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Delineation of Recharge Zones in Vamanapuram River Basin

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***Abstract*—The sustainable development and management of groundwater resource requires precise quantitative assessment based on scientific principle and modern techniques. In the present study, groundwater recharge zones are delineated using geographical information system (GIS) and multi-criteria decision making (MCDM) technique in Vamanapuram River Basin, Kerala. The weights of various themes and their features for identifying the groundwater recharge zones were assigned based on Saaty's Analytical Hierarchy Process (AHP). These thematic layers were then integrated in the GIS environment to delineate the groundwater recharge zones in the study area. Eleven year mean pre-monsoon and post-monsoon groundwater level maps for the study area were also prepared and these maps were used to validate the groundwater recharge zones. The suitable zone identified for groundwater recharge is at the downstream portion of the Vamanapuram river basin.**

Keywords*—Analytical Hierarchy Process (AHP); Geographical Information System (GIS); groundwater recharge

I. INTRODUCTION

Water is the vital natural resource essential for the survival of mankind. Rainfall is the main source of water which is unevenly distributed spatially and temporally. Thus availability of groundwater also varies spatially and temporally. The rapid growth rate of population, urbanization, industrialization and agricultural expansion leads to higher levels of water demand. As the water demand increases, issues on water availability and demand become critical. This makes the need of sustainable water management for water requirements in the present and future for various purposes.

Artificial recharge plays a pivotal role in the sustainable management of groundwater resources. Groundwater recharge through artificial recharging structures is one of the effective techniques for the management of groundwater resources [5].

In this study, the AHP (analytic hierarchy process) a multi criteria decision making (MCDM) technique was used for the identification of recharge zones in Vamanapuram river basin. Few studies have been started recently on the application of GIS merged with analytical hierarchical process (AHP) in demarcating groundwater recharge zones. The AHP technique analyzes the multiple datasets in a pair-wise comparison matrix, which is used to calculate the geometric mean and normalized weight of parameters [1]. However, Singh et al. have used five thematic maps for the assessment of groundwater recharge zones of Allahabad city. Suitable sites for artificial recharge can also be determined by AHP [2].

II. STUDY AREA

The Vamanapuram river basin with a catchment area of 687 sq. km. is located mainly in Thiruvananthapuram district and a small part falls in Kollam district of Kerala state. Vamanapuram river basin is bounded by latitudes of 8° 35' 24'' N and 8° 49' 13'' N and longitudes of 76°44' 24'' E and 77°12' 45'' E. The Vamanapuram river basin is bounded by Nedumangad Taluk of Thiruvananthapuram district in the South, Kottarakkara Taluk of Kollam district in the North, Tamil Nadu in the East and Arabian Sea in the West. The area forms part of the midland terrain of the state, characterized by lateritic uplands with undulating topography and intermittent valleys. The two tributaries of this river are the Upper Chittar & Manjaprayar streams.

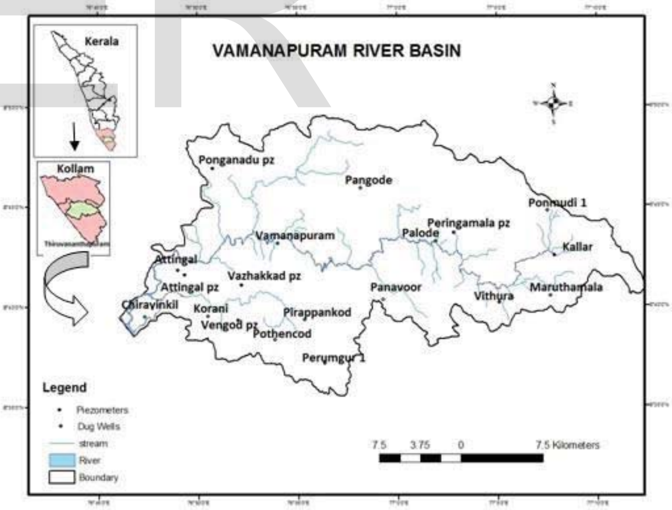

Fig. 1. Study area.

A. *Data Used*

The Groundwater monitoring wells (GWMWs) in the river basin (period 2003 to 2013) were collected from Central Ground Water Board (CGWB) Kerala Region, Thiruvananthapuram. The total number of GWMWs in the basin as on 31.3.2013 is 19. Out of these, 14 are dug wells tapping phreatic aquifers and 5 are borewells /tubewells tapping deeper aquifers of confined / semi-confined nature. The data of these GWMWs were used to understand the depth to water level scenario in the basin.

For the present study, the relevant maps were created using ArcGIS 9.3 software. The study area comprising Vamanapuram River Basin was delineated from Survey of India (SOI) Topographic maps of scale 1:50000, numbered 58 D/13, 58 D/14, 58 H/1, and 58 H/2. The drainage networks were digitized from SOI toposheets. The soil map and land use map were prepared by digitizing the map collected from Kerala State Land use Board (KSLUB). The Geology and Geomorphology map (year 2008) of the basin were collected from Kerala State Remote sensing and Environment Centre (KSREC), Trivandrum. The contour map at 10 m interval was prepared from the NASA Shuttle Radar Topography Mission (SRTM) data, which in turn was used to prepare the slope map.

III. METHODOLOGY

Identification of groundwater recharge zones in a basin is essential to suggest suitable recharge techniques for the augmentation of groundwater resources. The delineation of groundwater recharge zones in the basin has been carried by utilizing the application of Analytical Hierarchial Process (AHP) on geospatial analysis

A. Delineation of Groundwater Recharge Zones

In order to delineate artificial recharge zones in the study area, a multi-parametric dataset comprising seven thematic maps were used. The thematic layers, viz., geomorphology, geology, land use/land cover, drainage density, slope, soil and aquifer transmissivity, were considered for the delineation of artificial recharge zones.

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The geology and geomorphology map were collected from Kerala State Remote sensing and Environment Centre (KSREC), Trivandrum. The soil and land use map were prepared by digitizing the maps obtained from the Kerala State Land Use Board (KSLUB), Trivandrum.

To prepare the drainage density map of the study area, initially, the drainage network for the study area was digitized from the Survey of India toposheets at 1:50,000 scale. After preparing the drainage network map, the entire area was divided into sub watersheds. Further drainage map is overlaid on subwatershed map to find out the ratio called drainage density. The drainage density of the subwatershed is calculated as: DD = L/A where, DD = drainage density of subwatershed, L = Total length of drainage channel in the subwatershed (km), A = area of subwatershed (km^2).

In order to prepare the slope map, elevation contours (10 m interval) were generated from the SRTM data. Using surface analysis in the spatial analyst tool of ArcGIS software slope map was prepared. The aquifer transmissivity map of the area was prepared from the CGWB data by Inverse Distance Weighted Method using ArcGIS spatial analyst tool.

After preparing all the thematic layers, different features/ classes of the individual themes were identified, which were then assigned weights according to their relative importance in groundwater recharge in the study area following the Saaty's analytic hierarchy approach. To demarcate the recharge zones, all these thematic layers were integrated using ArcInfo software.

B. Deriving Weights Using AHP

In this study, the Analytic Hierarchy Approach developed by Saaty (1980) was used as a decision-aiding method to finalize the weights assigned to different themes and their features used in artificial recharge zoning. Table 1 shows Saaty's 1-9 scale of relative importance where a score of 1 represents equal importance between the two themes, and a score of 9 indicates the extreme importance of one theme compared to the other one.

TABLE I. SAATY'S 1-9 SCALE OF RELATIVE IMPORTANCE

Importance	Scale
Equal importance	1
Weak	2
Moderate importance	3
Moderate plus	4
Strong importance	5
Strong plus	6
Very strong importance	7
Very very strong	8
Extreme importance	9

The different class of thematic maps is assigned a weight age depending on its influence/ contribution on ground water recharge. Higher the weight, higher will be the effect of that particular class on the ground water recharge. The Saaty's AHP is basically a scoring method for the relevance of one parameter over the other. Thus a pair wise scaling of importance for a given end objective provides a matrix of important values which when solved using eigen- vector methods yields a solution of optimum weightages for the n parameters. The paired comparison matrix was prepared for each criterion using Saaty's nine-point scale.

After finalizing the suitable weights by considering their hydrogeologic importance in artificial groundwater recharge in the study area, the geometric mean of each row of the matrix was calculated. The normalized weight of each theme was obtained by dividing the individual geometric means with sum of the geometric means.

Further, the 'consistency ratio' of the assigned weights was calculated following the procedure suggested by Saaty (1980). A consistency ratio of 10% or less is considered acceptable. Saaty gave a measure of consistency, called Consistency Index

(CI) as deviation or degree of consistency using the following equation.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (1)$$

Where λ_{max} is the largest eigen value of the pairwise comparison matrix and n is the number of classes. Consistency ratio (CR) is a measure of consistency of pairwise comparison matrix and is given by

$$CR = \frac{CI}{RI} \qquad (2)$$

where RI is the ratio index. The value of RI for different n values is given in Table II.

TABLE II. SAATY'S RATIO INDEX FOR DIFFERENT VALUES OF N

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

If the value of CR is smaller or equal to 0.1, the inconsistency is acceptable. If CR is greater than 10%, we need to revise the subjective judgment.

To demarcate groundwater recharge zones, all seven thematic layers after assigning weights were integrated (overlaid) step by step using ArcInfo GIS software. The total normalized weights of pixels in the integrated layer were derived from the following equation using raster calculator in the spatial analyst tool of ArcGIS software. Thus the groundwater recharge index (GWRI) is calculated as below.

$$GWRI = (GM_w GM_{wi} + GG_w GG_{wi} + LULC_w LULC_{wi} + DD_w DD_{wi} + SL_w SL_{wi} + SO_w SO_{wi} + AT_w AT_{wi}) \qquad (3)$$

where, GWRI = groundwater recharge index, GM = geomorphology, GG = geology, LULC = land use/land cover, DD = drainage density, SL = slope, SO = soil, AT = aquifer transmissivity, 'w' = normalized weight of a theme, 'wi' = normalized weight of the individual features of a theme.

The total range of GWRI values was divided into four zones. Finally, a map showing different groundwater recharge zones in the study area was prepared using ArcInfo software.

IV. RESULTS AND DISCUSSION

The zones for groundwater recharge were delineated by analyzing the different themes such as geomorphology, geology, land use/land cover, drainage density, slope, soil and aquifer transmissivity and were integrated in ArcInfo Software after assigning weights using AHP method. The various thematic maps prepared are given below.

A. *Geomorphology*

Morphologically the study area is overlaid by various land forms such as coastal plain, denudational hills, denudational structural hills, weathered/buried pediplain, pediment zone, lateritic plateau, residual hill etc. The coastal plain is spread as a small area over the west part. The north eastern region of the study area is covered by dense vegetation with structural hills. Pediment zones are noticed with outcrops near to the structured hills. The midland terrain is covered by lateritic plateau. There are small pockets of weathered/buried pediplain in the midland region. The middle region of the study area is also comprised of residual hills at some parts and water bodies which is a mixture of pebbles and granules predominantly seen at the bottom of residual hills Among these landforms coastal plain and lateritic plateau have more potential for groundwater recharge, but structural hills, pediplain and pediment zones which is having steep slopes are not suitable for groundwater augmentation. Geomorphology map is shown in Fig.2.

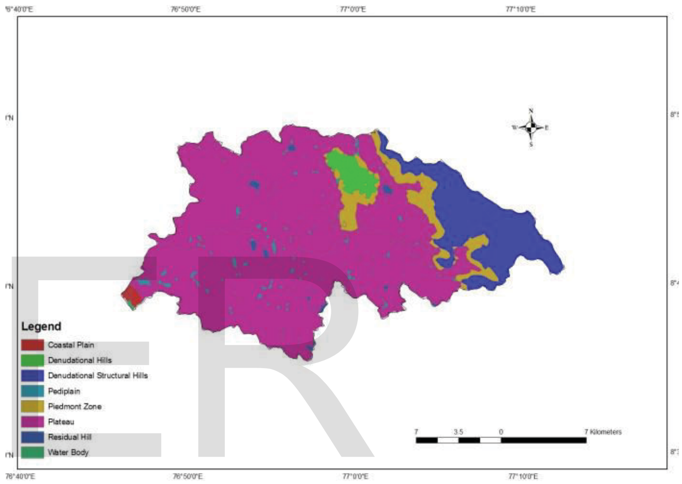

Fig. 2. Geomorphology map.

B. *Geology*

In the study area various types of rocks present are basic rocks, charnockite, khondalite, laterite, migmatite complex, sand and silt, sandstone and clay with lignite inters. Basically the study area is underlain by metamorphic rocks namely khondalite groups. Sand and silt is present near the coastal plain area and generally considered as good zone for groundwater recharge. There are few patches of laterite and sandstones in the western region and they are moderate zone for groundwater recharge. The midland region and eastern area is also comprised of migmatite complex and charnockite groups of rock in small percentage. Generally rock types charnockite, khondalite and migmatite complex are poor zone for groundwater recharge. Geology map is shown in Fig. 3.

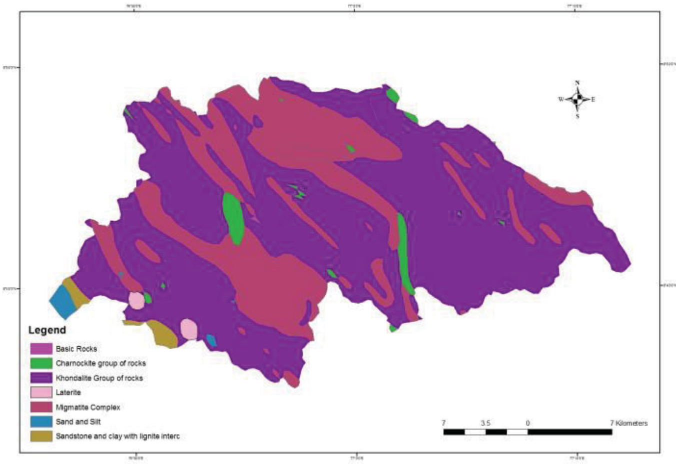

Fig. 3. Geology map.

C. *Land use/Land cover*

Various types of landuse pattern identified in the study area, which include built-up, agricultural, forest evergreen, forest plantations, grass land, waste land and water bodies. Agricultural lands and water bodies are good zones for groundwater recharge. Forest plantations and grass lands are moderate steep zones and are moderately good for groundwater recharge. Forest evergreen dense and open are steep slopes and less suitable zone for groundwater recharge. Built-up areas are thickly populated and more surface runoff from these areas, therefore moderately suitable zone for groundwater recharge. Land use land cover map is shown in Fig. 4.

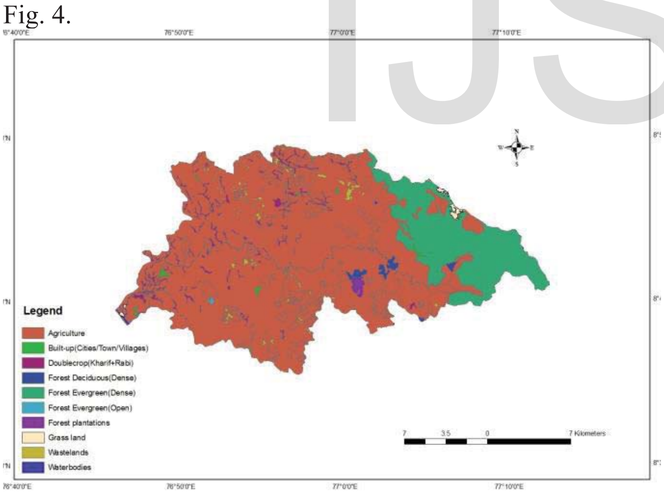

Fig. 4. Land use/land cover map.

D. *Drainage Density*

Drainage map is overlaid on subwatershed map to find out the ratio of total length of drainage network to the total area of subwatershed. The value ranges from 0.65 km^{-1} to 4.36 km^{-1} and it is categorized into 5 classes. Drainage density is an inverse function of infiltration. The less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. High drainage density values are favourable for runoff, and hence indicate poor zone for groundwater recharge. Areas of less drainage density values are good potential zone for groundwater recharge. The North West and South West region of the study area has less drainage density values and are suitable for groundwater recharge. The central portion has medium values and is classified as moderate zone. The eastern region has high drainage density values and is not suitable for groundwater recharge. Drainage density map is shown in Fig.5.

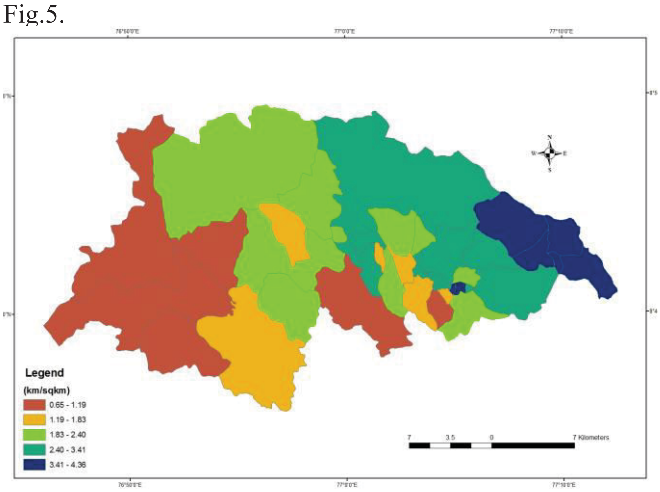

Fig. 5. Drainage density map.

E. *Slope*

The slope influences the direction and amount of surface runoff or subsurface drainage. A smooth/flat surface allows water to flow slowly and therefore infiltration will be high which also depends upon the soil type. Steeper slopes are more susceptible to surface runoff than recharge. The slope in the area varies from 0 to 82 degrees. On the basis of the slope, the study area can be divided into 5 classes. Along the eastern region the landform is found to be steep and not suitable for groundwater recharge. The slope in the western and central region is slightly gentle and these landforms are considered suitable for groundwater recharge. Slope map of the basin is shown in Fig. 6.

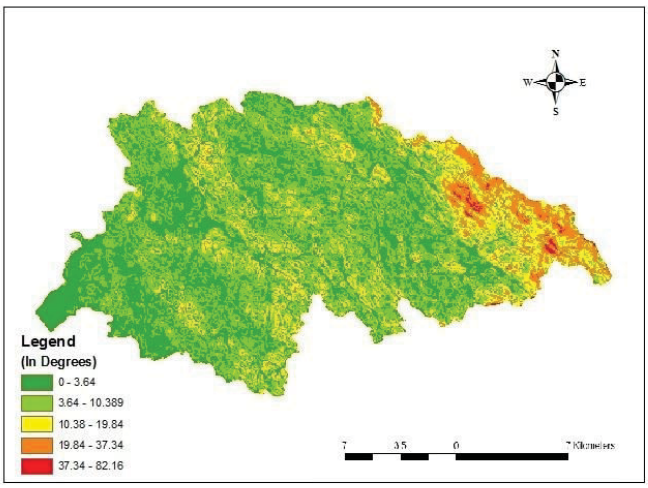

Fig. 6. Slope map.

F. Soil

Soil is one of the significant control factors to determine the infiltration rate of an area. The major soil types of the study area are clay, gravelly clay, loam and gravelly loam. The majority of the study area is covered by gravelly clay which is spread over the western, northern, southern and central part of the study area. This area is moderately suitable for groundwater recharge. A small portion in the central region and north eastern part is basically loam and are generally high potential of groundwater infiltration. Eastern part of the study area is found clay which is not suitable zone for groundwater recharge. Soil map of the basin is shown in Fig. 7.

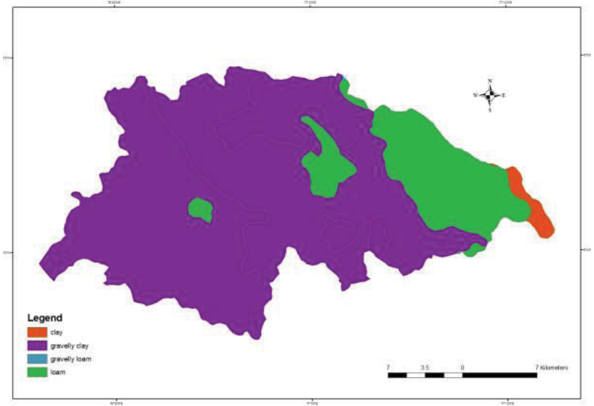

Fig. 7. Soil map.

G. Aquifer Transmissivity

Aquifers are water-bearing unconsolidated layer of geological structure of an area. The aquifer transmissivity is the groundwater discharge through an aquifer section of unit width under a unit hydraulic gradient. The transmissivity of this area is found between 0.90 and 17.57 m^2/day. The area in the western region and a small percentage in the central region have high transmissivity and are considered as high potential zones for recharge. The North West part of the study area has moderate values of transmissivity and is considered as moderately suitable zone. The North east and south east part has less transmissivity values and are considered less suitable zone. Aquifer transmissivity map is shown in Fig. 8.

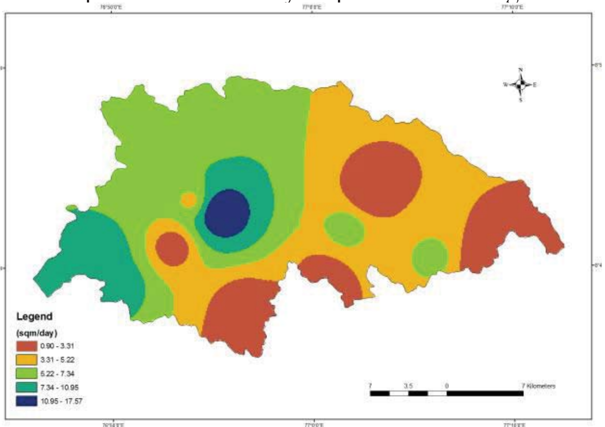

Fig. 8. Aquifer transmissivity map.

H. Groundwater Recharge Zone

The systematic analysis of AHP technique on weighted parameters has produced groundwater recharge zone map in raster format using raster calculator in ArcGIS environment. The normalized weight of individual parameters and different feature classes of the parameters were derived from assigned weight and geometric mean. The normalized weight of themes and individual features are shown in Table III.

TABLE III. WEIGHTS ASSIGNED FOR THEMES

Themes	Assigned weight	Normalized weight
Geomorphology	7	0.19
Geology	6	0.17
LULC	6	0.17
Drainage density	5	0.14
Slope	5	0.14
Soil	4	0.11
Aquifer Transmissivity	3	0.08

A pair wise comparison matrix is derived using Saaty's nine-point importance scale based on thematic maps used for the delineation of groundwater recharge zone. The pair wise comparison matrix for the seven themes is given below. The Consistency ratio was computed and it was found to be 0%, which is less than the recommended value, 10%.

TABLE IV. PAIRWISE COMPARISON MATRIX FOR THE SEVEN THEMES

Themes	Themes							Geometric mean	Normalized weight
	GM	GG	LULC	DD	Slope	Soil	AT		
GM	7/7	7/6	7/6	7/5	7/5	7/4	7/3	10.22	0.19
GG	6/7	6/6	6/6	6/5	6/5	6/4	6/3	8.76	0.17
LULC	6/7	6/6	6/6	6/5	6/5	6/4	6/3	8.76	0.17
DD	5/7	5/6	5/6	5/5	5/5	5/4	5/3	7.30	0.14
Slope	5/7	5/6	5/6	5/5	5/5	5/4	5/3	7.30	0.14
Soil	4/7	4/6	4/6	4/5	4/5	4/4	4/3	5.84	0.11
AT	3/7	3/6	3/6	3/5	3/5	3/4	3/3	4.38	0.08
							Total	52.54	1.00

Assigned weight and normalized weight calculated from the derived pairwise comparison matrix of the individual features of each theme are given in Table V to XI.

TABLE V. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-GEOMORPHOLOGY

Features	Assigned weight	Normalized weight
Coastal plain	7	0.23
Denudational hills	2	0.07
Denudational Structural hills	2	0.07
Pediplain	3	0.10
Piedmont zone	2	0.07
Plateau (Lateritic)	5	0.17
Residual hill	4	0.13
Water body	5	0.17

TABLE VI. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-GEOLOGY

Features	Assigned Weight	Normalized weight
Basic rocks	2.5	0.10
Charnockite	2.5	0.10
Khondalite	2.5	0.10
Laterite	5	0.20
Migmatite complex	2	0.08
Sand and silt	6	0.24
Sandstone & clay	4	0.16

TABLE VII. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-LAND USE/LAND COVER

Features	Assigned weight	Normalized Weight
Agriculture	6	0.14
Built-up	3	0.07
Double crop	6	0.14
Forest deciduous (dense)	4	0.09
Forest evergreen (dense)	3	0.07
Forest evergreen (open)	5	0.12
Forest plantations	4	0.09
Grass land	4.5	0.11
Waste land	2	0.05
Water bodies	5	0.12

TABLE VIII. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-DRAINAGE DENSITY

Range	Assigned weight	Normalized weight
0.65-1.19	5	0.30
1.19-1.83	4	0.24
1.83-2.40	3	0.18
2.40-3.41	2.5	0.15
3.41-4.36	2	0.12

TABLE IX. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-

SLOPE Range	Assigned weight	Normalized weight
0-3.64	5	0.27
3.64-10.38	4.5	0.24
10.38-19.84	4	0.22
19.84-37.34	3	0.16
37.34-82.16	2	0.11

TABLE X. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-SOIL

Soil Type	Assigned weight	Normalized weight
Clay	2	0.16
Gravelly clay	3	0.24
Gravelly loam	3.5	0.28
loam	4	0.32

TABLE XI. NORMALIZED WEIGHT FOR INDIVIDUAL FEATURE-AQUIFER TRANSMISSIVITY

Range	Assigned weight	Normalized weight
0.90-3.31	3	0.14
3.31-5.22	4	0.19
5.22-7.34	4.5	0.21
7.34-10.95	4.5	0.21
10.95-17.57	5	0.24

After obtaining the normalized weights of all the seven thematic layers and its features, all the thematic layers were integrated with one another using ArcInfo GIS software in order to demarcate groundwater recharge zones in the study area. As a first step, normalized weights are assigned to the individual features of the themes and converted each theme into raster format. Finally all the seven themes were integrated