be utilized in an effective manner without affecting societal needs of future generations.

The objectives of this chapter are to delineate potential zones of groundwater and generate site suitability maps for irrigation and drinking purposes using data obtained through remote sensing and GIS. This chapter initially develops a methodological framework to assess potential zones on the basis of groundwater suitability for different beneficial uses. Finally, a case study of hyper-arid zone (with annual precipitation range 100–350 mm) of Bikaner district of Rajasthan, India has been taken to demonstrate applicability of basic framework. The proposed methodology is quite useful in exploring critical issues of groundwater along with their impact on potential zones of groundwater and its quality. The understanding and insights gained through a case study has been applied to identify strategies that can be adopted to control adverse environmental impacts and achieve a cleaner, sustainable fresh groundwater.

4.2 MATERIALS AND METHOD

The research methodology utilized in this study is given in Figure 4.1. It comprises of mainly four steps with several extended sub-steps. The first step is associated with planning and development of an integrated framework to perform groundwater quality and quantity assessment. In this step, the entire problem is conceptualized for model formulation/construction to identify, analyze and structure the complexity of the problems into an appropriate framework. The parameters required for the groundwater quantity and quality along with groundwater potential zones mapping are collected from literature studies as discussed in introduction section. The second step includes the data collection processes from various sources with the validation of the data using appropriate methods.

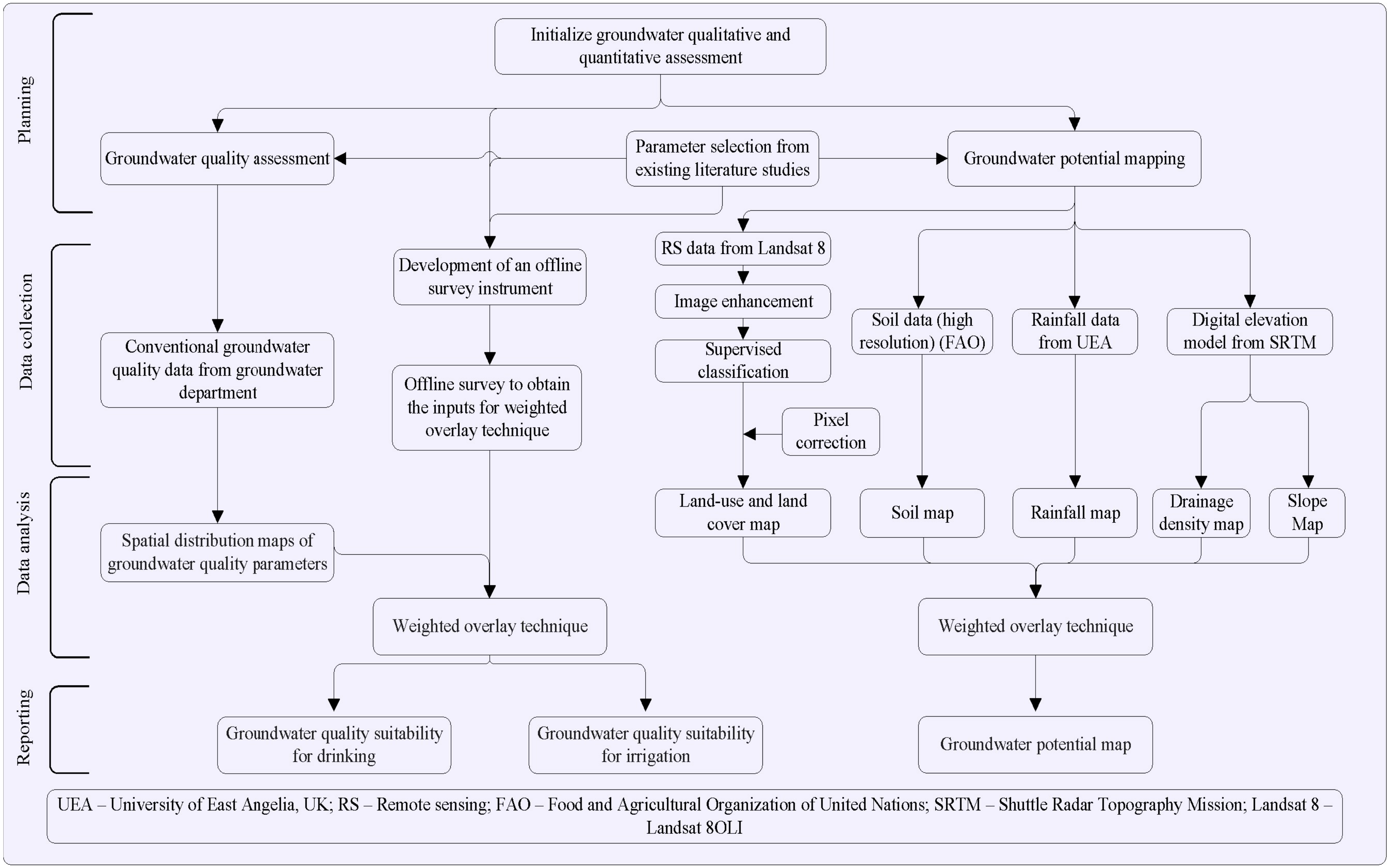
The collected data was then analyzed to develop different maps and assessed against weighted overlay technique using inputs obtained from the offline survey method. The last step of the methodology reports the groundwater suitability analysis for irrigation and drinkability along with potential map of groundwater in the selected region. The data obtained from various sources has been analyzed using two software tools – ERDAS IMAGINE v15.0 and ArcGIS v10.2.

4.2.1 Planning

In the first step of the research methodology, a detailed plan of groundwater quality and quantity assessment has been developed and initial steps have been identified to move forward.

4.2.2 Data Collection

In the second step of the study, multiple data collection processes have been carried out to attain all necessary data required for the qualitative and quantitative assessment of groundwater. Literature reviews, interactions with experts and practitioners, and questionnaires were used to grasp various aspects of the problem in comprehensive manner. The steps associated with the process of data collection are described under the following sub-sections.



UEA – University of East Angelia, UK; RS – Remote sensing; FAO – Food and Agricultural Organization of United Nations; SRTM – Shuttle Radar Topography Mission; Landsat 8 – Landsat 8OLI

Figure 4.1. Research methodology used for the current study

Since the study deals with both qualitative and quantitative aspects of the groundwater in selected region, data were collected by considering the specific needs with respect to both pre–monsoon and post–monsoon periods during recent years from 2011 to 2017. They were analyzed in order to validate values of various quality parameters. The dataset of 2016 (pre and post monsoon) was used to compute various quality parameters maps in the region. Also datasets of years before 2011 were explored for the wells, which are dried up or buried up due to sand and wind storms frequently occurring in the area, in order to ascertain the values of parameters for these wells.

4.2.2.1 Conventional Data Collection from Ground Water Department

In this step, historical data for various groundwater quality parameters has been collected with respect to both pre–monsoon and post–monsoon conditions over some selected time period (i.e. 2011 to 2017). The Ground Water Department (GWD) is an organization under the aegis of State Government of Rajasthan and works for collection of groundwater data for the whole state of Rajasthan. The department also provides regular reports on groundwater quality and quantity to support the policy making and management of groundwater resource in the state. In the present study, the data has been collected from the department for the Bikaner district (i.e. study area) and a very few villages of nearby Churu district (which are included in Landsat images).

4.2.2.2 Offline Survey Instrument to Obtain Input for Weighted Overlay Technique

Survey questionnaire are useful tools that help us to get subjective opinions on a topic and learn more about how experts feel about a particular area. They are useful to investigate user needs, expectations, perspectives, priorities and preferences. They are easy to analyse and simple to administer. In this step, an offline survey has been carried out to obtain the input for weighted overlay technique, which has been used in this study to perform multiple analysis. Expert opinions have been taken to rate the importance weight of different aspects of groundwater. The details of the weighted overlay technique can be found in section 4.3.3. In this survey, a group of experts has been asked to rate the importance of various thematic layers and their field values. A total of 35 experts were asked to provide input on the survey to obtain the weights. These 35 experts include 6 members from central groundwater board (CGWB), 18 members from State Ground Water Board and 11 experts from academia. The experts bear a deep knowledge with experience ranging from 15-30 years in the area of groundwater management. The designations of the respondent include - technical assistant hydrogeology, junior and senior hydrogeologist, superintending hydrogeologist, junior and senior chemist, assistant engineer drilling, and geophysicists. The experts were involved in dealing with all kind of groundwater management issues in the field. The experts provided opinions on the questionnaire shared with them by weighing and rating the various parameters along with their percentage influences in groundwater management. The opinions gathered through survey questionnaire were helpful in carrying out the weighted overlay analysis (see Table 4.3, 4.4 and 4.5). The survey respondents requested to keep their identity anonymous, therefore the contact information from the respondents was kept optional.

4.2.2.3 Collection of Remotely Sensed Data from Satellite Landsat 8

Remote sensing data has been obtained from the platform of USGS's Earth Explorer to derive suitable maps of land cover and land use practices. This is a public platform through which data can be downloaded remotely for research purposes. A total of four scenes from Landsat 8 Operational Land Imager (OLI) were downloaded as given in Table 4.1. Similarly, the spectral range and applications of Landsat 8 bands are given in Table 4.2. The area covered in the four scenes of Landsat 8 OLI is shown in Figure 4.2.

Table 4.1. Four scenes used in the study (received from Landsat 8 OLI)

S. No.	Scene ID/Product ID	Path-Row	Date of Observation
1	LC08_L1TP_148040_20170927_20171013_01_T1	148-40	2017-09-27
2	LC08_L1TP_148041_20170927_20171013_01_T1	148-41	2017-09-27
3	LC08_L1TP_149040_20171004_20171014_01_T1	149-40	2017-10-04
4	LC08_L1TP_149041_20171004_20171014_01_T1	149-41	2017-10-04

Table 4.2. Spectral range and application of Landsat 8 (source: Barsi et al., 2014)

Band	Spectral Range (µm)	Application
Band 1 – Coastal Aerosol	0.435 - 0.451	Studies on coastal and aerosol (both natural or anthropogenic) related issues
Band 2 – Blue	0.452 - 0.512	Studies on applications like bathymetry mapping to understand oceanic depth, deciduous from coniferous vegetation and differentiation of soil and vegetation
Band 3 – Green	0.533 - 0.590	Emphasize on peak vegetation to assess plant vigor
Band 4 – Red	0.636 - 0.673	Studies to discriminate vegetation slopes
Band 5 – Near Infrared	0.851 - 0.879	Studies to emphasize on shore-lines and biomass content
Band 6 – Short-Wave Infrared 1	1.566 - 1.651	Penetrates thin clouds, discriminates soil and vegetation's moisture content
Band 7 – Short-Wave Infrared 2	2.107 - 2.294	Moisture content studies for soil and vegetation along with thin cloud penetration
Band 8 – Panchromatic	0.503 - 0.676	15 meter resolution with sharper image definition
Band 9 – Cirrus	1.363 - 1.384	Cirrus cloud contamination detection improved
Band 10 – Thermal Infrared Sensor 1	10.60 – 11.19	100 meter resolution and studies on soil moisture and thermal mapping
Band 11 – Thermal Infrared Sensor 2	11.50 - 12.51	100 meter resolution and studies on soil moisture and thermal mapping.

The downloaded images were then further processed to enhance their quality as shown in Figure 4.3. A supervised classification of these images has been carried out to generate the classes of land cover and land-use practices.

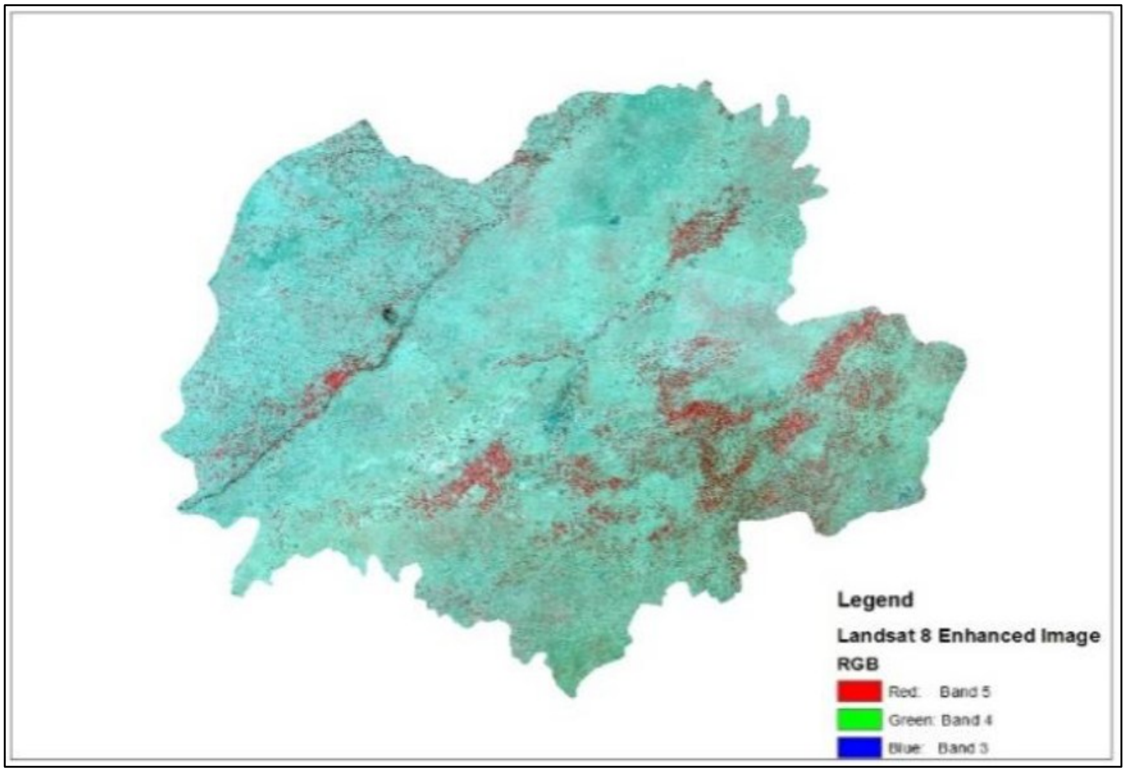


Figure 4.2. Study area selected from the Landsat 8 OLI

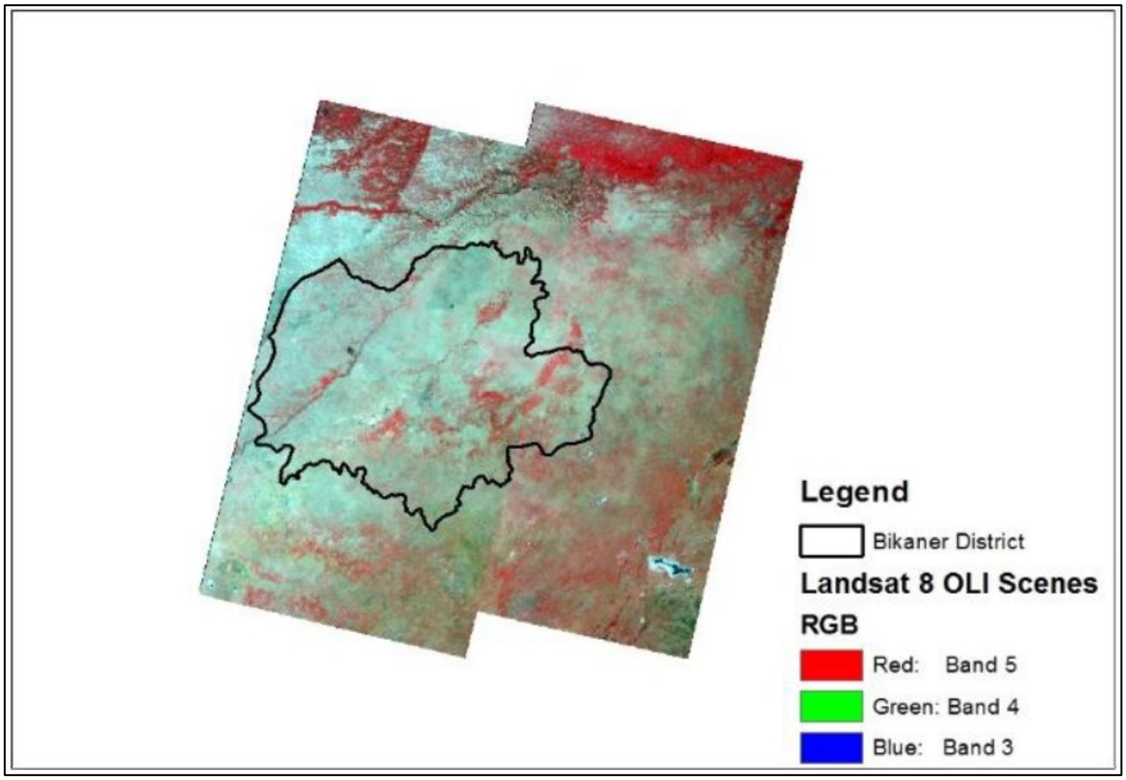


Figure 4.3. Landsat 8 enhanced image for the case study

Before generating the land-use and land cover map from the classified images, pixel correction of these images has also been performed to ensure the appropriate pixels into appropriate classes.

4.2.2.4 Soil Data Collection

The important high resolution gridded data related to various types of soils of the selected region has been collected from the official website of Food and Agricultural Organization (FAO, 2019). The digital soil map of the study area has been downloaded and further processed to generate raster layers of the soil type occurring in the selected study location. The soil data information was verified with the local research unit responsible for soil quality assessment in the region.

4.2.2.5 Rainfall Data Collection

The rainfall data for the region has been collected from the official website of University of East Anglia, UK (UEA, 2019). For the ease of access and convenience in generating the raster layers for further analysis, the data were downloaded from this research center website. The data from the research center website were compared with the local weather stations data repository.

4.2.2.6 Digital Elevation Model (DEM) Data Collection

The DEM data were collected from the official website of Shuttle Radar Topography Mission (SRTM) of USGS (United States Geological Survey) Earth explorer. The downloaded tiles of path/row – 148/40, 148/41, 149/40, and 149/41 were mosaiced together and processed for generating all necessary thematic layers.

4.2.3 Data Analysis

The collected data in various steps explained above were analyzed for generating various thematic layers/maps for further process of weighted overlay analysis. All the data were tested to determine charge imbalance error. A total of 291 samples out of 427 samples were found suitable for further analysis in this study.

As the first step, maps representing spatial distribution of all important critical parameters have been obtained using the data obtained in section 4.3.2.1. The soil data obtained from FAO (as discussed in section 4.3.2.4) were utilized to derive soil map using the ArcGIS version 10.2 software. Similarly, data collected for the rainfall in the study (see section 4.3.2.5) were considered to develop the rainfall map. Figures 4.4 and 4.5 represent the existing soil types and rainfall distribution in the selected region, respectively.

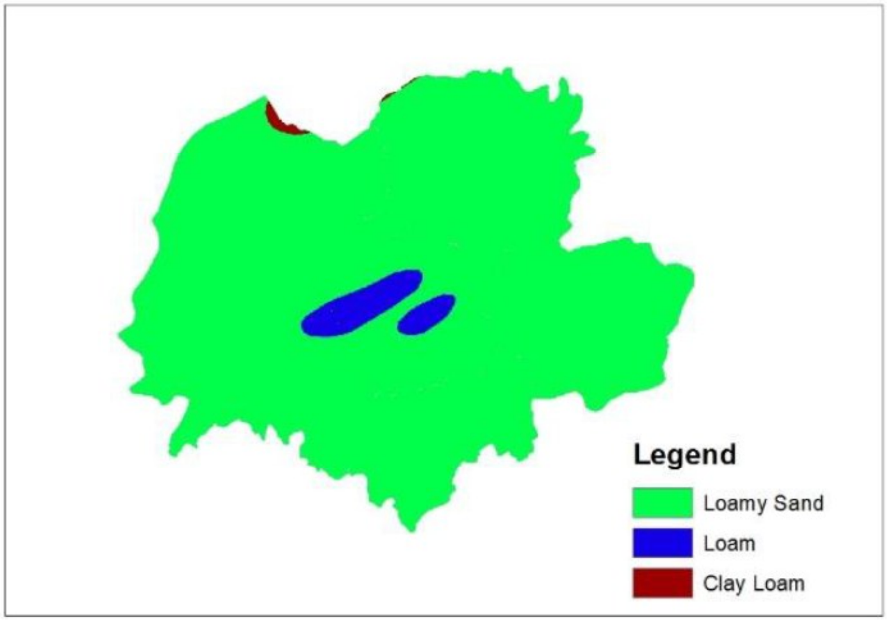


Figure 4.4. Variation of soil types in the study area

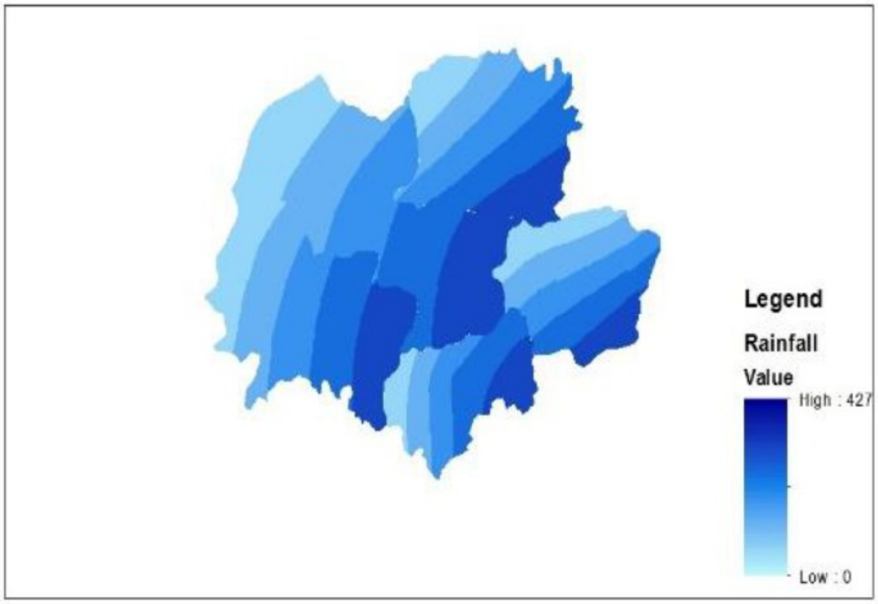


Figure 4.5. Variation of rainfall (mm) in the study area

To derive the land-cover and land-use maps, image enhancement and supervised classification techniques have been used. The Landsat 8 data thus downloaded were analyzed using Erdas Imagine software, a geospatial tool, created by Hexagon Geospatial. First of all, the Landsat 8 images were turned into band composites and mosaicked using the ArcGIS 10.2 software and the required area was extracted by masking. Further, the developed mosaiced images were enhanced to improve ability of visual interpretation of a remotely sensed image by improving apparent distinction among various features on land (Shalaby and Tateishi,2007). Spatial frequency feature of an image can be changed using convolution filtering process by considering the average of small sets of pixels used in the image (Jensen, 1996).

A desired spatial frequency in a remotely sensed image can be achieved by performing convolution filtering (Corner et al 2003). The image of the area of study has been pre-processed for its enhancement using contrast stretching and convolution filtering under the category of spatial enhancement. A 3x3 convolution kernel was applied to change the spatial frequency of the image as shown in Figure 4.6.

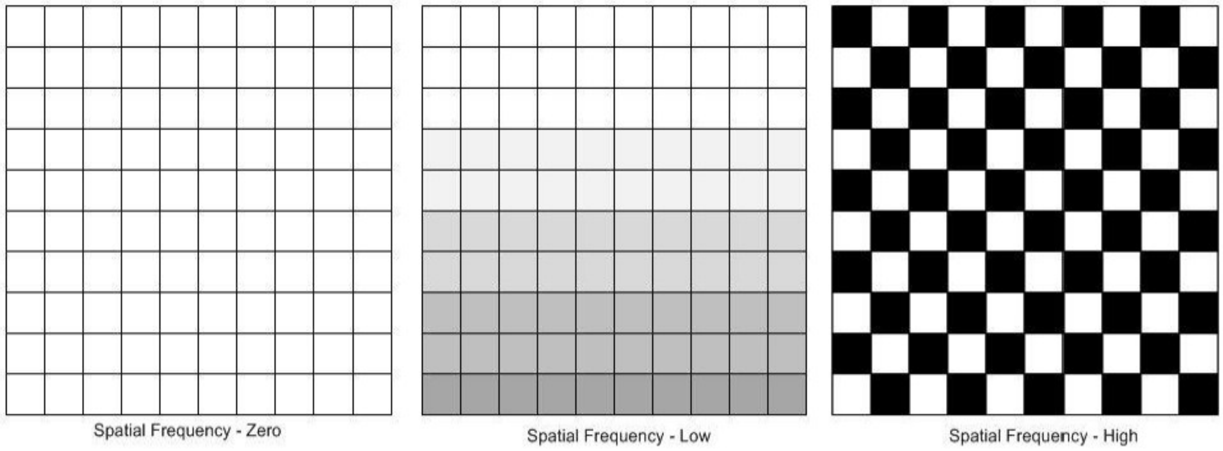
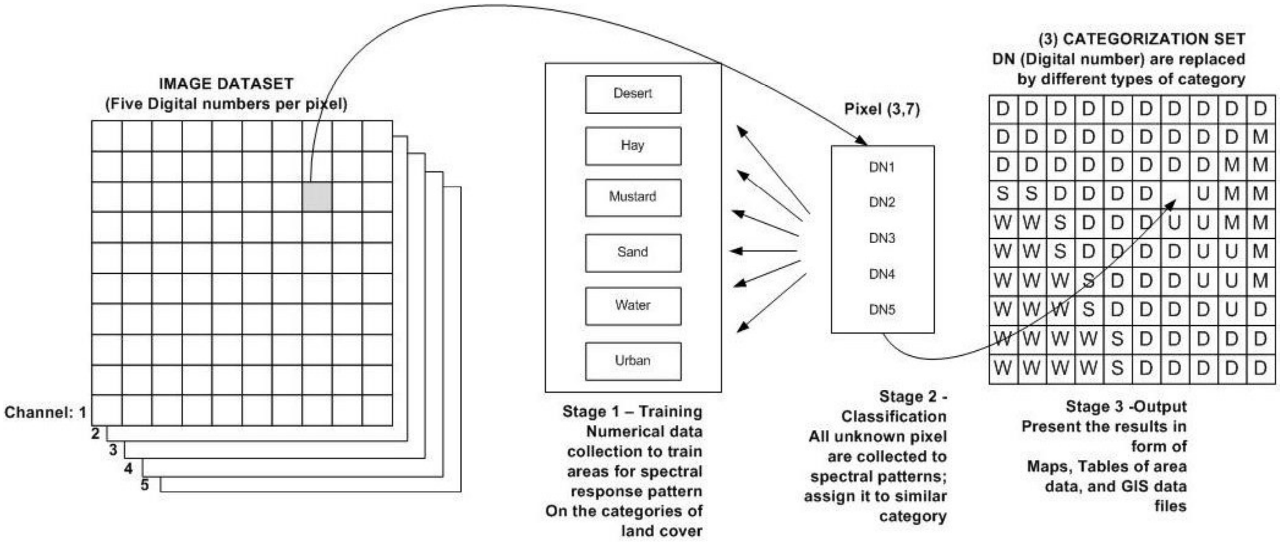


Figure 4.6. Illustration of spatial frequency patterns (source: Lillesand et al., 2015)

Thus, the enhanced image developed in the previous step was classified using supervised classification tool to sort out pixels used in an image into classes of land cover as shown in Figure 4.7 (Lillesand et al., 2015). Area of interest (AOI) and spectral signature files were created for each land feature visible in the Landsat 8 scene as a part of the training phase and all the spectral signatures thus generated were assigned a particular class. Further, the supervised classification was performed using parallelepiped classifier with the training samples developed in the training phase. Parallelepiped classifier is very fast and computationally efficient. It assigns a pixel to a class if its value falls within the range of the training data. The spectral values of pixels are not repeated within a class. Rather, they exemplify the usual centralizing tendency and variation of the spectral properties within each land cover class. These points, in the form of a cloud, signifies multi-dimensional attributes of the spectral-response pattern of each class for type of land cover to be inferred.



D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	M
D	D	D	D	D	D	D	D	M	M
S	S	D	D	D	D		U	M	M
W	W	S	D	D	D	U	U	M	M
W	W	S	D	D	D	D	U	U	M
W	W	W	S	D	D	D	U	U	M
W	W	W	S	D	D	D	D	U	D
W	W	W	W	S	D	D	D	D	D
W	W	W	W	S	D	D	D	D	D

Figure 4.7. Basic steps involved in supervised classification (source: Lillesand et al. 2015)

These training sets are explanations of the response of spectrum of each class used as the interpretation keys by which the unidentified pixels of land cover type are classified into their respective classes. Hence, the land–use and land–cover map for area of present study were obtained for further investigation. Figure 4.8 shows the Landsat 8 color infrared (5-4-3 band scheme) showing built-up areas, agriculture, water bodies, and barren Land. The land-cover and land-use maps of area of present study has been shown in Figure 4.9. It is observed from analysis that the study area includes: 24 sq. km. of water bodies, 978 sq. km. of built-up area, 2081 sq. km. of agricultural area (type I), 10927 sq. km. of agricultural area (type II), and 17262 sq. km. of barren land. Here, agriculture land type I refers to most cultivated land and type II refers to the least cultivated land. Further, DEM data processing has been carried out to generate maps for slope and drainage density variations. The SRTM data downloaded was processed further to derive distribution of slope and drainage density in the form of respective maps using the ArcGIS 10.2 software package. These distribution maps are shown in Figures 4.10 and 4.11, respectively.

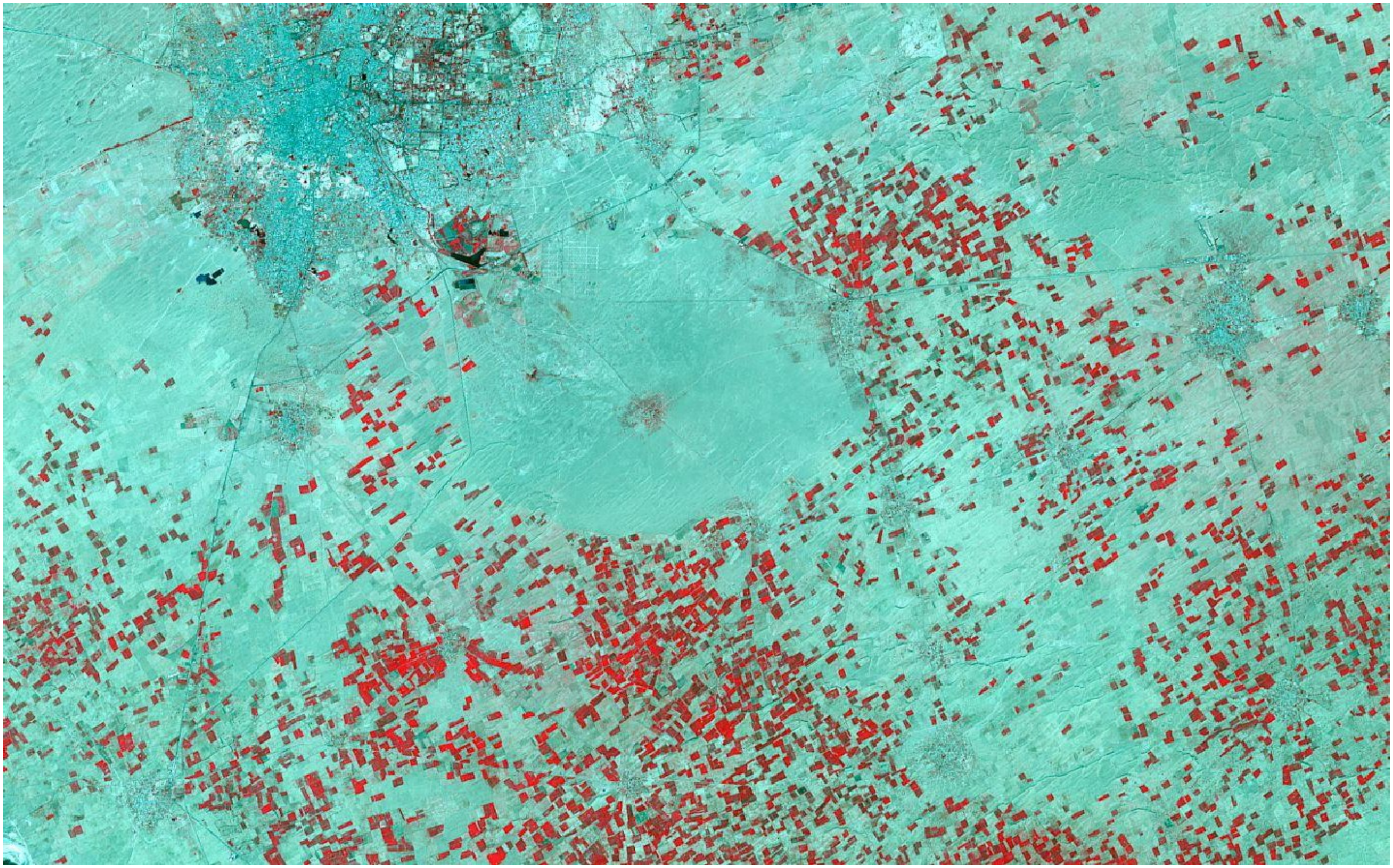


Figure 4.8. Landsat 8 Color Infrared (5-4-3 Band Scheme) showing Built-Up areas, agriculture, water bodies and barren Land

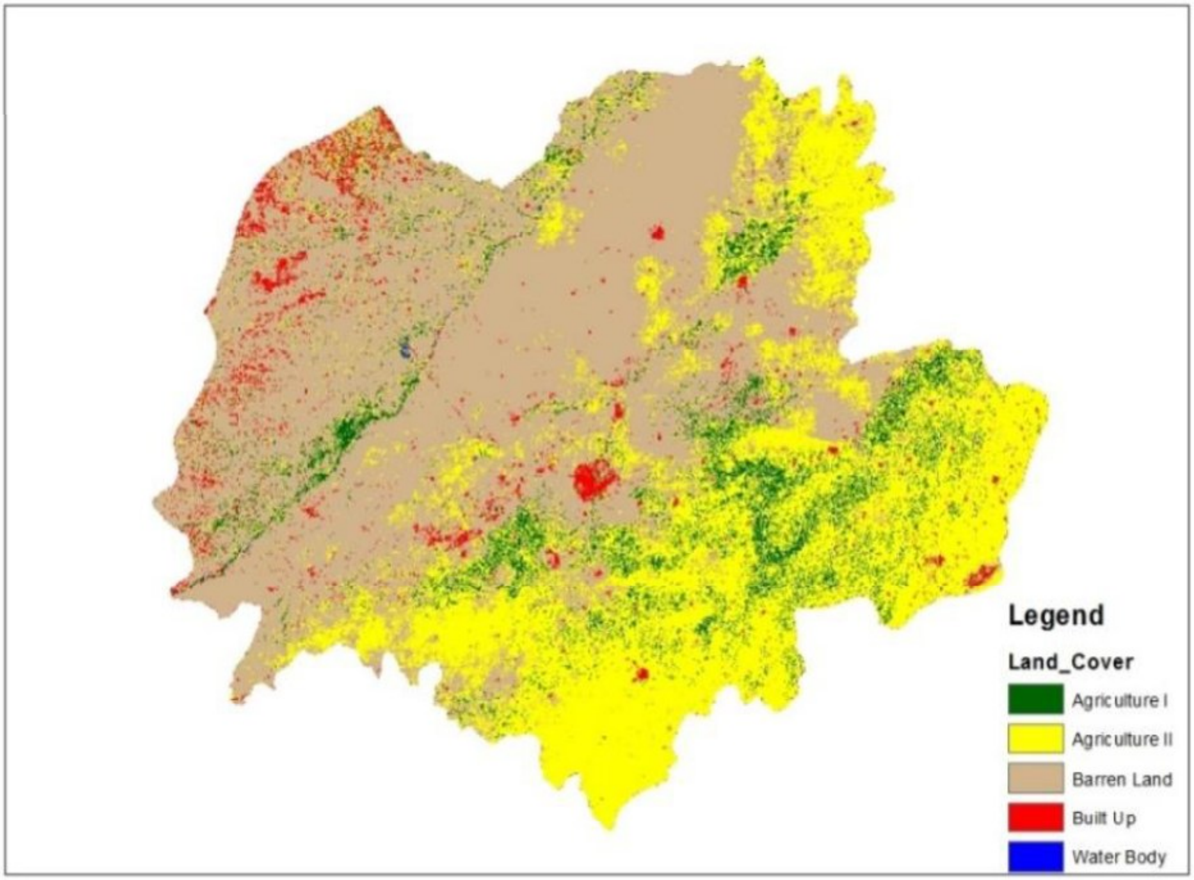


Figure 4.9. Land cover and land-use map for the case study

4.2.3.1 Weighted Overlay Analysis

Groundwater potential zones were delineated using weighted overlay analysis available in the spatial analysis tool of version 10.2 of ArcGIS (Samake et al 2010). Weighted overlay analysis is widely used tool for site suitability analysis problem. It is a simple technique for analyzing and solving multi-criteria problems.

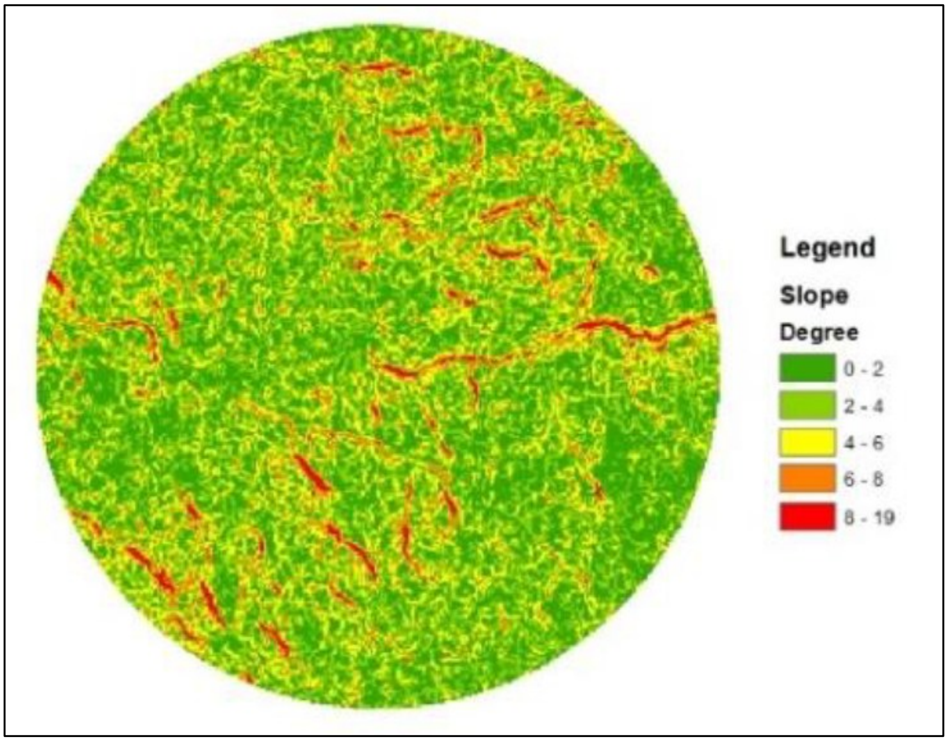


Figure 4.10. Variation of Slope in the study area

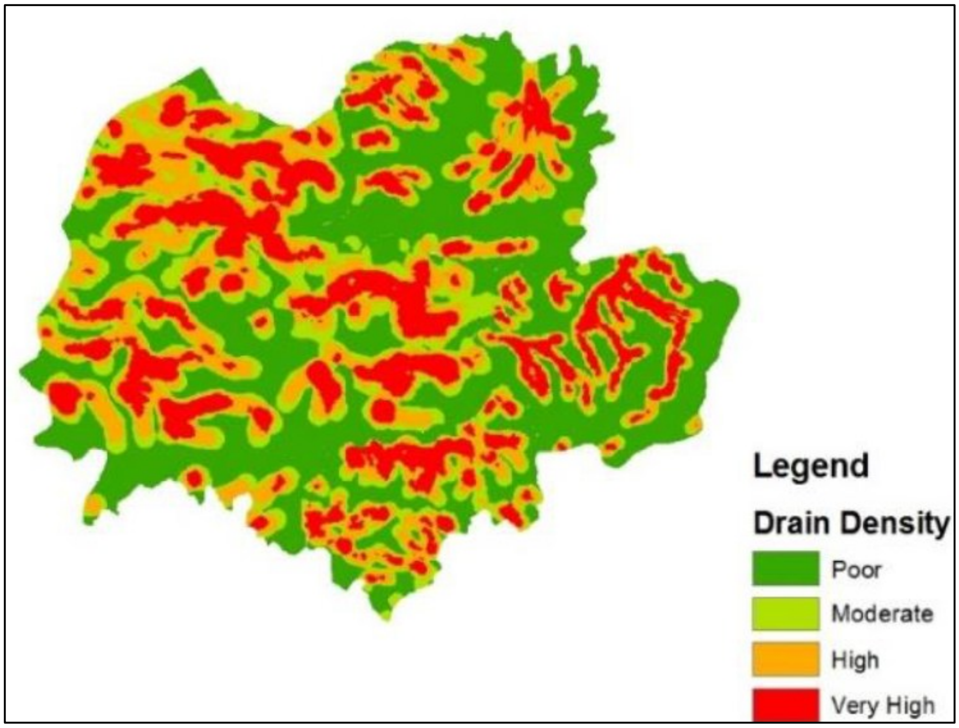


Figure 4.11. Variation of Drainage density in the study area

The technique proves to be advantageous because expert judgement can be incorporated appropriately in GIS to achieve realistic results. A weight or percent influence infers the relative importance of an attribute over another. There are no such fixed rules for scaling in weighted overlay analysis and therefore it is essential to identify appropriate criteria to be considered in the analysis along with their importance values (Saraf and Choudhury 1998). While performing the weighted overlay in ArcGIS, the scaling is done for each parameter in a thematic layer and percent influence is assigned accordingly to understand how a thematic layer will contribute or affect the objective. The suitability maps for potential and quality were obtained using equation (4.1):

$$\text{GWS} = \sum PI \times S \tag{4.1}$$

where GWS = Groundwater Suitability, PI = Percent Influence and S = Scale.

The weighted overlay analysis has been carried out for two qualitative aspects i.e. groundwater irrigation suitability and groundwater drinking suitability, and one quantitative aspect i.e. groundwater potential zones. The details of qualitative/quantitative weighted overlay analysis to assess suitability of irrigation and drinking water and potential zones of groundwater are shown in Tables 4.3, 4.4 and 4.5, respectively.

Table 4.3. Weighted overlay scheme for groundwater suitability (Irrigation)

S. No.	Raster Layer	Percent Influence	Field Value	Scale Value
1	SAR	40	0 - 5	5
			5 - 10	4
			10 - 20	3
			20 - 27	1
2	Na %	20	0 - 25	5
			25 - 50	4
			50 - 80	3
			80 - 100	1
3	TDS (Irrigation)	15	0 - 500	5
			500 - 1500	4
			1500 - 3000	3
			3000 - 7500	1
4	EC	15	0 - 1000	5
			1000 - 2000	4
			2000 - 3000	3
			3000 - 21000	1
5	Mg-Ca Ratio	10	0 – 0.75	5
			0.75 – 1.5	4
			1.5 - 3	3
			3 - 25	1

Table 4.4. Weighted overlay scheme for groundwater suitability (Drinking)

S. No.	Raster Layer	Percent Influence	Field Value	Scale Value
1	Nitrate	20	0 - 20	5
			20 - 30	4
			30 - 45	3
			45 - 1500	1
2	TDS (Drinking)	20	0 - 500	5
			500 - 1000	4
			1000 - 2000	3
			2000 - 7500	1

S. No.	Raster Layer	Percent Influence	Field Value	Scale Value
3	Fluoride	10	0 – 0.5	5
			0.5 - 1	4
			1 – 1.5	3
			1.5 - 5	1
4	pH	10	0 – 6.5	1
			6.5 – 7.5	5
			7.5 - 8	4
			8 – 8.5	3
			8.5 - 11	1
5	EC	10	0 - 1000	5
			1000 - 2000	4
			2000 - 3000	3
			3000 - 21000	1
6	Total Hardness	10	0 - 200	5
			200 - 400	4
			400 - 600	3
			600 - 4000	1
7	Na	4	0 - 50	5
			50 - 100	4
			100 - 200	3
			200 - 2500	1
8	Chloride	4	0 - 250	5
			250 - 500	4
			500 - 1000	3
			1000 - 7000	1
9	Ca	4	0 - 75	5
			75 - 150	4
			150 - 200	3
			200 - 1500	1
10	Mg	4	0 - 50	5
			50 - 100	4
			100 - 150	3
			150 - 700	1
11	Sulphate	4	0 - 100	5
			100 - 200	4
			200 - 400	3
			400 - 1800	1

Table 4.5. Weighted overlay scheme for groundwater potential mapping

S. No.	Raster Layer	Percent Influence	Field Value	Scale Value
1	DEM	30	Very Low	5
			Low	4
			Moderate	2
			High	1
			Very High	1
2	Slope	5	Very Low	5
			Low	4
			Moderate	2
			High	1
			Very High	1
3	Soil	10	Loamy Sand	5
			Loam	3
			Clay Loam	2
4	Land Use Land Cover	10	Water Body	5
			Built Up	2
			Agriculture I	4
			Agriculture II	4
			Barren Land	1
5	Rainfall	10	Very Low	1
			Low	1
			Moderate	3
			High	4
			Very High	5
6	Drainage Density	30	Very Low	1
			Low	1
			Moderate	3
			High	4
			Very High	5

4.3 RESULTS AND DISCUSSION

This section deals with the findings of assessment in detail. Groundwater potential zones and its suitability for drinking and irrigation has been analyzed with proper justification.

4.3.1 Groundwater Potential Zones

Major factors influencing the movement and percolation of groundwater are land cover, land use, type of soil, drainage densities, slope, and precipitation over an area. For assigning the percent influence, digital elevations and drainage density were assigned higher percent of influence whereas the rainfall, soil and land use-land cover were assigned equal influence.

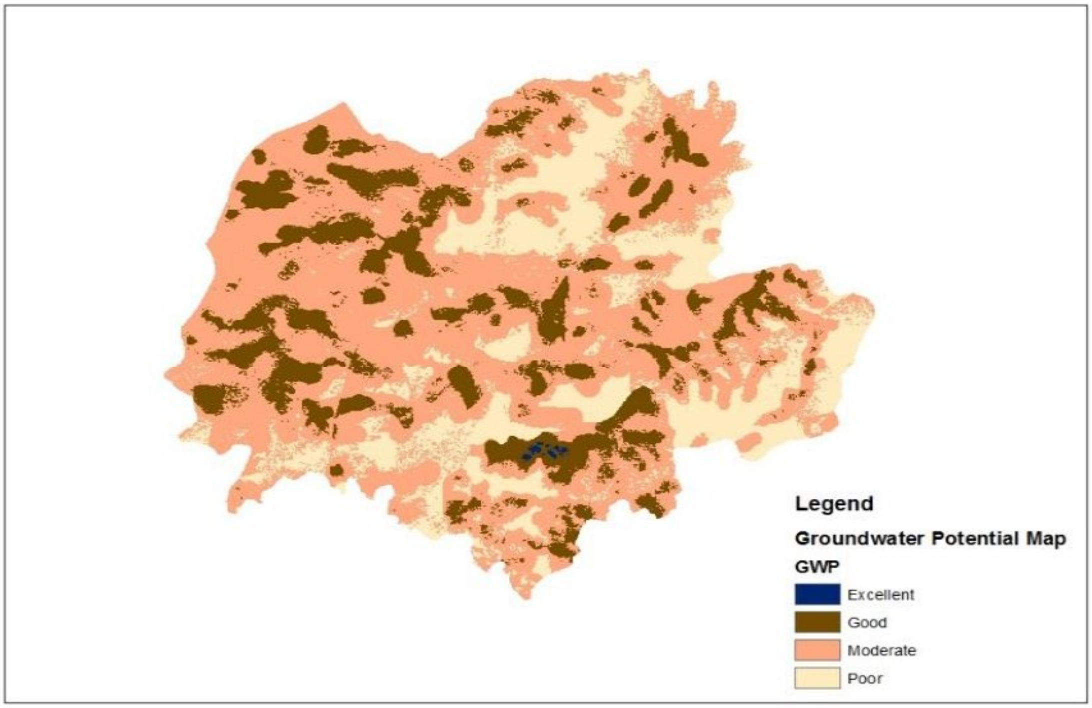


Figure 4.12. Groundwater Potential Zones

Slope was assigned the minimum percent of influence as the area is mostly comprised of plains. The output of groundwater potential zones is classified under excellent, good, moderate, and poor categories as shown in Figure 4.12. A total of nearly 2409 sq. km. area falls under the poor category whereas nearly 3268 sq. km. falls under moderate category for groundwater development. An area about 571 sq. km. bears good water potential and an area of nearly 1.5 sq. km. shows excellent groundwater.

4.3.2 Groundwater Suitability for Drinking

Various physico-chemical parameters were analyzed in comparison with the recommendations by World Health Organization (WHO,2008). The standardized data of groundwater quality parameters has been used to plot the map demonstrating spatial distribution for each and individual parameter in the study area using ArcGIS. In the weighted overlay scheme, while assigning the percent influence and scale values, the observed values have been compared with the prescribed standards of drinking water as given by WHO (2008). The suitability map of quality of groundwater for drinking was obtained by integrating thematic layers of each quality parameter. The suitability in terms of groundwater quality has been classified as restricted, doubtful, moderate, good, and excellent. A total of nearly 7207 sq. km. area falls under the restricted category, whereas nearly 16054 sq. km. seems doubtful for drinking. An area about 6235 sq. km. bears moderate water for drinking and an area of nearly 1541 sq. km. has good groundwater with only 235 sq. km. of excellent groundwater for drinking (as shown in Figure 4.13)

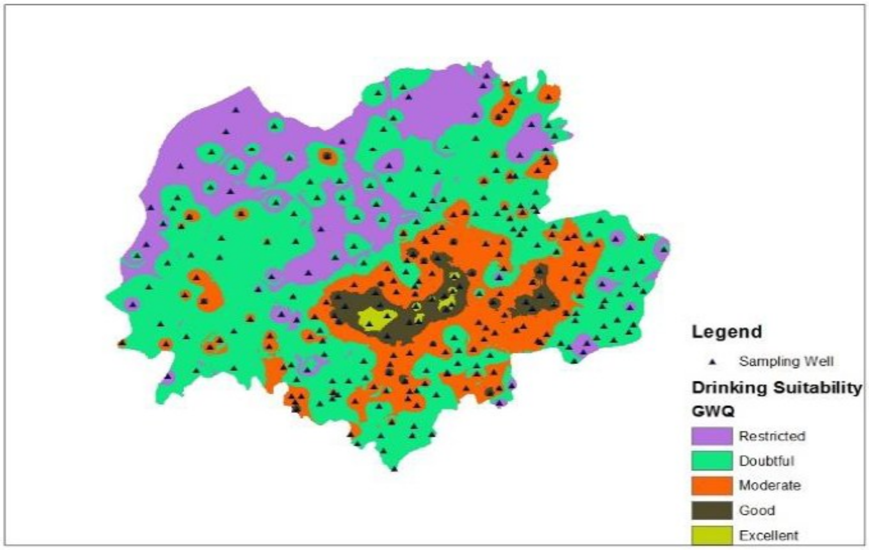


Figure 4.13. Groundwater Suitability for Drinking

4.3.3 Suitability of Groundwater for Irrigation

The study is performed to assess suitability of groundwater by considering various key water quality parameters such as EC, SAR, Sodium percent, Mg-Ca ratio, and TDS. The values assigned for TDS in weighted overlay scheme were drawn from the research work carried out by Rabinove et al. (1958), Davis and DeWeist (1966), Catroll (1962), and Freeze and Cherry (1979). The safeguard values for TDS are shown in Tables 4.6, 4.7 and 4.8, respectively.

Table 4.6. Groundwater quality classification on the basis of TDS values (Davis & Deweist 1966)

TDS	Water Type
<500	Desirable for the purpose of drinking
500-1000	Permissible for the purpose of drinking
1000-3000	Useful for the purpose of irrigation
>3000	Unfit for both drinking and irrigation

Table 4.7. Groundwater salinity classification on the basis of TDS values (Rabinove et al. 1958)

TDS	Salinity
<1000	Not Saline
1000-3000	Somewhat Saline
3000-10000	Moderately Saline
>10000	Highly Saline

Table 4.8. Groundwater classification on the basis of TDS values (Catroll 1962, Freeze & Cherry 1979)

TDS	Water Type
0 - 1000	Fresh water
1000 – 10,000	Brackish water
10,000- 100,000	Saline water
>100,000	Brine water

In the weighted overlay scheme, while assigning the percent influence and scale values, observed values were compared with the irrigation standards as prescribed by various researchers (Catroll 1962, Davis & DeWeist 1966, Eaton 1950, Freeze & Cherry 1979, Rabinove et al 1958, Richards 1954, Wilcox 1955). The suitability map for irrigation has been obtained by integrating thematic layers of each quality parameter (as shown in Figure 4.14). The suitability in terms of groundwater quality has been classified as restricted, doubtful, moderate, good, and excellent.

A total of nearly 28.5 sq. km. area falls under the restricted category, whereas nearly 575 sq. km. seems doubtful for irrigation. An area about 19304 sq. km. bears moderate water for irrigation and an area of nearly 11009 sq. km. shows good groundwater with only 357 sq. km. of excellent groundwater for irrigation.

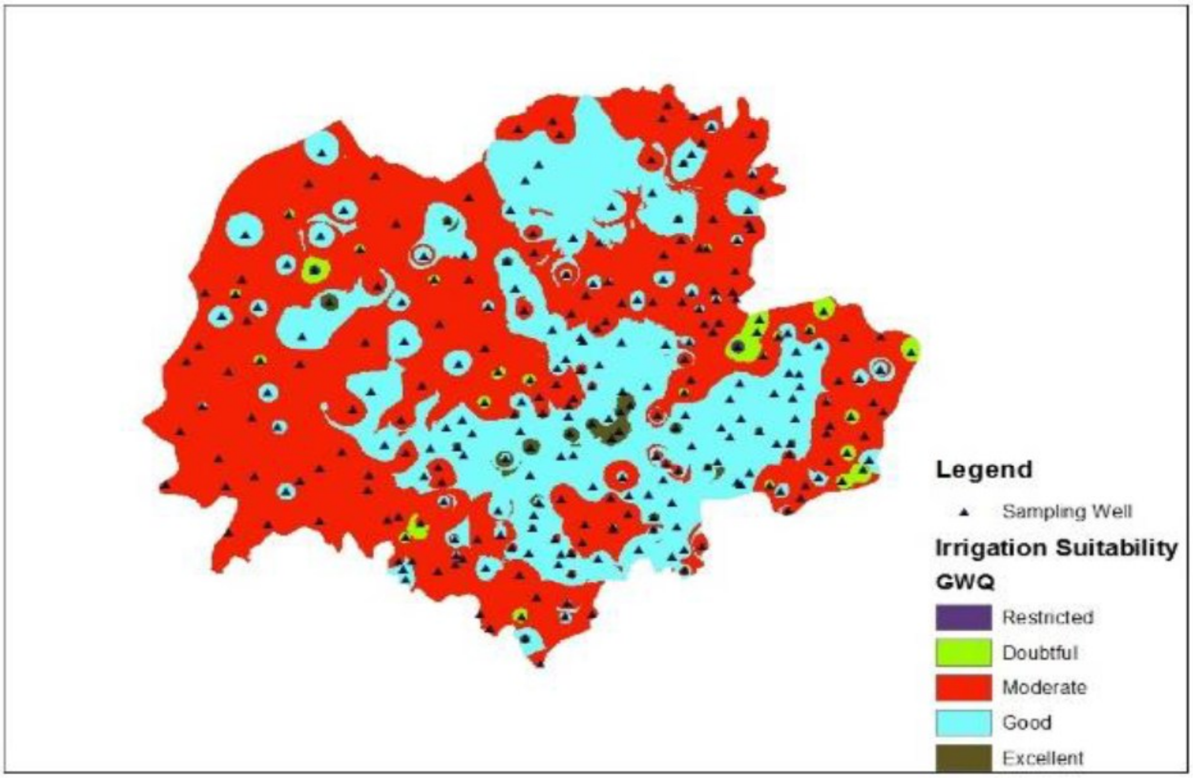


Figure 4.14. Groundwater irrigation suitability

4.3.4 Salinity Hazard

It is the most influencing water quality parameter which can be expressed in terms of EC (electrical conductivity). It is reflected when groundwater's TDS value increases. Wilcox

(1955) has classified water quality based on EC as Excellent, Good, Moderate, Doubtful, and Restricted water as shown in Table 4.9.

Table 4.9. Irrigation suitability based on Electrical Conductivity

Water Type	EC
Excellent	<250
Good	250-750
Permissible	750-2000
Doubtful	2000-3000
Unsuitable/Restricted	>3000

4.3.5 Sodium Absorption Ratio (SAR)

It indicates availability of sodium concentration in soil and water medium in relation with calcium and magnesium, which influences the growth of plant depending upon soil properties. It is a general tendency that Sodium ions get adsorbed in the soil colloids. The SAR value can be estimated by the relation provided by Karnath (1987) as given in equation (4.2):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}} \tag{4.2}$$

The values of SAR are represented in meql/litre. As per recommendations from Richards (1954), the water quality with SAR value less than 10 is treated as excellent; SAR value 10-18 is considered as good; SAR value 18-26 is considered as fair; whereas SAR value > 26 is considered as poor, as shown in Table 4.10.

Table 4.10. Irrigation suitability based on alkalinity hazard (Richards 1954)

SAR	Alkalinity Hazard	Water Type
<10	S1	Excellent
10-18	S2	Good
18-26	S3	Doubtful
>26	S4	Unsuitable

4.3.6 Sodium Percentage (Na%)

Another important parameter is Sodium concentration which is used to classify the suitability of groundwater for irrigation. In fact, sodium reduces the soil permeability by reacting with it (Kaur & Singh 2011). The percentage of sodium in the water can be expressed as equation (4.3):

$$Na(\%) = \frac{(Na^{+}+K^{+})100}{Ca^{+2}+Mg^{+2}+Na^{+}+K^{+}} \times 100 \quad (4.3)$$

The values are termed/expressed in meq/litre. Wilcox (1955) has classified irrigation water on the basis of Na% as if “Na%: <20” – Excellent; “Na%: 20-40” – Good; “Na%: 40-60” – Permissible; “Na%: 60-80” – Doubtful; and “Na%: >80” - Unsuitable. The groundwater classification based on Wilcox 1955 is provided in Table 4.11. Similarly, Eaton (1950), has also classified suitability of groundwater quality on basis of sodium percentage as - sodium percentage <60 is Safe and >60 is unsafe water, as provided in Table 4.12.

Table 4.11. Groundwater classification on the basis of Na% (Wilcox 1955)

Na Percent	Water Type
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

Table 4.12. Groundwater classification on the basis of Na% (Eaton 1950)

Na Percent	Water Type
<60	Safe
>60	Unsafe

4.3.7 Mg-Ca Ratio

In general, magnesium and calcium are essential to sustain equilibrium condition in most of the waters. Higher value of magnesium in water affects the crop yield adversely by making the soils more alkaline. The consideration of water quality for irrigation purpose based upon the Mg/Ca ratio clearly depicts that quality of groundwater in the study area belongs to moderate and safe category as given in Table 4.13.

Table 4.13. Suitability based on Mg/Ca ratio for Irrigation water

Mg-Ca Ratio	Water Type
< 1.5	Safe
1.5–3.0	Moderate
> 3.0	Unsafe

It is observed from the results that some of the regions in the study area have excellent groundwater potential whereas other regions have poor potential. Groundwater potential depends mainly on groundwater recharge and groundwater recharge in turn depends upon many other factors such as DEM (topography/elevation), rainfall, drainage density, land use land cover, slope, and soil. Gentle slope, more rainfall, plains are the major contributing factors for excellent groundwater potential in some areas and vice versa. Similar results are also observed for the groundwater quality of the various regions in the study area. Groundwater quality depends upon many chemical water quality parameters such as nitrate, TDS, chloride, etc. So, if the values of these chemicals are within the specified range established by WHO and BIS, then the groundwater quality is excellent otherwise it falls under the poor category.

4.4 SUMMARY

The current study has assessed suitability of groundwater quality and its potential to use for different beneficial purposes in the western arid region of India. The region where the study has been carried out is a water scarce region and solely dependent on the groundwater. The region has a fertile soil quality. But due to overexploitation of the groundwater resource and increased number of minerals in the extracted groundwater for irrigation, the fertility of the soil is getting affected. The development of sustainable groundwater management plans is a dire need for the region. This study for the first time has carried out both quantitative and qualitative assessment to support the groundwater management in the region. Others studies carried out in the region are only oriented towards quality of groundwater and assess the quality of a very small study area (Kaur and Singh, 2011). Since, no studies have been found for a larger study area and particularly oriented towards mapping of both quality and groundwater potential, this study will serve as basis for effective policy making to manage groundwater in an effective way, especially in the scarce region of desert state.

Remote sensing and GIS integrated approach has proven capabilities in assessing the quantitative as well as qualitative aspects of the groundwater in the region. The proposed methodology is mainly a weight and score based model that considers the major problems of groundwater suitability for drinking and irrigation as well as groundwater quality for further development of the resource for consumptive use. The weighted overlay technique combines the expert based knowledge with the mathematical knowledge of machines in order to resolve the common world problem. Once the groundwater suitability and potential maps are created, it is fairly simple for the policy makers and stakeholders to understand the scenario thereof. Integrated use of GIS and remote sensing is a good approach to explore the suitability of groundwater and demarcation of potentiality of groundwater in an area of interest. Based on the findings of the study, it is observed that groundwater suitability is really alarming in the present case study. In addition, the study has also developed potential zones, which will ultimately help policy and decision makers to conclude the problem of over-exploitation in Western Rajasthan, India.

The lineament mapping has not been reported in the study, which is a limitation of the current study. However, multiple and unsuccessful attempts to develop lineament maps have been made. In-depth analysis of the potential zones observed in the current study could be carried out in further. Inclusion of other districts/areas/regions (where, groundwater is the key source of livelihood and particularly for irrigation purposes) could also be a future scope of the current study.