Scientific Journal of Impact Factor (SJIF): 4.72

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 8, August -2017

Multicriteria Decision Analysis and Probabilistic Modeling for Evaluation in Groundwater Prospects

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Abstract —*Groundwater resources quantification is necessary for developing an efficient strategy for sustainable groundwater management. Integration of Remote Sensing and Geographic Information System (GIS) technique with Multi-criteria Decision Analysis (MCDA) has a power fool tool for the assessment of groundwater resources at macro scale. The main aim of this study is to appraise the performance of two GIS based approaches, namely MCDA and probabilistic modeling for groundwater prospecting. In MCDA, the thematic layers and their relevant features to groundwater prospect are extracted from Remote sensing and GIS and weightages were assigned using Analytical Hierarchy process (AHP) scale. The thematic layers have been integrated in GIS environment to generate groundwater prospect map. In probabilistic models, viz. frequency ratio (FR) and weight of evidence (WOE), were used. The probability values were calculated for each of the selected theme and groundwater prospect map has been generated by overlay analysis using GIS by FR and WOE method. The Groundwater prospect maps thus obtained by two methods were classified into five discrete groundwater prospect zones. These Groundwater prospect maps were verified using available well yield data through receiver operating characteristic curve. The AHP technique is superior to the probabilistic models. It is concluded that for more consistent results, the AHP technique is used for assessing groundwater prospective in a region.*

Keywords*- Remote Sensing and Geographical Information System, Multi-criteria Decision Analysis (MCDA), Probabilistic modeling, Frequency ratio, weight of evidence.*

I. INTRODUCTION

Groundwater is important source of water for domestic, industrial and agriculture purposes. The distribution of groundwater on spatio-temporal variations depends up on the underlying rock formations and their structural fabric, geometry and surface expression (Srivastav, 2012). The mismanagement of groundwater resources leads to depletion and pollution problems (Machiwal et al., 2011). In hard rock terrains the availability of groundwater is limited extent and occurrence is confined to fractured and weathered zones (Saraf A K et al.,) . The Groundwater depletion problems associated land subsidence, reduction in stream flows, loss of wetlands and decline of groundwater quality. It is essential to find out quantitative estimation of groundwater resources in a basin. In this regards, groundwater prospective mapping is important in the identification of zones. Subsurface investigations of groundwater exploration using geophysical method and pumping test method are quite expensive (lokesh N et al., 2005).

Geospatial technology is a quick and cost-effective tool in producing data on geomorphology, geology, lineaments, slope, etc. that help in decide groundwater potential. Integrated remote sensing and GIS techniques have provided the appropriate platform for analysis of diverse data sets for decision making in groundwater resource identification, mapping and planning. Many workers such as Kamaraju et al. (1995), Krishnamurthy et al. (1996), Gogu et al. (2001), Sikdar et al. (2004), Dawoud et al. (2005), Lokesh et al. 2005, 2007, Solomon & Quiel (2006), Leblanc et al. (2007), Münch & Conrad (2007), Vijith (2007), Chatterjee & Bhattacharya (1995), and Vittala et al. (2005) have used the approach of remote sensing and GIS for groundwater exploration. From the review of literature the most of the studies on application of RS and GIS technology in delineation of groundwater prospect have estimated single method approach only that is either Multi=criteria decision analysis method (AHP) or probabilistic method.

Therefore the present study aims that to identify suitable method for ground water prospecting which provides high accuracy. It also demonstrates the usefulness of two GIS based approaches , viz., MCDA approach and probabilistic approach for delineation of groundwater prospect. To achieve this goal, the upper pincha basin of Chittoor district, Andhra Pradesh, India, was considered for the study area.

II. STUDY AREA

Upper Pincha Basin lies between Latitude 13^{0}42’ to 13^{0}28’ N and Longitude 78^{0}54’ to 78^0 45’ E (Figure 1) . It comprises an area of 147 km^2 , in the Survey of India topographical sheet No. 57 K/10,K/11,K/14 and K/15 on a scale of 1:50,000. and is spread over three mandals; Somala, Sodumu and Chowdapalle. The basin has an altitude of 500 to 999 m of above mean sea level. The basin has highest altitude in south-west corner and lowest altitude in north-east corner.

The elevation in the basin varies from level ground to steep slope. The major soils presents in the basin are red loamy soils, red clayey soils and rocky lands.

Geologically, the study area consists of hard rock formation such as Hornblende-Biotite Gneiss. This region is influenced by semi arid climate with temperature varying between 30 ^{0}C and 42 ^{0}C. Normal annual rainfall over the study area is about 860 mm. The farmers are mostly dependent on groundwater for irrigation purpose. The major crops cultivated in the region are groundnut, paddy, tomato etc.

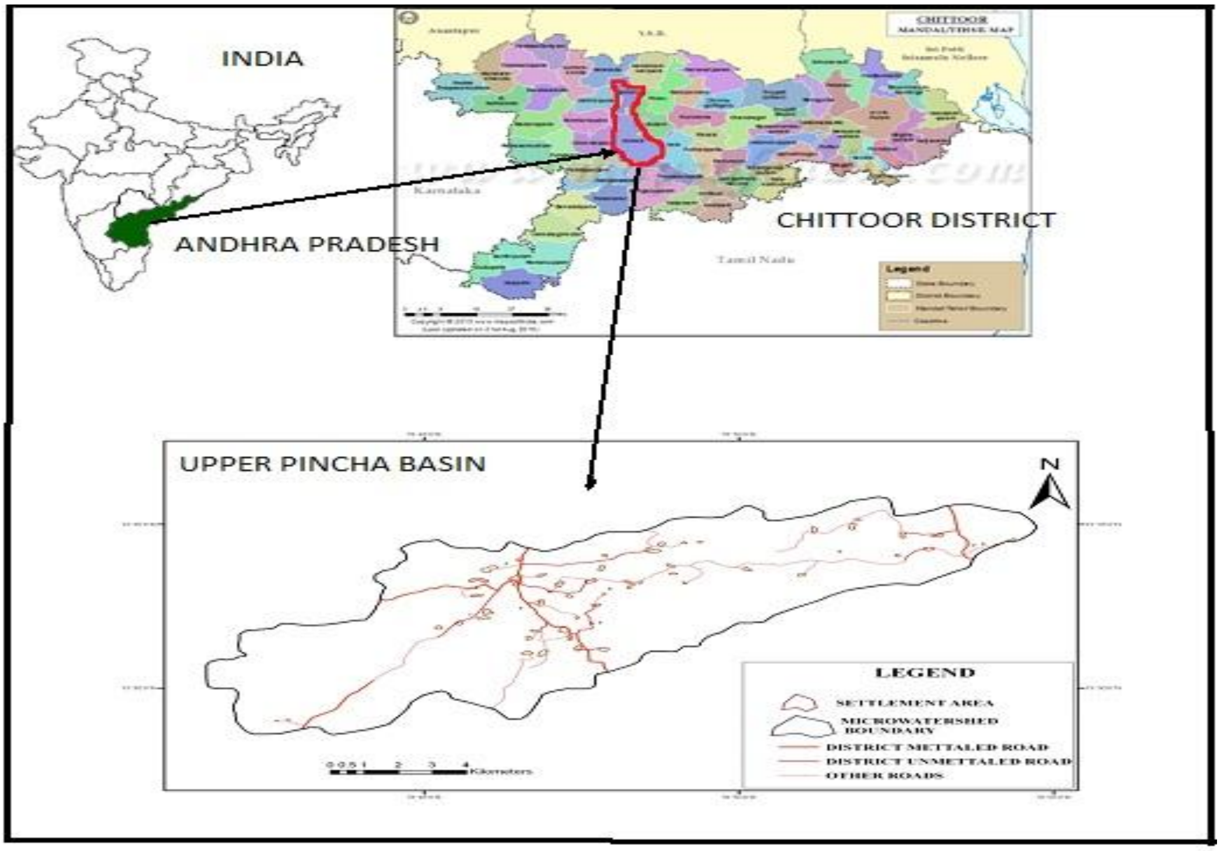

Figure 1 Location map of the study area

III METHODOLOGY

Different data sets comprising satellite data, conventional map (including topographic map) and field data was utilized in the study to demarcate groundwater potential zones. The geomorphology features and lineaments were identified using high-resolution Indian Remote Sensing (IRS), Linear Imaging Self Scanning Sensor (LISS) III satellite imageries. The False Colour Composite (FCC) images were visually interpreted with image interpretation characteristics for delineating the geomorphology and lineaments. ArcGIS Spatial Analyst module was used for the generation of slope from Advanced Space Borne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTER DEM) used to generate slope map. The Geology map was digitized and prepared in ArcGIS software using geology map from Geological Survey of India (GSI). Soil map was acquired from the National Bureau of Soil Survey and digitized in ArcGIS platform to obtain the digital soil map. The drainage network of the study area was prepared using DEM map. The rainfall distribution data of 28 years (1988-2016) for the study area collected from Indian Meteorological Department (IMD), Pune. The rainfall distribution map was generated using spatial interpolation by Inverse Distance Weighted (IDW) method. Groundwater potential of the study area was assessed using seven thematic maps, viz., Geomorphology (Gm), Slope (Sl), Soil (S), Lineament density (Ld), Drainage density (Dd), Rainfall (Rf) and Land use (LU). These maps are generated using RS and conventional data in GIS platform. These thematic maps are converted into a raster format, maintaining the same resolution (30 m) and coordinate system before they are taken into GIS environment. The software, ArcGIS (Version 10.2.2) is used for GIS analysis.

3.1 Identification and delineation of Groundwater prospect zones:

In this study two methods were used to identify groundwater prospect zones in the study area. In method 1, multi-criteria analysis AHP and GIS technique were used and in method 2, the two probabilistic models, namely Frequency ratio and weight of evidence method (WOE) along with GIS technique were used.

Method 1: Groundwater prospect using AHP and GIS

The methodology used for the preparation of groundwater prospect map by using method 1 is shown in Fig 2. An AHP technique is a comprehensive methodology that incorporates both empirical data as well as the subjective opinion of the experts to achieve sound decision-making process. It aids in identifying and weighting of selection criteria, analysing the collected data, and accelerating the decision-making process. The hierarchy is compartmentalized into pair comparison matrix with one-half value of each matrix is allotted as the off-diagonal relationship. The point scale of 9 ranges from 1 (insignificant or equal significance) to 9 (extreme preference or absolute significance) used for analytic hierarchy decision-making show in Table 1. In AHP, each pair of factors in a particular element group is examined at a time, regarding their relative importance. A pairwise comparison matrix is formed in which a_{ij}=1 and a_{ij}=1/a_i. The weight vector, which is calculated from the maximum absolute eigenvalue (λ max). The grading values of all the criteria are normalized to 1.

Table 1 The quantitative comparison and gradation scale for alternatives in AHP (Saaty 1980)

Importance	Definition	Explanation
1	Equal importance	Two activities
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured, and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent judgments the two	When compromise is needed
Reciprocals of above non zero	If activity has one of the above nonzero number assigned to it when compared with activity j, then j has reciprocal value when compared with i	

Therefore normalized weights and consistency ratio were calculated for all thematic maps. The Groundwater Potential Index (GWPI) is a dimensionless quantity that helps in the prediction of groundwater potential zones in an area. The weighted linear combination technique was applied to determine the GWPI as follows (Adiat et al. 2012)

$$\mathrm{GWPI} = \sum_{t=1}^{m} \sum_{f=1}^{n} (Wt * Xf) \quad (1)$$

where Wt represents the normalized weight of the thematic layer, Xf represents the rank value of the each class with respective to the f layer, m represents the total number of thematic layers and n represents the total number of classes in the thematic layer. The GWPI considering all the themes and features in an integrated layer is calculated using Equation (2) below (Shaker & Pandey 2014)

$$GWPI = Gm_{wi} * Gm_r + Sl_{wi} * Sl_r + S_{wi} * S_r + Ld_{wi} * Ld_r + Dd_{wi} * Dd_r + Rf_{wi} * Rf_r + LU_{wi} * LU_r \quad (2)$$

Gm_{wi} represents the weight index of geomorphology and Gm_r is the rank of the theme; Sl_{wi} represents the weights index of the slope and Sl_r is the rank of the theme; Ld_{wi} represents the weight index of the lineament density and Ld_r is the rank of the theme; Dd_{wi} represents the weight index of the drainage density and Dd_r is the rank of the theme; Rf_{wi} represents weight index of rainfall and Rf_r is the rank of the theme; LU_{wi} represents weight index of land use and LU_r is the rank of the theme.

Method 2 Groundwater prospect zoning using probabilistic models and GIS

In this method groundwater prospect maps were prepared using Frequency ratio and weight of evidence model. This model requires data on location and observation wells over the study area. A well location map was prepared observing 25 wells over the study area are shown in Figure 3. Out of which 13 were using training the wells and 12 were used for testing the wells. The training wells were used in FR and WOE probabilistic model. The testing wells were used only for verification of model results. The step by step procedure of FR model and WOE model were explained below.

1. Frequency ratio modeling

Frequency ratio is the probability of occurrence of attributes. For groundwater prospecting, frequency ratio method indicates quantitative relation between well occurrence and different parameters. For determining groundwater potential zones, the area ratio and well occurrence ratio were calculated for different classes of thematic maps. FR for different classes of each thematic layer was calculated by dividing well occurrence ratio to area ratio. These values were used for generation of groundwater prospect map using overlay analysis in GIS. The step by step procedure for frequency ratio method is as follows

Step 1: selection of thematic layers and the preparation of thematic maps
Step 2: Preparation of well location map and selection of training and testing wells
Step 3: overlaying thematic maps with the training well map
Step 4: Identification of pixels under different classes of given factor
Step 5: computation of area ratio for a particular class of a given factor by dividing total number of pixels present in the class with the total number of pixels present in the study area.
Step 6 : calculation of well occurrence ratio for a particular class of a given factor by dividing the number of training wells present in that class with the total number of training wells present in the study area.
Step 7: calculation of FRs for each class of a given factor by dividing the 'well occurrence ratio' with the 'area ratio'.

Step 8: overlaying of the thematic layers and the computation of groundwater potential index (GWPI) over the study area. The pixel-wise GWPI over the study area was computed as follows:

$$GWPI = \sum_{i=1}^{n} (FR)i \quad (3)$$

.Step 9: preparation of a groundwater prospect map of the study area in the GIS environment based on the range of GWPI values over the study area.
Step 10: validation of the prepared groundwater prospect using testing wells

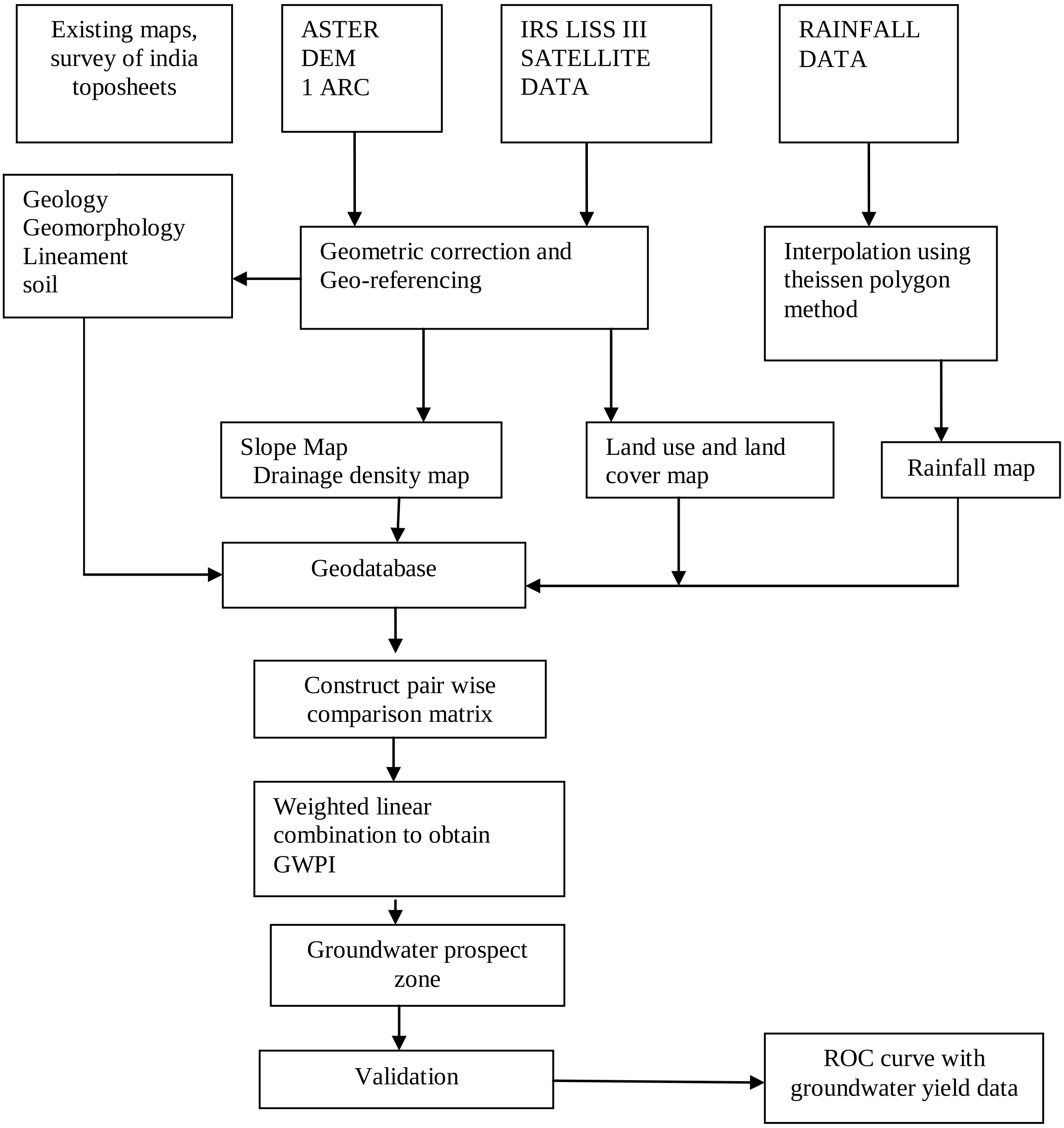

Figure 2: Flow chart showing the methodology for groundwater prospective zones using AHP method

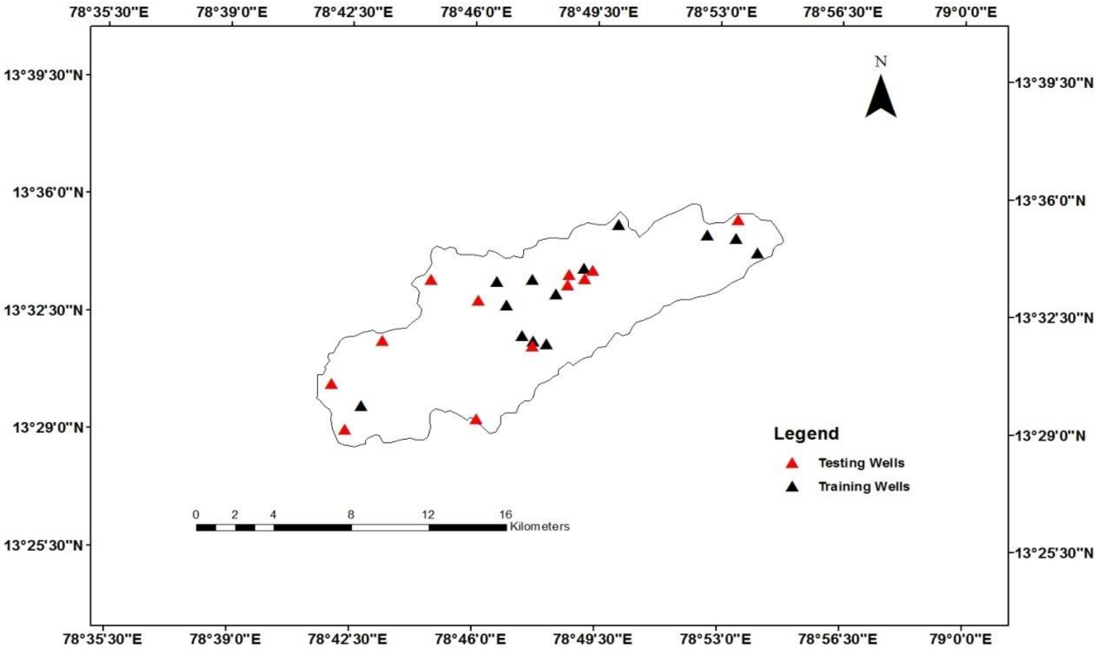

Figure 3: Map showing the training wells and testing wells in the study area

Method 2: Weight of Evidence Modelling

The weight of evidence model estimates the weights for groundwater prospecting based on the presence or absence of wells in thematic maps. Similar to the FR model, WOE model also requires a set of training and testing wells. The thematic layers were overlaid with the map depicting training wells. On the basis of these intersections, weight and WOE probability values were calculated for different thematic layers. The step-by-step procedures for WOE modelling to delineate groundwater prospect zones are as follows:
Step 1: selection of thematic layers and the creation of thematic maps
Step 2: preparation of well location map and the selection of training and testing wells.
Step 3: overlaying of the thematic maps with the training well map
Step 4: identification of the pixels under different classes of a given factor (theme).
Step 5: calculation of weights (W+) for each class of a theme. Weights for the individual classes of different themes were calculated as:

$$W+ = \ln \left(\frac{\dfrac{\text{Number of wells in the class}}{\text{Total Number of wells in the study area}}}{\dfrac{\text{Number of pixels in the class - Number of wells in the class}}{\text{Number of pixels in the study area - Total number of wells in the study area}}} \right) \quad (4)$$

Step 6: Calculation of WOE probability (P) for each class of theme. The WOE probability of individual classes of different themes were calculated as

$$P=\exp \left[\Sigma \text{ W+ ln Pp} \right] \quad (5)$$

Step 7: Preparation of groundwater prospect map of the study area based on the range of WOE probability values over the study area
Step 8 : Validation of groundwater prospect map with testing wells data

Finally, comparative evaluation of two methods for groundwater prospective map was performed on the basis of prediction accuracy calculated.

IV RESULTS AND DISCUSSIONS

4.1 Development of thematic layers in upper pincha basin

Various factors such as geology, geomorphology, lineament density, drainage density, slope, soil, rainfall , land use / land cover has been prepared using ArcGIS 10.2.2 software. To delineate the groundwater potential zones eight influencing factor such as geology, geomorphology, lineament density, drainage density, slope, soil, rainfall, land use / land cover have been identified in the present study area. But the geology of the study area is uniform and hence neglecting the parameter. So, therefore the weights are assigned to seven thematic layers and normalization of weights done using AHP technique is shown in Table 2.

Table 2 Pairwise comparison matrix and normalized weights of thematic layers

	GM	LD	SOIL	SLOPE	DD	RAINFALL	LU/LC	Normalized weights
GM	0.501	0.538	0.458	0.340	0.620	0.392	0.3	0.450
LD	0.100	0.107	0.152	0.170	0.077	0.168	0.166	0.134
SOIL	0.083	0.053	0.076	0.127	0.051	0.112	0.133	0.091
SLOPE	0.062	0.026	0.025	0.042	0.031	0.028	0.066	0.040
DD	0.125	0.215	0.229	0.212	0.155	0.224	0.2	0.194
RAINFALL	0.071	0.035	0.038	0.085	0.038	0.056	0.1	0.060
LU/LC	0.055	0.021	0.019	0.021	0.025	0.018	0.033	0.027

Note: GM- Geomorphology; LD- Lineament density; DD- Drainage density; LU/LC- Land use/Land cover

Geology

The geology map of the basin was prepared using the data collected from Geological Survey of India. The geology map of Chittoor district on 1:250000 scale was projected, georeferenced and digitized to develop geology map of the study area. The rock present in the total study area is Hornblend biotite gneiss (Hard rock). The groundwater present in these types of rock is poor and the influence for the groundwater potential zone is uniform . So, for estimation of groundwater potential zone the geology map is not considered.

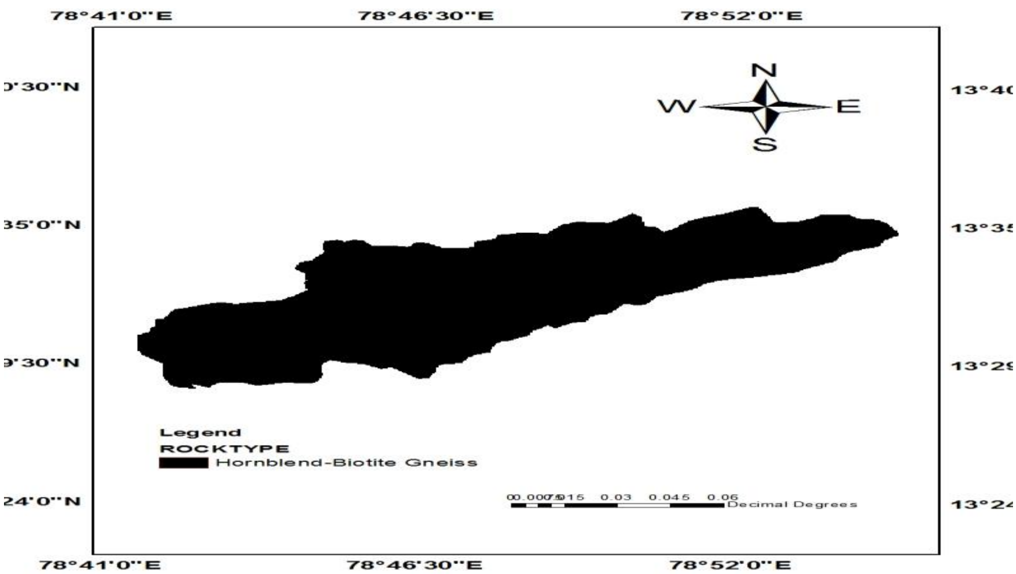

Figure 4 Geology Map of the study area

Geomorphology map

Geomorphology exhibits various land forms and structural features. The land forms play a vital role for the occurrence and distribution of groundwater. Many of these features are favorable for the occurrence of groundwater and classified in terms of groundwater potentiality. Five type of geomorphic units are identified in the study area, they are Valley fills, Shallow weathered pediplane, Pediplane inselberg complex, Denudation hills, Residual hills.The ranks were assigned to the individual landform, according to its respective influence of groundwater occurrence, holding and recharge, are shown in Table 3.

Table 3: Classification and weights assigned based on AHP method for Geomorphology map

Geomorphology	Groundwater Prospect	Area		Groundwater potential	score	Weights (%)
		Km2	%			
Valley fill	Good to very good	3.939	2.679	Very good	5	57.61
Shallow weathered pediplane	Very good	33.072	22.49	Good	4	19.95
Pediplane inselberg complex	moderate	58.177	39.576	Moderate	3	14.75
Denudation hill	Poor	50.349	34.25	Poor	2	3.8
Residual hill	Poor	1.423	0.96	Poor	1	3.8

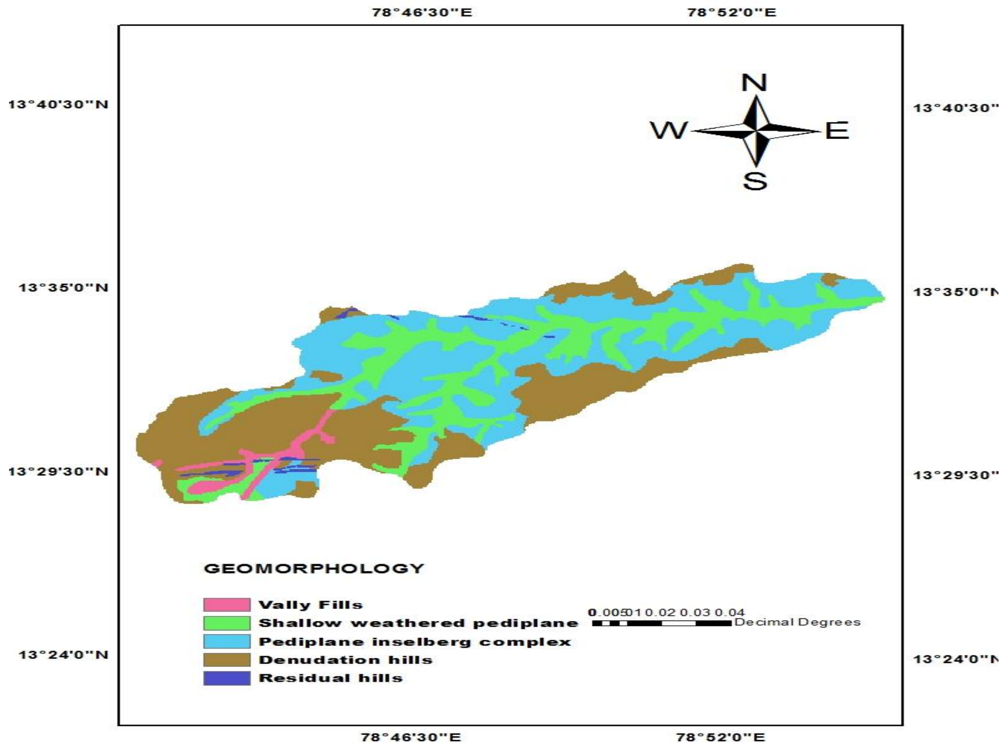

Figure 5 Geomorphology map of the study area

Lineament map

Structures are the rock failure and deformation created by the changes in stress with time. Lineaments, faults and fractures are the important linear structures for increasing the permeability of the bed rock. The geologically core area is subdivided by straight long fractures, called lineament. Lineament is an important layer in determining the groundwater potential as it indirectly provides the information about the movement and storage of groundwater. Lineaments are any linear features that can be picked out as lines in aerial or satellite imagery. From satellite imagery, lineament data is extracted and then lineament density map is generated.

Table 4: Classification and weights assigned based on AHP method for Lineament Density map

Lineament density Km/km2	Area		Groundwater potential	score	Weights (%)
	Km2	%			
0-2.401	86.83	59.06	Very good	4	51.99
2.401- 6.542	35.308	24.01	Good	3	26.81
6.542 – 11.096	22.25	15.13	Moderate	2	14.09
11.096-21.117	2.52	1.714	Poor	1	7.09

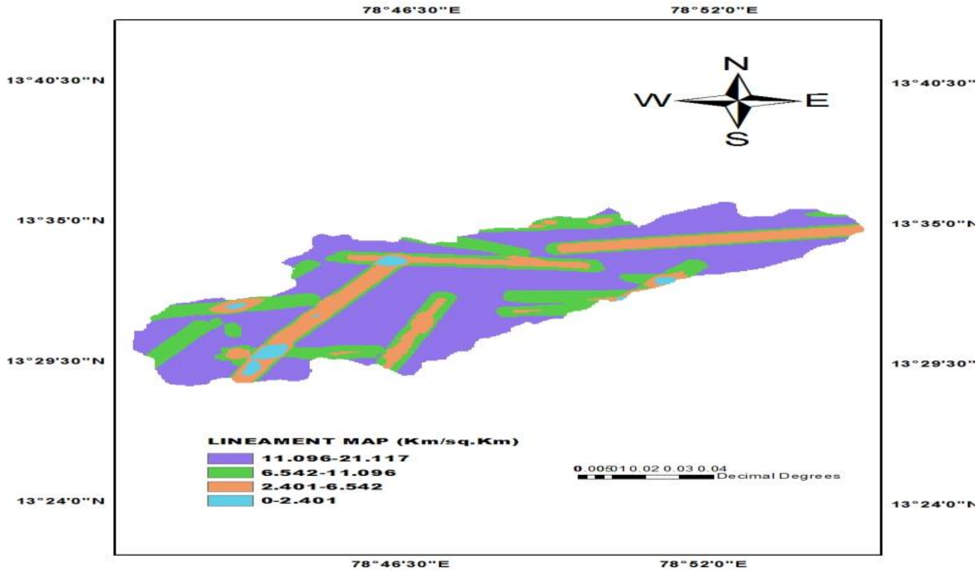

Figure 6 Lineament density map of the study area

Soil map

The soil for the study area reveals four main categories Red gravelly loam soils, Red clayey soils, Rocky lands and Cullivio alluvial calc clayey soils. Rank of soil has been assigned on the basis of their infiltration rate. Red gravelly lo am soils have high infiltration rate, hence given high priority , while the clayey soils has least infiltration rate hence assigned low priority. The ranks were assigned to the individual soil type, according to its respective influence of groundwater occurrence, holding and recharge, are shown in Table 5

Table 5: Classification and weights assigned based on AHP method for Soil map

Soil	Area		Groundwater potential	score	Weights (%)
	Km2	%			
Red loamy soils	26.826	18.241	Very good	4	65.264
Red clayey soils	75.56	39.08	Good	3	15.936
Cullivio alluvio clayey soils	4.132	2.81	Moderate	2	12.36
Rocky lands	58.53	39.61	Poor	1	6.43

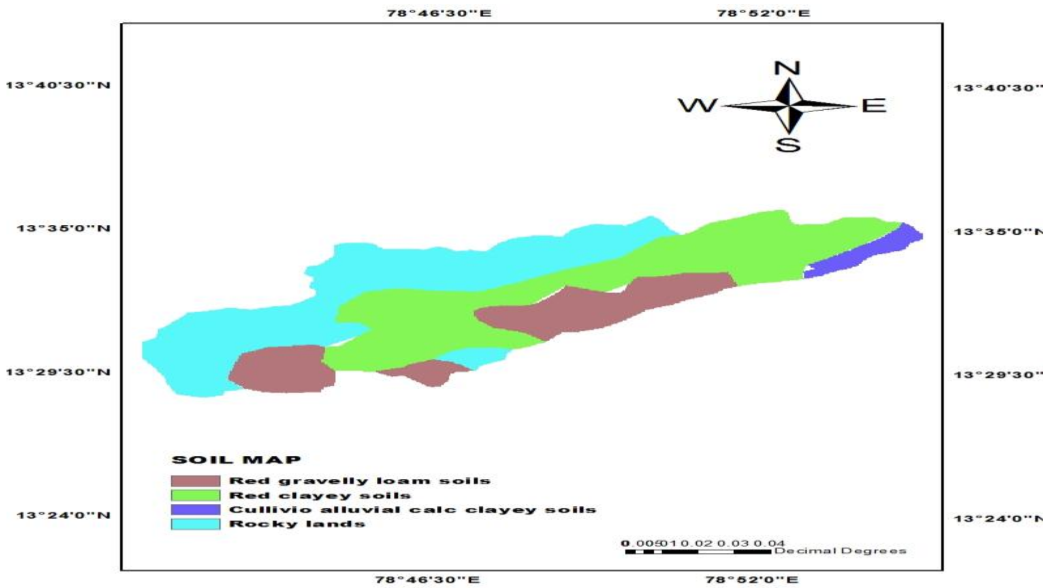

Figure 7: Soil map of the study area

Slope map

The abrupt terrain causes rapid runoff and does not store water easily. Slope of any terrain is one of the factors allowing the infiltration of groundwater into subsurface . In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas, steep slope area facilitates high runoff allowing less residence time for rainwater to percolate and hence comparatively less infiltration. The ranks were assigned to the individual slopel type, according to its respective influence of groundwater occurrence, holding and recharge, are shown in Table 6

Table 6: Classification and weights assigned based on AHP method for Slope map

Slope (%)	Area		Groundwater potential	Score	Weights (%)
	Km2	%			
0-1	25	17	Excellent	5	90
1.1-3	00	00	Very good	4	
3.1-5	00	00	Good	3	
5.1-15	00	00	Moderate	2	
15.1-89.99	122	82.99	Poor	1	10

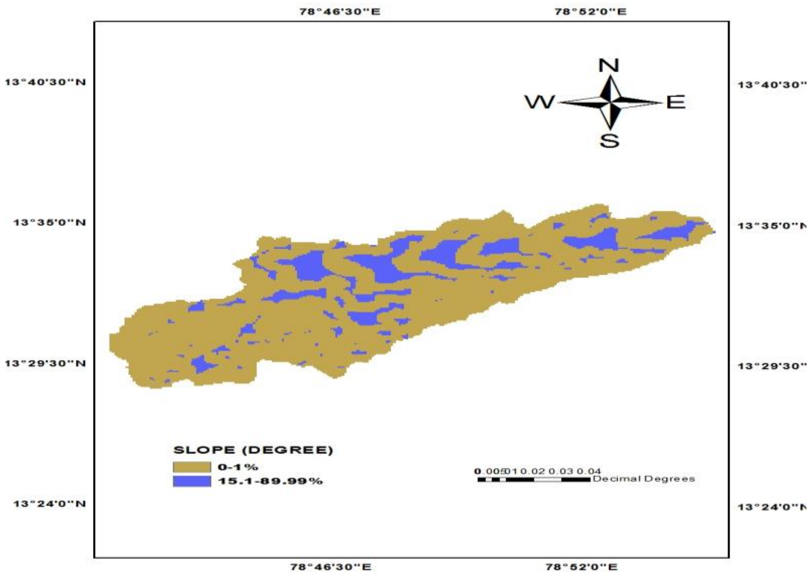

Figure 7 Slope map of the study area

Drainage density map

Drainage pattern reflects the characteristic of surface as well as subsurface formation. Drainage density (km/sq. km) indicates closeness of spacing of channels as well as the nature of surface material. More the drainage density, higher would be runoff. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zone. The drainage pattern, in general, is dendritic, typical of granitic terrain. The high drainage density area indicates low-infiltration rate whereas the low-density areas are favourable with high infiltration rate. The ranks were assigned to the individual class type, according to its respective influence of groundwater occurrence, holding and recharge, are shown in Table 7

Table 7: Classification and weights assigned based on AHP method for Drainage Density map

Drainage density Km/sq. km	Area		Groundwater potential	score	Weights (%)
	Km2	%			
0-1.08	61.168	44.161	Very good	4	60.79
1.08-2.488	64.69	44	Good	3	27.20
2.488-6.749	21.108	14.35	Moderate	2	11.99

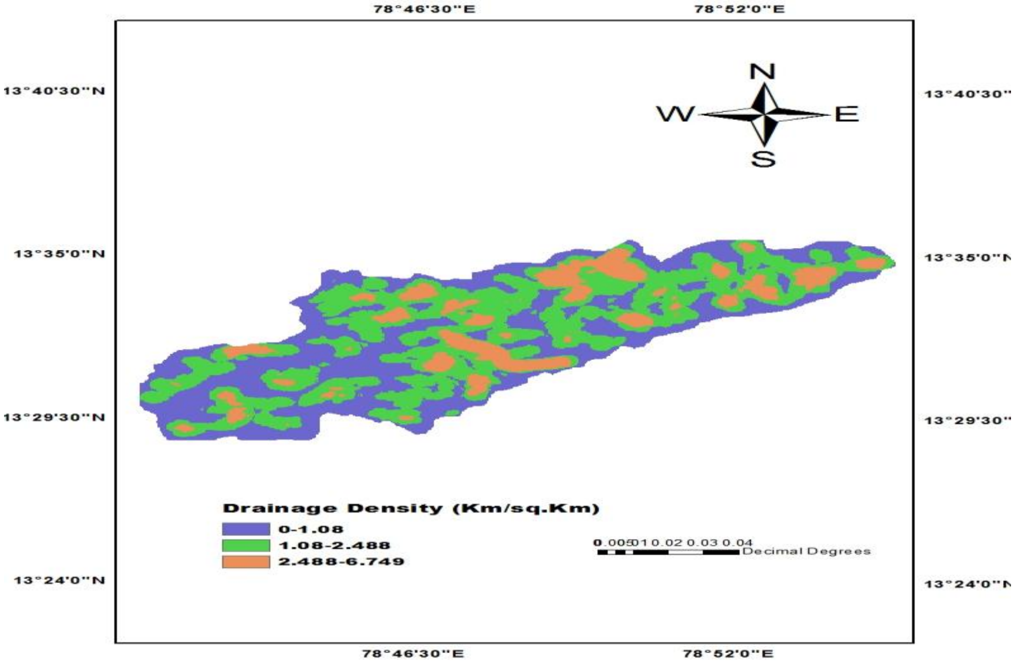

Figure 8 Drainage density map of the study area

Rainfall map

The rainfall availability is the major source of groundwater recharge . It regulates the quantity of water that would be available to percolate into the groundwater system. The rainfall has a significant effect on the groundwater potential and the efficiency of MCDA (Adiat et al. 2012). The rainfall map depicts high rainfall in the north-east region as compared to the central portions that record moderate rainfall area. The southern region exhibits low rainfall. Table 8 shows the normalized weights and ranks.

Table 8: Classification and weights assigned based on AHP method for Rainfall map

Rainfall Range (mm)	Area		Groundwater potential	score	Weights (%)
	Sq. Km	%			
799.017-821.985	56.81	38.62	Poor	1	6.829
821.985 – 841.891	55.16	37.52	Good	2	14.11
841.891 – 868.686	16.78	11.41	Very good	3	26.87
868.686 – 896.631	18.21	12.38	Excellent	4	52.17

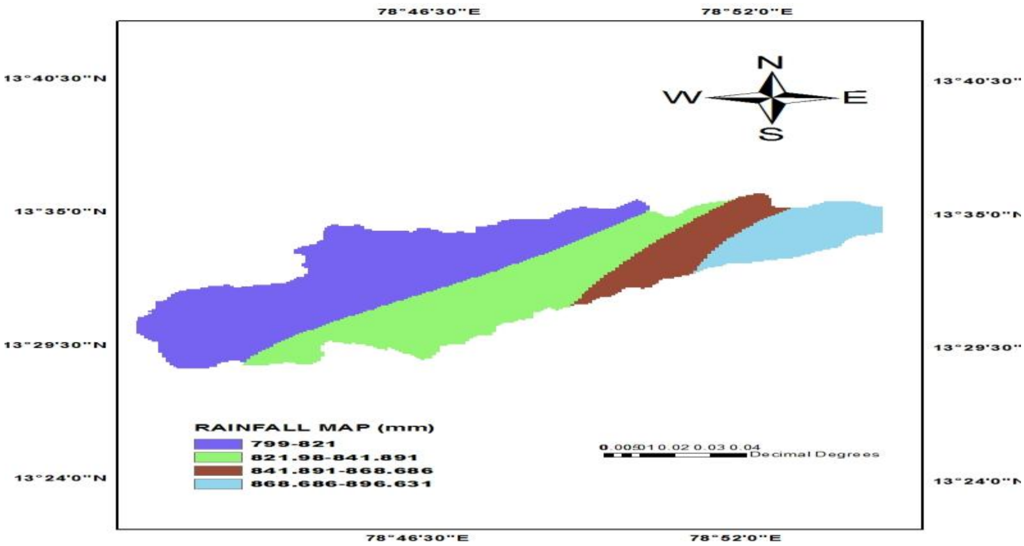

Figure 9 Rainfall map of the study area

Land use / Land cover map

Land use land cover features control the occurrence of groundwater and also causes for infiltration for recharge, with variety of classes among itself. Remote sensing data and GIS technique provide reliable, accurate baseline information for land use land cover mapping, which plays vital role in determining land use pattern and their changes on different times. The ranks were assigned to the individual class type, according to its respective influence of groundwater occurrence, holding and recharge, are shown in Table 9

Table 9: Classification and weights assigned based on AHP method for Land use/Land cover map

Land use/ land cover	Area		Groundwater potential	score	Weights (%)
	Sq. Km	%			
Agricultural land	81.719	55.59	Excellent	6	43.62
Water bodies	2.164	1.47	Very good	5	24.29
Waste lands	13.558	9.22	Good	4	15.57
Forest evergreen	39.726	27.02	Poor	3	8.99
Forest deciduous	7.486	5.09	Poor	2	4.89
Built-up land	2.316	1.57	Poor	1	3.306

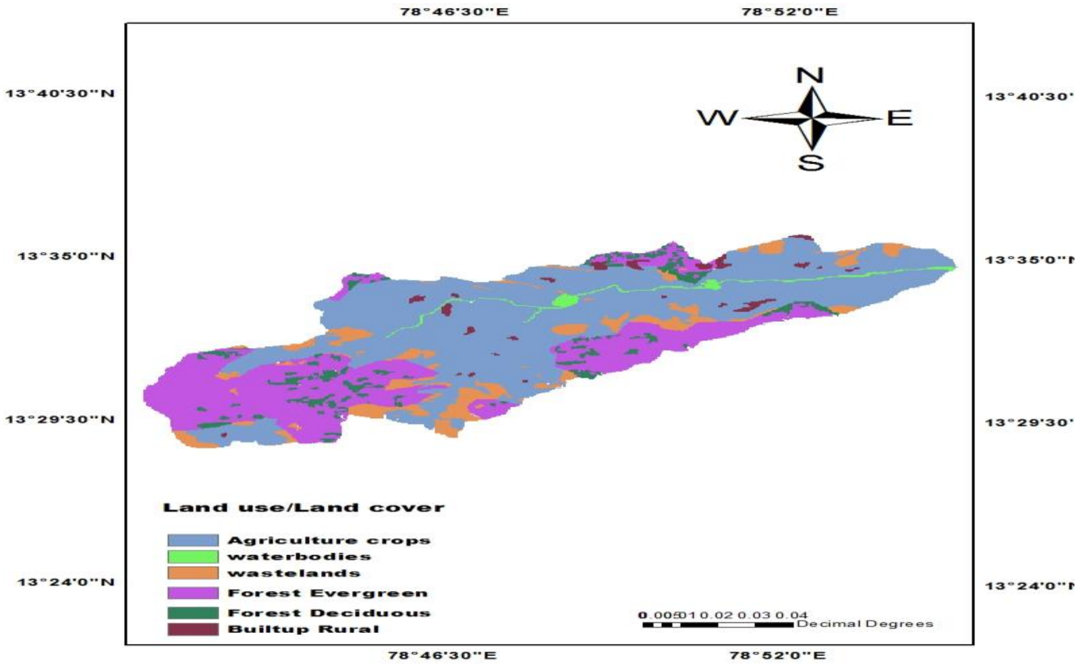

Figure 10 Land use / Land cover map of the study area

4.2 Groundwater prospective map of the study area using AHP method

In this approach, RS, GIS and AHP technique is integrated for identifying groundwater prospective zones. The weights are assigned all thematic layers using Saaty's 9 point scale and converted in to normalized weights. For delineation of the groundwater potential map, all the thematic layers were aggregated in a linear combination equation by multiplying individual theme weight by its respective weight (Equation 2). The output map has weight values varying from 149 to 473 in the study area. These weight values classified into different intervals (GWPZ values) using standard deviation classification method in the ArcGIS environment as viz. 149 – 184.92, 184.92-232.84, 232.84-280.76, 280.76-328.68 and 328.68-473 to represent different groundwater potential zones. The GWPI is then classified into five categories as very poor, poor, moderate, good and very good potential zones respectively (Table 10, Figure.11). The results of study reveals that 8.643 km^2 (5.87 %) of area was classified to have very good groundwater potential and 37.916 km^2 (25.79%) of area was classified as good groundwater potential, with over 53.058 km^2 (36.09 %) being moderate and 40.685 km^2 (27.67 %) area is poor, 6.645 km^2 (4.52 %) of the area is of very poor groundwater potential are shown in Table 5

Table 10 Classification of groundwater potential zones (after integration of all thematic maps)

GWP Zone	Percentage of area	Area (sq.Km)
Very Good (328.687-473)	5.87	8.643
Good (280.76-328.687)	25.79	37.917
Moderate(232.84-280.76)	36.09	53.058
Poor (185.92-232.84)	27.67	40.685
Very poor (149- 185.92)	4.52	6.645

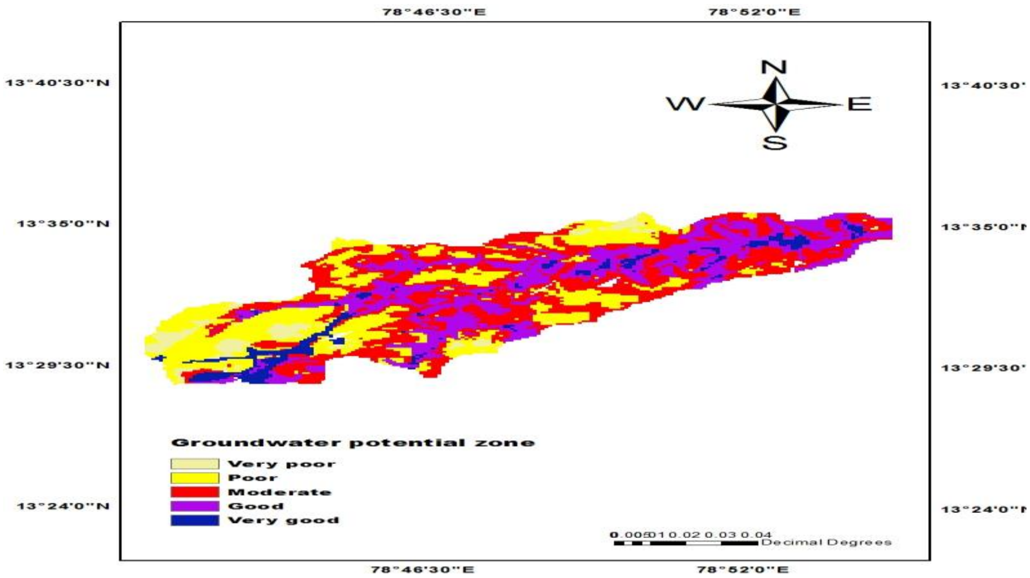

Figure 11 Groundwater potential zone map of the study area

4.3 Groundwater prospects map based on Method 2

The groundwater prospective maps are prepared by using two probabilistic methods viz., Frequency ratio method and weight of evidence method. The number of wells and number of pixels presented in individual features of thematic maps are shown in Table 11

1. Frequency ratio method

The calculation of FR for geomorphology factor is prescribed below is an example

Number of wells present in the valley fills = 1.04

Total number of wells in the study area = 13

Number of pixels in the valley fills in geomorphology map = 4281

Total number of pixels in the geomorphology factor = 160479

Percentage of wells for the vally fills in the geomorphology map = (1.04/13)*100= 8%

Percentage of area for the valley fills in the geomorphology map = 4281/160479 *100 = 2.66%

Therefore the Frequency ratio (FR) for valley fills in geomorphology map is 8/2.66 = 2.98

Similarly, FR for each feature of the thematic layers was calculated as shown in Table 13. The GWPI obtained from the FR values provided a basis for identifying groundwater prospect zones. Based on the GWPI values, a groundwater prospect map of the study area was generated by dividing the study area into five distinct zones: 'poor' ,'very poor', 'moderate' 'good' and 'very good' as shown in Fig. 12. Groundwater potential statistics of the study area as obtained from the FR model are presented in Table 13.

Table 11: Number of pixels and number of wells of the classes in the study area

Factor	Classifications of factor	No. of pixels	No. of wells
Geomorphology	Valley fills	2400	1
	Pediplane shallow (PPS)	8000	5
	Pediplane Inselberg (PPI)	8000	6
	Denudation hill	2400	1
	Residual hill	0	0
	Total	20800	13
Lineament Density (km/sq. Km)	0-2.401	11200	7
	2.401- 6.542	6400	4
	6.542 – 11.096	3200	2
	11.096-21.117	0	0
	Total	20800	13
Drainage Density (km/sq.km)	0-1.08	6400	4
	1.08-2.488	9600	6
	2.488-6.749	4800	3
	Total	20800	13
Slope(%)	0-1	3200	2
	1.1-3	0	0
	3.1-5	0	0
	5.1-15	0	0
	15.1-89.99	17600	11
	Total	20800	13
Soil	Red loamy soils	4800	3
	Red clayey soils	4800	3
	Cullivio alluvio clayey soils	1600	1
	Rocky lands	9600	6
	Total	20800	13
Rainfall (mm)	799.017-821.985	9600	6
	821.985 – 841.891	6400	4
	841.891 – 868.686	0	0
	868.686 – 896.631	4800	3
Land use/Land cover	Agricultural land	17600	11
	Water bodies	0	0
	Waste lands	0	0
	Forest evergreen	3200	2
	Forest deciduous	0	0
	Built-up land	0	0
			13

Table 12: Frequency ratio (FR) , weight of evidence (W+) and weight of evidence (WOE) probability for thematic maps

Factor	Classifications of factor	Area(%)	Well(%)	FR	W+	P
Geomorphology	Valley fills	2.68	8	2.98	1.059	0.000233
	Pediplane shallow (PPS)	22.50	42	1.86	0.534	0.000138
	Pediplane Inselberg (PPI)	39.59	42	1.06	0.154	0.0000945
	Denudation hill	8	34.56	0.233	-1.94	0.0000181
	Residual hill	0	0	0	0	0.00008101
Lineament Density (km/sq. Km)	0-2.401	59	54	0.915	-0.0941	0.00007229
	2.401- 6.542	24	31	1.29	0.249	0.000101
	6.542 – 11.096	15	15	1	0.014	0.0000806
	11.096-21.117	2	0	0	0.000	0.0000794

Drainage Density (km/sq.km)	0-1.08	41.611	30.769	0.739	-0.301	0.00005925
	1.08-2.488	44.024	46.135	1.048	0.0474	0.0000839
	2.488-6.749	14.362	23.076	1.606	0.4728	0.000128
Slope(%)	0-1	1.76	15.38	8.714	2.162	0.000690
	1.1-3	0	0	0	0	0
	3.1-5	0	0	0	0	0
	5.1-15	0	0	0	0	0
	15.1-89.99	98.39	84.615	0.861	-0.14	0.0000684
Soil	Red loamy soils	19.667	23.076	1.173	0.161	0.0000936
	Red clayey soils	38.46	23.076	0.6	-0.511	0.0000478
	Cullivio alluvio clayey soils	2.88	7.692	2.67	0.978	0.000212
	Rocky lands	38.988	46.153	1.18	0.169	0.0000944
Rainfall (mm)	799.017-821.985	46.934	46.153	0.98	-0.0171	0.0000784
	821.985 – 841.891	31.251	30.76	0.98	-0.0161	0.0000785
	841.891 – 868.686	10.642	0	0	0	0.0000798
	868.686 – 896.631	11.166	23.076	2.06	0.727	0.000165
Land use/Land cover	Agricultural land	54.98	84.615	1.539	0.430	0.000120
	Water bodies	1.414	0	0		0.0000782
	Waste lands	9.401	0	0		0.0000782
	Forest evergreen	27.726	0.15	0.541	-0.580	0.0000434
	Forest deciduous	4.937	0	0		0.0000782
	Built-up land	1.535	0	0		0.0000782

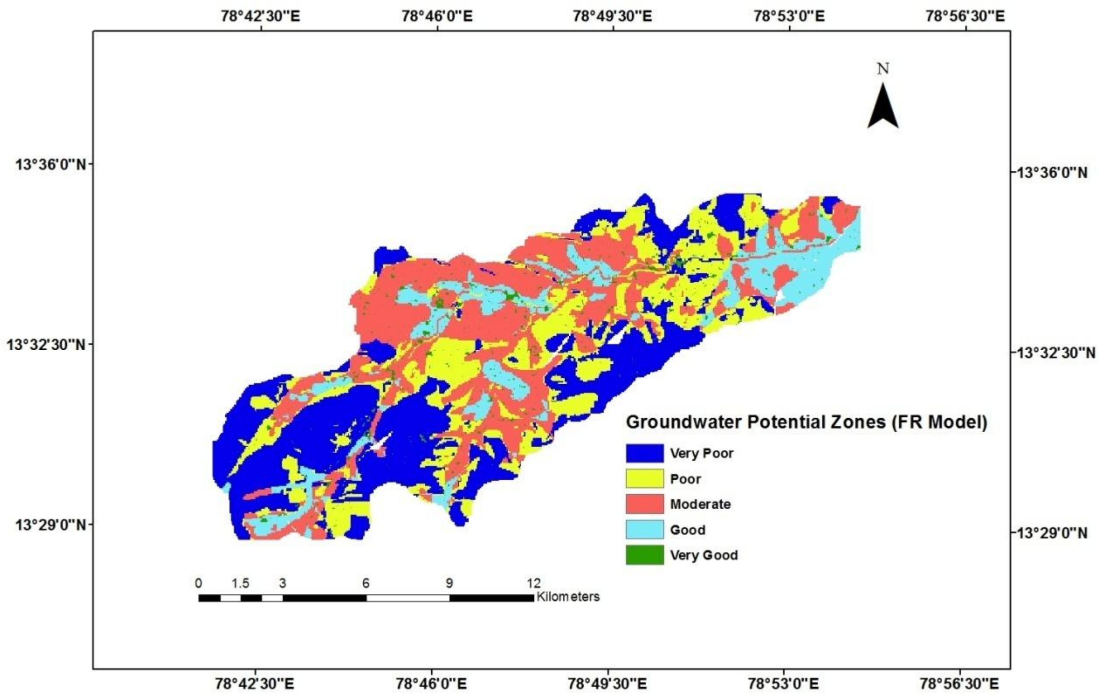

Figure 12: Groundwater Prospective Map of the Study Area using FR Model

Table 13 Classification of groundwater potential zones using Frequency ratio method

GWP Zone	Percentage of area	Area (sq.Km)
Very Good (12.181-19.482)	1..82	2.68
Good (8.433-12.181)	12.5	18.382
Moderate(7.14-8.433)	30.44	44.75
Poor (5.84-7.14)	23.4	34.41
Very poor (3.00-5.84)	31.72	46.61

2. Weight of evidence modeling:

The calculation of weight of evidence (WOE+) and weight of probability (P) for valley fills for the geomorphology factor is illustrated below

Number of wells present in the valley fills = 1.04

Total number of wells in the study area = 13

Number of pixels in the valley fills in geomorphology map = 4281

Total number of pixels in the geomorphology factor = 160479

$$W+ = \frac{\ln(1.04/13)}{(4281-1.04)+(160471-13)} = 1.051$$

Pp= 13 / 4281 = 0.00008101

P=exp(1.051 + ln(0.0000810)) = 0.000233645

Similarly, WOE Probability for each feature of the thematic layers was calculated as shown in Table 12. The GWPI obtained from the WOE Probability values provided a basis for identifying groundwater prospect zones. Based on the GWPI values, a groundwater prospect map of the study area was generated by dividing the study area into five distinct zones: 'poor' ,'very poor', 'moderate' 'good' and 'very good' as shown in Fig. 13. Groundwater potential statistics of the study area as obtained from the WOE model are presented in Table 14.

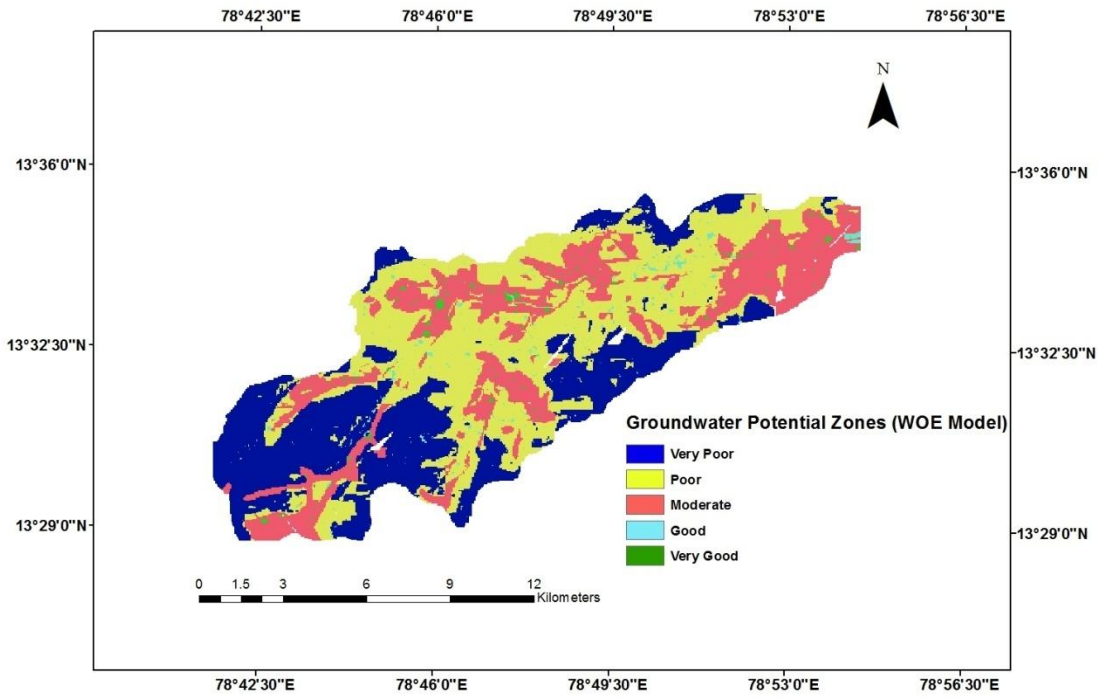

Figure 13:Groundwater Prospective Map of the Study Area using WOE Model

Table 14 Classification of groundwater potential zones using weight of evidence method

GWP Zone	Percentage of area	Area (sq.Km)
Very Good (0.00038-0.00051)	0.79	1.162
Good (0.00051-0.000625)	1.142	1.68
Moderate(0.000625-0.00089)	26.21	38.54
Poor (0.00089-0.00125)	39.809	58.52
Very poor (0.00124-0.00125)	31.931	46.94

4.3 Efficiency of multi criterion decision analysis and probabilistic modeling:

Delineated groundwater potential map was finally validated with the available well yield data from RGDWM atlas (2011) (Shekhar & Pandey 2014) was superimposed on the final output map of groundwater prospect zones. It was observed that the results obtained coincided very well with the well yield data from the RGDWM atlas (2011). It was found that very good to good and poor to very poor groundwater potential zones delineated in this study coincides with the high well yield zone (150-200 LPM) and low well yield (<50 LPM) , respectively. The quantitative validation, receiver operating characteristic (ROC) curve analysis was used by comparing the existing groundwater well locations in the validation data-sets with the GWPZ map obtained by AHP method and Probabilistic method. The ROC curve analysis is a standard method applied to assess the accuracy of a diagnostic test (Egan 1975). It plots the false positive rate on the X-axis and the true positive rate on the Y-axis. ROC predication curve represents the trade-off between the two rates shown in Figure 12. An area under the curve (AUC) values of the ROC curve for AHP method was 0.815, which corresponds to the prediction accuracy of 81.5% (Figure 12) which indicates good test. The ROC curve for Frequency ratio method 0.795 and Weight of evidence method 0.753. Hence, the map produced by AHP method exhibited good results in predicting the groundwater potential as compared to the probabilistic method (FR and WOE) in the upper pincha basin. The two methods shows the good accuracy of prediction but AHP shows the higher accuracy prediction as compared to probabilistic method. Among Probabilistic methods Frequency ratio method shows higher accuracy as compared to Weight of evidence method.

4.4 Spatial Prediction of Groundwater prospects:

A comparison of the areas under the Five identified zones ‘very good’, ‘good’, ‘moderate’ ‘poor’ and very poor as predicted by the three methods (AHP, FR and WOE) is illustrated in Figure. 14

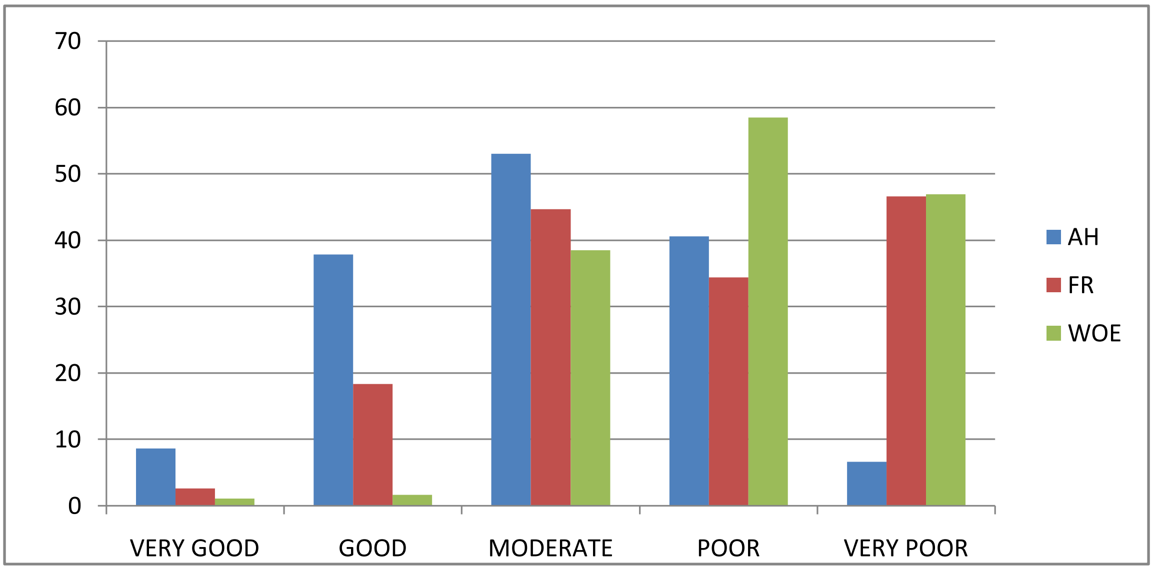

Figure 14 : Comparison of Groundwater Potential Zones using AHP method, FR Model and WOE Model

In AHP method, it shown that the groundwater potential increases from very good to moderate and it is decreasing from moderate to poor. But in the case of probabilistic method viz., Frequency ratio method the groundwater potential increases with very good to moderate potential and from moderate to very poor it is showing equal variation. In case of weight of evidence method the percentage of very good and good groundwater potential are very less as compared to AHP and FR. From moderate to very poor it is showing groundwater potential area for poor is more as compared to moderate and very poor. It is revealing that the spatial distribution zones of prediction of FR method matches the prediction of WOE method. The major portion of spatial prediction is found on northern part of the study area this is because of less number of observation wells. It should be noted that the presence and absence of wells provides basic criteria for FR , WOE method. But, AHP technique is dependent on hydrological and hydro geological factors.

Thus for finding the groundwater prospective zone by using the AHP method is greater than the probabilistic methods (WOE and FR). Among the probabilistic models the FR model is superior than the WOE method. Therefore AHP method is strongly recommended for better identification and delineation of groundwater prospective zone in the study area. The FR method can be used in the study area as alternative method. However considering more number of observation wells in the basin for probabilistic method. The practicability of this method is limited for data scare areas.

V CONCLUSIONS

In the present study the groundwater potential zones has been evaluated by using two methods. Seven thematic maps have been considered for the evaluation of groundwater prospect zones. In the first method includes integrated RS, GIS and AHP method, where as second method includes RS,GIS and Probabilistic modeling using FR and WOE models.
The groundwater prospective map obtained by AHP method is classified in to five categories. The results of the study reveals that 8.643 km^2 (5.87 %) of area was classified very good groundwater potential and 37.916 km^2 (25.79%) of area was classified as good groundwater potential, with over 53.058 km^2 (36.09 %) being moderate and 40.685 km^2 (27.67 %) area is poor, 6.645 km^2 (4.52 %) of the area is of very poor groundwater potential. In the second method Frequency ratio model shows that 2.68 km^2 (1.82 %) of area was classified very good groundwater potential and 18.382 km^2 (12.5 %) of area was classified as good groundwater potential, with over 44.75 km^2 (30.04 %) being moderate and 34.41 km^2 (23.4 %) area is poor, 46.61 km^2 (31.72 %) of the area is of very poor groundwater potential. Whereas weight of evidence model shows that 1.162 km^2 (0.790 %) of area was classified very good groundwater potential and 1.68 km^2 (1.14 %) of area was classified as good groundwater potential, with over 38.54 km^2 (26.217 %) being moderate and 58.52 km^2 (39.80 %) area is poor, 46.94 km^2 (31.93 %) of the area is of very poor groundwater potential.

Based on findings of these two methods, it is observed that the performance of AHP method is much superior than the probabilistic models (FR and WOE models) , the performance of FR model is somewhat similar to the AHP technique. Therefore, for more accurate results AHP technique is recommended for groundwater potential zone in a basin. If adequate data is available in a region for probabilistic modeling, the use of FR model is preferred when compare to WOE model. Estimation of groundwater prospective zone is very important for selection of suitable sites for well drilling as well as effective planning and development of groundwater resources.

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