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Application of Analytical Hierarchy Process (AHP) and GIS in the Evaluation of Groundwater Recharge Potential of Rajkot District, Gujarat, India

Harsh H. Maniar[1], Neelkanth J. Bhatt[2], Indra Prakash[3] and Khalid Mahmood[4]

[1]*M.E. Student, Water Resources Engineering, Lukhdhirji Engineering College, Morbi.*
[2]*Assistant Professor of Civil Engineering, Lukhdhirji Engineering College, Morbi.*
[3]*Faculty at Academy of Geoinformatics, Bhaskarachrya Institue for Space Applications and Geoinformatics (BISAG), Gandhinagar.*
[4]*Project Managerr at Bhaskarachrya Institue for Space Applications and Geoinformatics (BISAG), Gandhinagar.*

ABSTRACT
Identification and mapping of groundwater recharge potential zones is important step to recharge the aquifer at appropriate locations for maintaining groundwater resource balance with consumption and exploitation. Rajkot district of Gujarat which is fast developing has been selected as study area considering present and future needs of ground water. In this area ground water occurs in weathered basalt and in the area dissected by lineaments (dykes, joints and shears). In the present study the Saaty's Analytic Hierarchy Process (AHP), which is a widely used Multi-Criteria Decision Analysis (MCDA) technique has been used to assess the groundwater potential zones. Weights to individual parameters were assigned based on AHP method and rates based on the importance of sub-category parameters in the recharge of ground water. Overlay analysis was done to integrate various thematic layers in GIS environment for the development of ground water recharge potential map. Based on this methodology, groundwater recharge potential zones map was classified into three main categories Major part of the area is having medium (46%) to high (36%) recharge potential. This study will help to managers to properly plan to recharge more potential area on priority basis for proper development of ground water resources of the district.

Introduction

There is a need of systematic assessment and evaluation of ground water resources for the development of a district in view of the increase in demand of water for domestic, industrial and irrigation purpose with increase in population and industrialisation. Groundwater potential mapping helps in the optimum utilization and proper conservation of groundwater resources (Naghibi et al., 2016, Naghibi et al., 2017). Identification and mapping of groundwater recharge potential zones is important step to recharge the aquifer at appropriate locations for maintaining groundwater resource balance with consumption and exploitation. Geospatial techniques help in generating and analysing thematic layers such as geology, topography, soil and land use for generating groundwater potential zones map (Dar et al. 2011, Singh et al. 2011a, Prafull Singh et al. 2013). In the present study the Saaty's Analytic Hierarchy Process (AHP), which is a widely used Multi-Criteria Decision Analysis (MCDA) technique (Saaty 1986) has been used to assess the groundwater potential zones. GIS techniques were applied to integrate topographical, geo-hydrological and meteorological data to evaluate groundwater recharge potential of Rajkot district for proper groundwater resource management.

Study Area

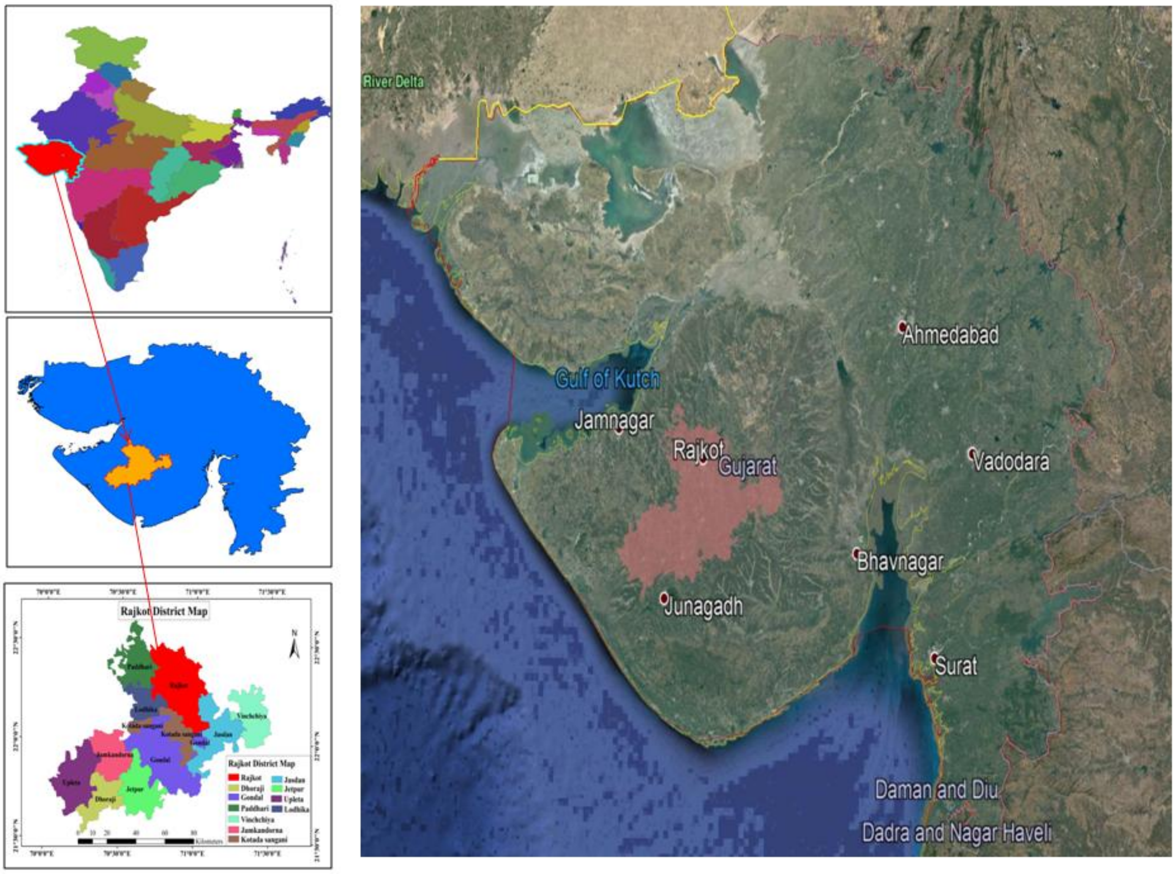

Figure 1: Study Area

The study area is located between Latitude 21°30’ & 22°37’ North and 70°00’ & 71°31’ East. Climate of the area is semi-arid with annual average precipitation ranging between 500-600 mm. There are total 13 major and minor rivers traverse the district. Among these, the main is Bhadar and Aji rivers. Soils in the area are mainly clayey loam to clay type varying in depth from shallow to moderately deep (25 to 75 cm).

Geology

A major part of the area is occupied by the Deccan basalt (Volcanic rocks) of Cretaceous- Eocene age intruded by a number of basic dykes. These dykes and associated major lineaments are predominantly oriented in E-W direction. A few minor lineaments are also oriented in NE-SW and NW-SE directions. Primary porosity of basalt is almost negligible. Shears, joints and lineaments form secondary porosity in the rock mass helping infiltration of surface water and movement of ground water. Dykes also help in the movement of ground water in the area. Rock mass is weathered down to 20 m in depth at places. Weathered rocks form good aquifer. Ground water in this area occurs in basalt and alluvium under phreatic and confined conditions. The depth of the ground water level ranges in the district from 1 m to 20m.

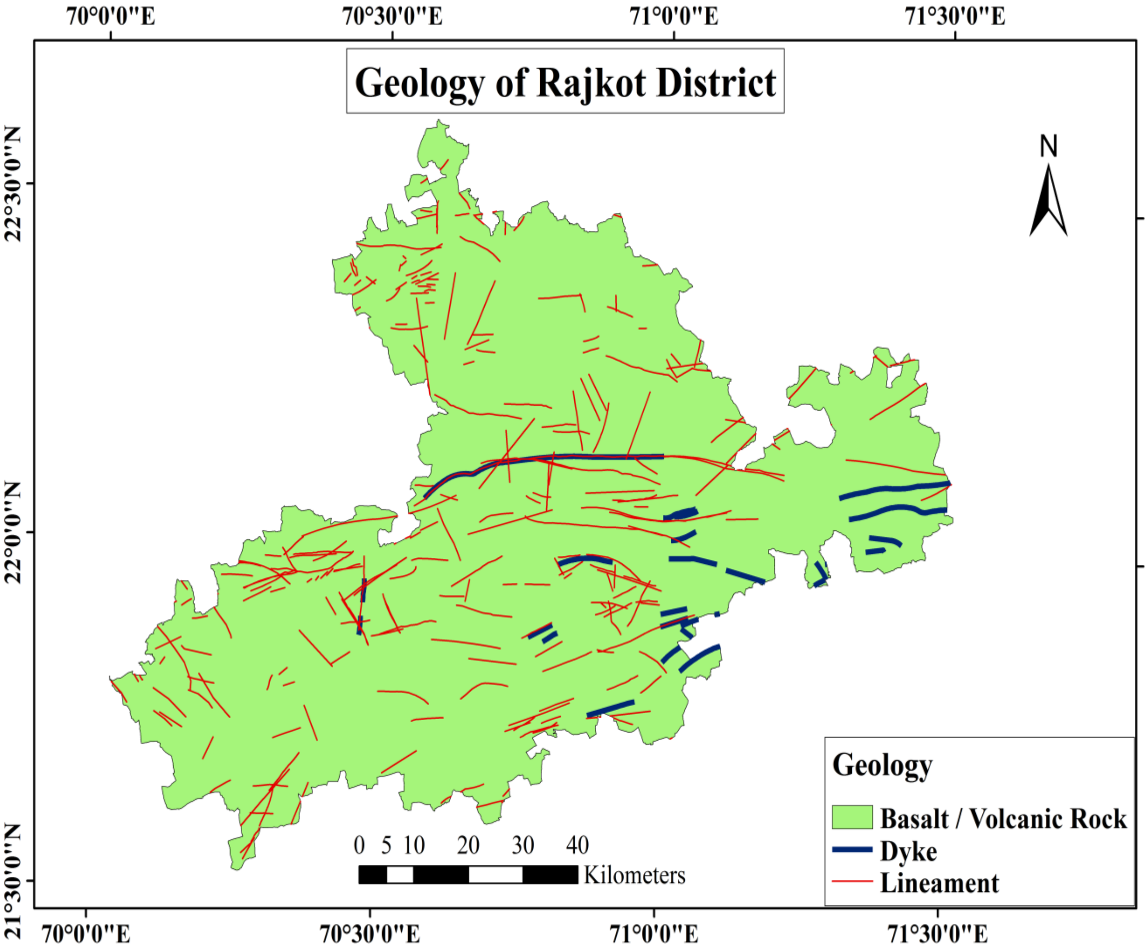

Figure 2: Geology of Rajkot District

Preparation of data

Thematic layers such as slope and drainage density were prepared from Aster DEM. Other layers such as soil, lineament and land use were prepared from available state and central government maps and Landsat images. Rainfall layer was prepared from Indian Meteorological Department data.

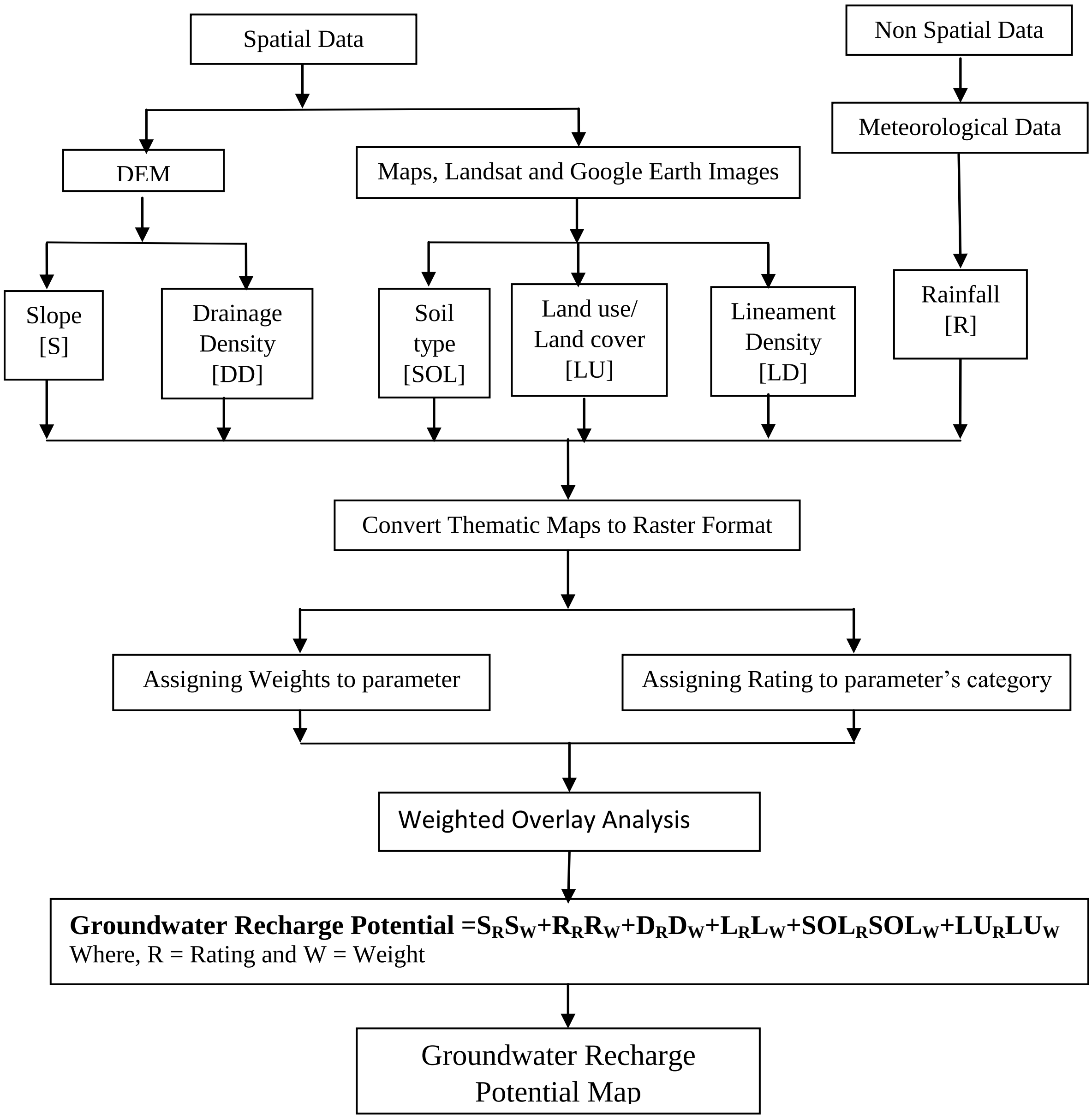

Fig. : Flowchart of adopted methodology for the development of ground water recharge potential map

Groundwater recharge potential was determined by using Saaty's Analytical Hierarchy Process (AHP) (Saaty 1980). In this process weights and rates were assigned to the thematic layers. These layers were integrated in GIS environment for the development of ground water recharge potential map by assigning appropriate weights and ranks to parameters.

Development of Thematic Maps

1. Slope

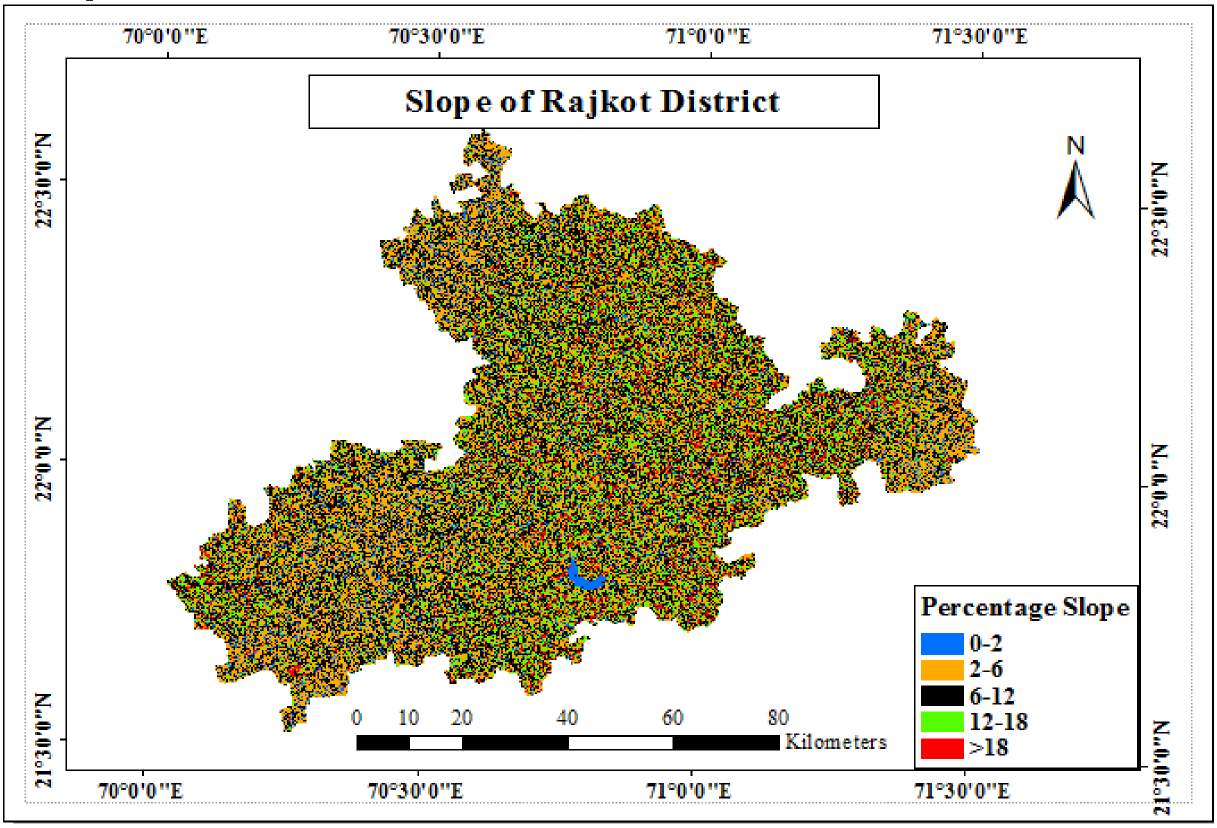

Figure 3: Slope of Rajkot District

The slope of ground surface mainly determines the runoff and infiltration in the area. Gentle sloping surface will have greater potentiality of infiltration and less runoff. Higher value of ground slope represents steeper terrain, whereas lower slope values indicate flatter terrain (Pankaj Kumar et al. 2016). In the present study percentage slope map was prepared from ASTER DEM. The percentage slope map was classified into six classes (Fig. 3)

1. Rainfall

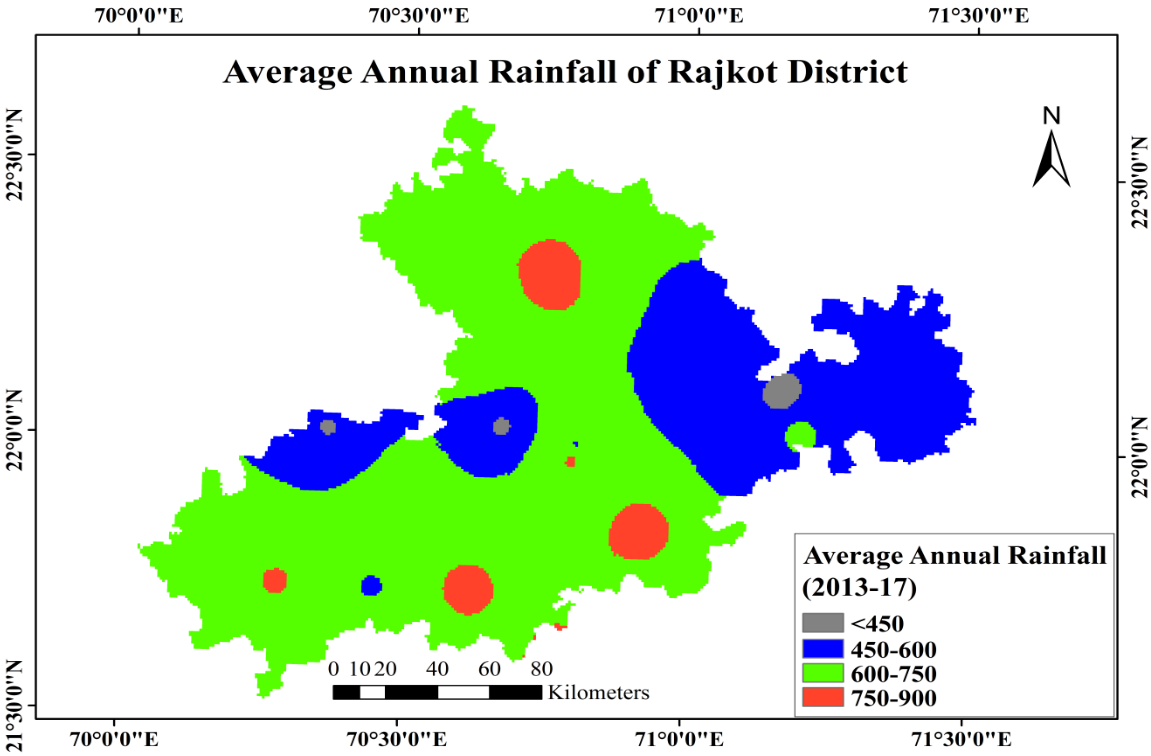

Figure 4: Average Annual Rainfall for five year (2013-17)

The rainfall is an important parameter for recharge of the ground water. Duration and amount of rainfall are important for determining the amount of runoff and infiltration. The rainfall map was prepared from the available data (2013-17) of the state ground water department (Fig.). This map was classified into four classes and appropriate weights and ranks were provided as mentioned in the Table.2.

2. Drainage density

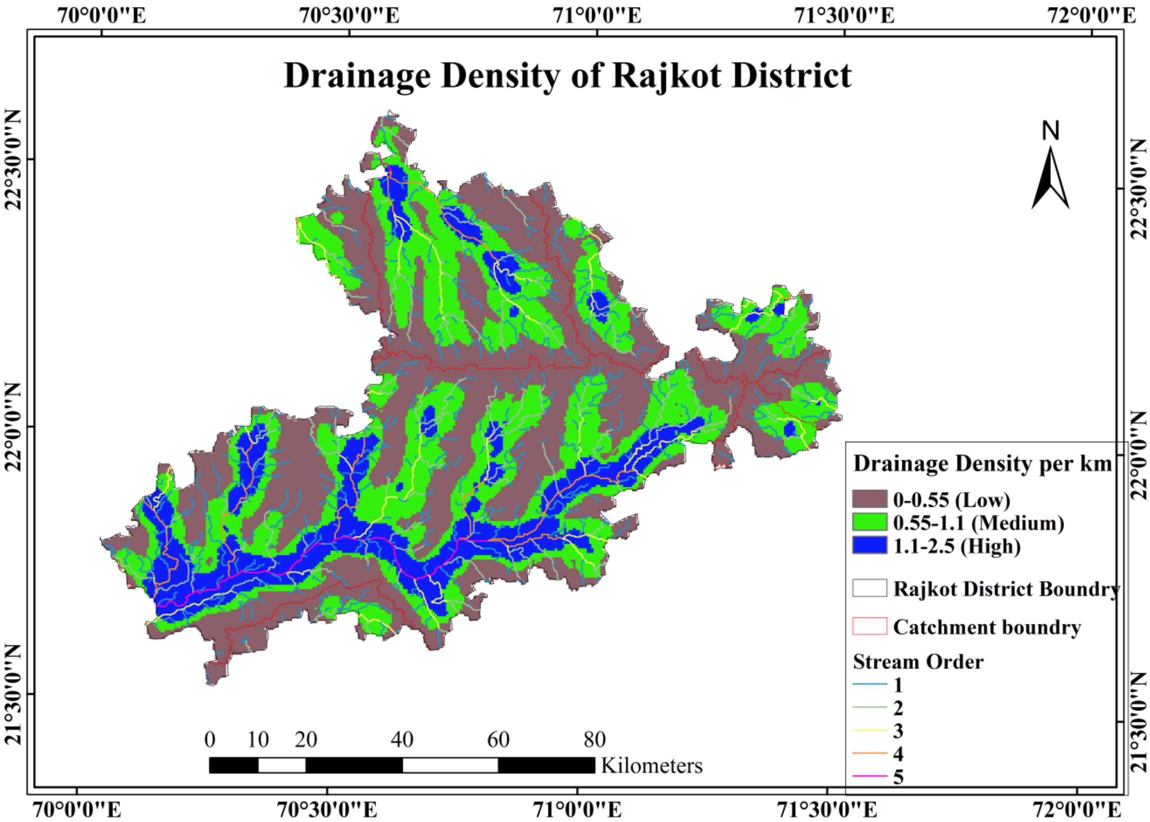

Figure 5: Drainage Density per km of Rajkot District

Drainage density is one of the important parameter in the determination of ground water recharge potential. High drainage density in an area reflects high runoff and low infiltration whereas low drainage density may result in less runoff and high infiltration. Drainage density map of the area was prepared using DEM and classified into three classes Low, Medium and High. The drainage density was calculated using following formula:

Drainage Density = $(\Sigma L) / A$; in (km/ km^2)

Where, Li is the total length of drainage of all stream order in km and A is area of the study area in km^2.

3. Lineament Density

Lineament map was prepared from the Landsat image in conjunction with the published geological map of the area. Lineaments include major joints, shears, faults and dykes traversing the area. These features act as secondary permeability zones in otherwise less impermeable basalt. However, dykes may also act ground water barrier in some cases. Lineament density was calculated using following formula:

Lineament Density = $(\Sigma L) /A$; in (km/ km^2)

Where, L is the total length of the lineaments in km and A is area of the study area in km^2.

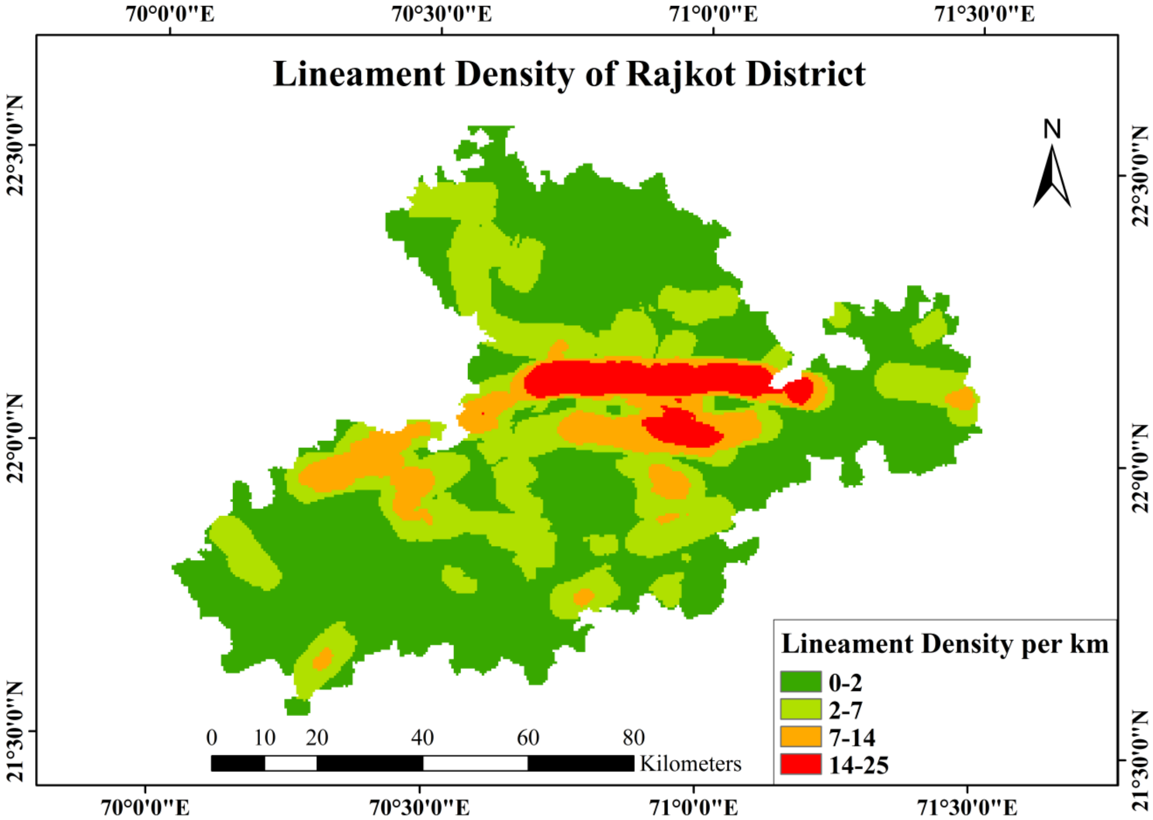

Figure 6: Lineament Density per kilometre of Rajkot District

4. Soil

Types of soil play important role in the infiltration of surface water to recharge the ground water in the area. Impervious clayey soil results in more runoff, on the contrary sandy and gravelly soil results in more infiltration. In the study area, high drainage density in the southern part of the district can be attributed to less permeable clayey loam soil (montmorillonite). Soil map was prepared from the available published map of the state and central agencies. Map was classified in five classes (Fig. 7). Weights and rates were assigned to each class as mentioned in the Table.2)

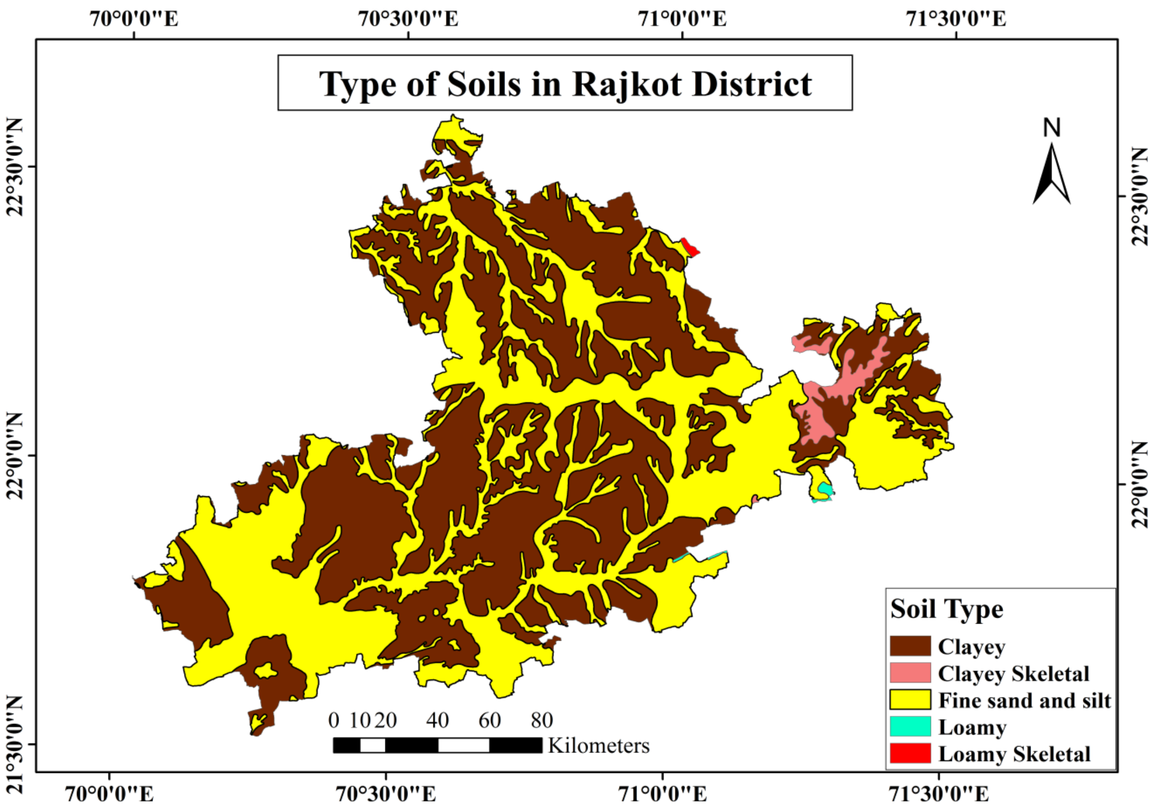

Figure 7: Soil type of Rajkot District

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5. Land use (LU)/Land cover (LC)

Infiltration of rain fall depends on the land use pattern of the area. Land use map was prepared with the help of Google Earth and Landsat images. It is very well known that area covered by vegetation increases infiltration, whereas roads and concrete pavement and buildings reduces infiltration. In the study area LU/LC map was prepared and classified into seven classes namely Forest, Agriculture, Grazing land, Built up, Wastelands and water bodies (Fig.8). Each class of the LU/LC was assigned weights and rates as mentioned in the Table 2

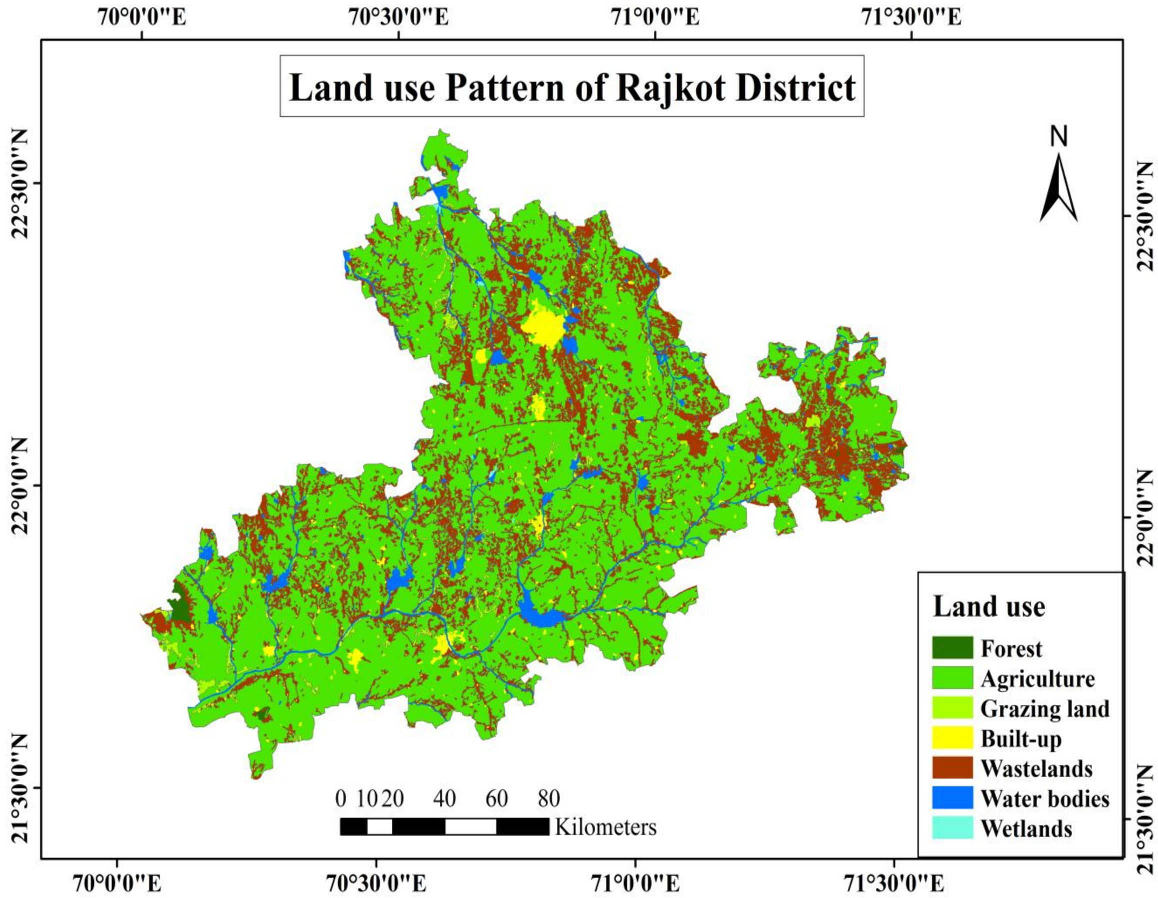

Figure 8: Land use pattern of Rajkot District

Application of Saaty's Analytical Hierarchy Process (AHP) in the study area

The AHP which is a decision support tool can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The pertinent data are derived by using a set of pair-wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. In the AHP method, weights are assigned to every parameters considering importance of their impact on ground water recharge. These values are to be assigned as per the nine points of the Saaty's scale. (Saaty1980).

The AHP considered uncertainty and used principal eigenvalue and the consistency index for better judgement (Saaty 2004). Consistency Index (CI) is expressed in following Equation:

Consistency Index, $CI = (\lambda max - n)/(n - 1)$

Where λmax is the largest eigenvalue of the pair wise comparison matrix, and n is the number of classes or features.

The Consistency Ratio (CR) which is a measure of consistency pair wise comparison matrix is determined using the following Equation:

Consistency Ratio, $CR = CI/RI$

Where, RI is the Ratio Index.

Satty (2004) gave RI value for different n values. If the value of the CR is less than or equal to 0.1, the inconsistency is acceptable, or if the consistency ratio CR is equal to 0.00, it means the judgment of the pair wise comparison matrix is perfectly consistent. If the CR is greater than 0.1, results are not acceptable and reassign the scale values. In the present study RI value is 1.26 (n=6) and CR value 0.013.

Table 1: Analytical Hierarchy Process (AHP) analysis of Rajkot district

		LULC	SLOPE	LD	RF	DD	SOIL	WEIGHT
		[1]	[2]	[3]	[4]	[5]	[6]	[7]
LULC	[1]	1.00	2.00	3.00	5.00	7.00	9.00	1.00
SLOPE	[2]	0.50	1.00	2.00	3.00	5.00	7.00	0.50
LD	[3]	0.33	0.50	1.00	2.00	3.00	5.00	0.33
RF	[4]	0.20	0.33	0.50	1.00	2.00	3.00	0.20
DD	[5]	0.14	0.20	0.33	0.50	1.00	2.00	0.14
SOIL	[6]	0.11	0.14	0.20	0.33	0.50	1.00	0.11
Col. Total	[7]	2.29	4.18	7.03	11.83	18.50	27.00	2.29

A_{11} = 1/2.29 = 0.4372; A_{12} = 2/4.18 = 0.4789; A_{13} = 3/7.03 = 0.4225; A_{14} = 5/11.83 = 0.4225
A_{15}= 7/18.50= 0.3784; A_{16}= 9/27= 0.333; A_{17}=(0.4372+0.4789+0.4225+0.3784+0.333)/6=0.413

		LULC	SLOPE	LD	RF	DD	SOIL	WEIGHT
		[1]	[2]	[3]	[4]	[5]	[6]	[7]
LULC	[1]	0.4372	0.4789	0.4265	0.4225	0.3784	0.3333	0.413
SLOPE	[2]	0.2186	0.2395	0.2844	0.2535	0.2703	0.2593	0.254
LD	[3]	0.1457	0.1197	0.1422	0.1690	0.1622	0.1852	0.154
RF	[4]	0.0874	0.0798	0.0711	0.0845	0.1081	0.1111	0.090
DD	[5]	0.0625	0.0479	0.0474	0.0423	0.0541	0.0741	0.055
SOIL	[6]	0.0486	0.0342	0.0284	0.0282	0.0270	0.0370	0.034
Col. Total	[7]		1	1	1	1	1	

Consistency Index, CI = $\frac{\lambda max - n}{n-1}$

λmax = 1/0. 4372x 0.413 + 1/0.2395 x 0.254 + 1/0.1422 x 0.154 + 1/0.0845 x 0.09 + 1/0.0541 x 0.055 + 1/0.037 x 0.034
= 6.085

CI = 0.0171

Consistency Ratio, CR = CI/RI = 0.0171/1.24 = 0.013< 0.1 (Hence assigned values are accepted)

The CR value 0.013 is less than 0.1, hence acceptable as per Satty's analysis (Satty 2004).

Overlay analysis

The relative weights obtained from AHP were assigned to each parameter of thematic map to generate a cumulative weight of the respective thematic maps based on the site condition. Rating of different categories of each thematic map parameter was also assigned considering their impact on ground water recharge. Overlay analysis of these thematic maps was done in GIS environment as per weight and rate of individual parameters using following equation (Rao and Briz-Kishore 1991; Prasad et al. 2008; Muheeb and Rasheed 2009; Kumar et al. 2014; Pinto et al. 2015):

Groundwater Recharge Potential =$S_RS_W+R_RR_W+D_RD_W+L_RL_W+SOL_RSOL_W+LU_RLU_W$

Where, S is Slope, R is Rainfall, D is Drainage density, L is Lineament density, SOL is Soil type and LU is Land Use/ Land Cover . Subscript R is Rating and subscript W is weight assigned to parameters.

GROUNDWATER RECHARGE POTENTIAL			
PARAMETER	**Category**	**RATING**	**WEIGHT**
Land use/ Land cover	Agriculture	3	0.413
	Builtup	1	
	Forest	5	
	Grazing Land	3	
	Waste Lands	2	
	Water bodies	5	
	Wet Lands	4	
Slope [%]	0-2	5	0.254
	2-6	4	
	6-12	3	
	12-16	2	
	18+	1	
Lineament Length Density (km/km^2)	0-2	1	0.154
	2-7	2	
	7-14	4	
	14-25	5	
Drainage Density (km/km^2)	0-0.55	5	0.055
	0.55-1.1	3	
	1.1-2.5	2	
Average Annual Rainfall (mm)	<450	2	0.09
	450-600	3	
	600-750	4	
	750-900	5	
Soil Type	Clay	1	0.034
	Clayey Skeletal	2	
	Fine sand	3	
	Loamy	4	
	Loamy Skeletal	5	

Table 2: Rates and Weights of the thematic parameters affecting ground water recharge

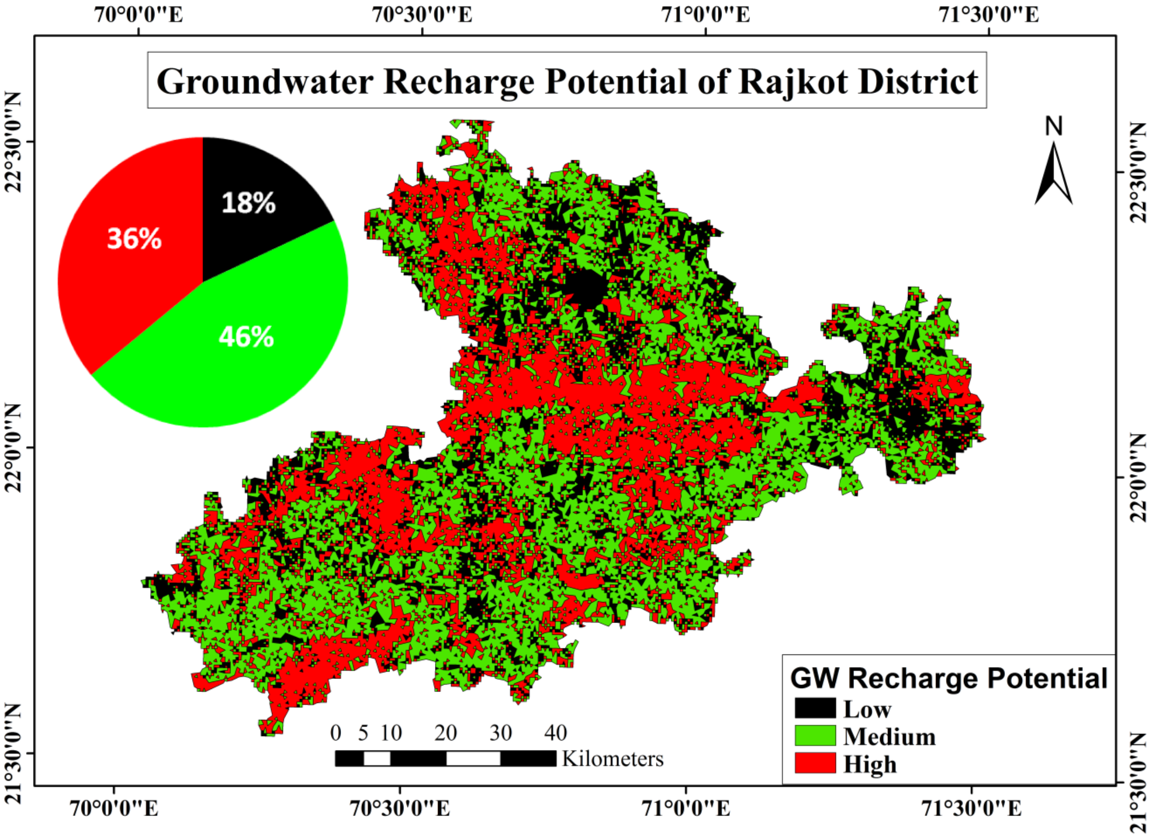

Figure 9: Groundwater Recharge Potential of Rajkot District

Concluding Remarks

The Analytic Hierarchy Process (AHP) which is a multi-criteria decision-making approach was used in the present study to delineate ground water recharge potential zones. This method uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. As ground water study involves a number of physical and meteorological parameters, the AHP method was considered appropriate in solving this complex decision problem for proper ground water management of the Rajkot district. Rating to parameters was provided based on the importance of each parameter. Based on the AHP method and overlay analysis ground water potential map was generated and classified into three categories Low (18%) Medium (46%) and High (36%). This study will help to managers to priorities the recharge areas for the improvement of ground water condition of the district.

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