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IDENTIFICATION AND DEMARCATION OF GROUNDWATER POTENTIAL AND RECHARGE ZONES IN ARKAVATHY RIVER BASIN USING RS AND GIS TECHNIQUES

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ABSTRACT

Investigation of the groundwater potential and recharge zones is of prime importance to find appropriate management solutions in a river basin facing water scarcity and drought. Methods such as test drilling and stratigraphy analysis, though reliable, are costly, time-consuming and require skilled man-power for understanding these factors and to identify groundwater recharge zones. Hence, Remote Sensing (RS) and Geographical Information System (GIS) that possess advantages in spatial, spectral and temporal resolution enable understanding the factors such as lithology or lineament or geomorphology that influence groundwater recharge which otherwise would be time consuming in covering large and inaccessible areas of a river basin. Therefore, RS and GIS have been adopted in the present study for identification of groundwater potential and recharge zones in Arkavathy river basin, the result of which, gives a crucial lead in the integrated study of this basin. Further, Analytical Hierarchical Process (AHP), developed by Saaty (1980), has been adopted to eliminate bias in assigning weights to various thematic layers.

Keywords: *Groundwater, Recharge Zones, Weighted Overlay, Analytical Hierarchy Process, Aquifer*

INTRODUCTION

Investigation of the groundwater potential and recharge zones is of prime importance for understanding the water scarcity of a river basin. As surface and groundwater is one resource, the groundwater investigation in a river basin is a very important component of integrated study of water management that helps in finding solutions to the problem of water scarcity and drought in a river basin. One solution to mitigate water scarcity and drought in a river basin is to recharge the aquifers so that the water is conserved. For a chronic water scarce basin like Arkavathy river basin considered for the present study, identification of ground water potential and recharge zones helps in overcoming the water stress. But, the study of lithology, lineament density, stream pattern, slope, geomorphology, soil and land use/land cover is vital to identify the right locations of groundwater potential and recharge zones in the basin.

Most of the time, lack of knowledge of these factors that influence groundwater recharge zones result in failure to locate potential recharge zones and therefore cause loss of investment on recharge-pits, boreholes, wells etc., Existing methods such as test drilling and stratigraphy analysis are reliable for identification of groundwater recharge zones, but these methods are costly, time-consuming and require skilled man-power (Palaka and Sankar, 2015). Therefore, Remote Sensing and Geographical Information System (RS and GIS) play very important role in identification of groundwater potential and recharge zones. They offer advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time (Palaka and Sankar, 2015). One of the advantages of RS and GIS in groundwater investigations is that it has the ability to generate information in spatial and temporal format that helps in identification, analysis and validation of the results (Valliammal et al., 2013).

The details of literature review and scholarly studies conducted for the present study is shown in Table 1 along with the details of thematic layers considered and their weightages. Except Palaka and Sankar (2015) rest of the scholars have adopted weightages according to their subjective interpretation with no consistency checks.

Almost all the scholars have identified ground water potential and recharge zones in output layer as very good, good, moderate, poor and very poor. But, very few scholars have conducted the consistency checks for the weightages assigned to thematic layers in order to eliminate bias in assigning weightages. Only Palaka and Sankar (2014) have adopted Analytical Hierarchical Process (AHP) in accordance with Saaty (1980) to assign weightages and eliminate bias in decision making. A list of various thematic layers considered by scholars and the weights assigned to them in percentage has been compiled and the same is shown in Table 1.

The objective of the study is to identify and demarcate the ground water potential and recharge zones in Arkavathy river basin using RS and GIS techniques.

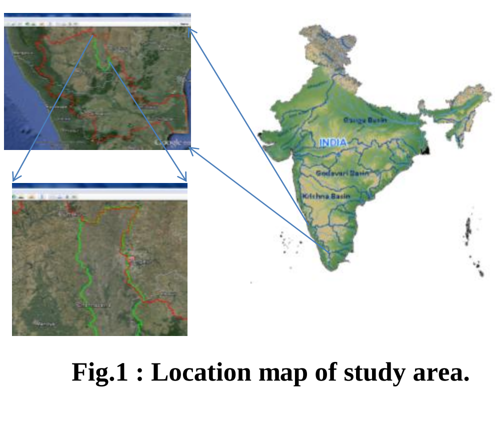

Fig.1 : Location map of study area.

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Table 1: Thematic layers and weightages (%) adopted by different scholars for identification of groundwater recharge zones

	Thematic Layers	Basavaraj et al (2016)	Aneesh and Deka (2015)	Patil and Mohite (2014)	Babu and Sashikumar (2010)	Kesavanan et al (2017)	Nagarajan and Singh (2009)	Nandi et al (2015)	Palaka and Sankar (2015)**	Valiam mal et al (2013)	Waikar and Nilawar (2014)
1	Land use/Land cover	20	4	25	15	25	25	15	12	10	15
2	Slope	15	6	20	NA	25	15	20	NA	15	20
3	Lithology	10	35	NA	25	25	NA	NA	NA	5	5
4	Lineament Density	NA	12	5	18	NA	5	15	19	15	15
5	Stream Density	10	9	5	NA	NA	5	15	27	15	15
6	Geomorphology	25	18	25	22	NA	25	30	42	25	30
7	Soil Group	20	7	20	20	25	25	5	NA	15	NA

**The weightages adopted for thematic layers have been checked for consistency as specified by Saaty, 1980.

STUDY AREA

Arkavathy river sub-basin is located within Cauvery river basin, southern India and constitutes 5% of the area of Cauvery river basin (Fig.1). Arkavathy river is a tributary to river Cauvery. The total area of Cauvery river basin is 81,155 km^2 (India-WRIS, 2012), whereas the area of Arkavathy river sub-basin is 4146 km^2. Arkavathy river sub-basin is geographically located between co-ordinates 12^{o}15’00” N and 13^{o}25’00” N latitude and 77^{o}10’00” E and 77^{o}45’00” E longitude. About 97% of the area is located in the Karnataka whereas only 3% is located in Tamil Nadu. It spans across 3 districts of Karnataka namely Ramanagara, Bangalore Rural and Bangalore Urban besides Krishnagiri district of Tamil Nadu. River Arkavathy originates at Nandi Hills located partly in Bangalore Rural district and partly in Chikkaballapur district in the north-eastern corner of the sub-basin and joins river Cauvery at Mekedatu, Kanakapura taluk, Ramanagar District.

DATA PRODUCTS

Table 2 : Data Products and their sources

Sl No	Data Products	Source of Data
i	Survey of India Toposheets (1: 50000)	Survey of India (SoI), Govt. of India
ii	Landsat-8 satellite image	USGS earth explorer website
iii	SRTM, Digital Elevation Model	CGIAR-CSI website
iv	Lineament and Lithology data	CGWB (2012)
v	Soil data	National Bureau of Soil Survey & Land Use Planning, Govt. of India
vi	Geomorphology data	WMS Server, Bhuwan Portal, NRSC, Govt of India

METHODOLOGY

The methodology adopted in the present study includes derivation of thematic layers that is crucial in identification and demarcating the potential ground water zones using RS & GIS techniques and then assigning weightages in accordance with the decision making tool called Analytical Heirarchical Process (AHP). Subsequently, the potential ground water recharge zones in Arkavathy basin are determined using weighted overlay analysis in GIS.

DERIVATION OF THEMATIC LAYERS

Geomorphology layer for Arkavathy river basin is derived in ArcGIS. Six different geomorphic units are identified in the Arkavathy river basin. The geomorphic units are pediment-pediplain complex, denudational – moderate and lowly dissected hills, structural – moderate and low dissected hills and anthropogenic origin units. The six geomorphic units are digitized in ArcGIS, converted into shape file or vector, merged them using “Union” tool. The same layer is converted to raster using “Polygon to Raster” tool and reclassified into various geomorphic units using “Reclassify” tool.

The lineament and lithology data has been georeferenced in ArcGIS 10.2 with the help of SoI toposheets, and then converted to shape file. The lineament units are then merged with the Arkavathy polyline boundary shape file using “Union” tool in ArcGIS 10.2 to derive vector layer of lineament unit. The lineament density has been calculated using “Line density” tool. Lineament density layer is then converted to raster layer using “Polygon to Raster” tool.

The slope and stream density in Arkavathy river basin has been derived by the primary data of the SRTM DEM (Digital Elevation Model) by watershed delineation using ArcHydro tools in Arc GIS 10.2. The stream density map is derived using “Line density” tool (Magesh et al., 2012). The resulting raster layers are then reclassified using “Reclassify” tool of ArcGIS 10.2 to derive requisite classes

Land use/land cover is derived using digital image processing of Landsat-8 satellite image for year 2014 in ERDAS-Imagine software. The output layer after supervised classification is imported to ArcGIS where the layer has been reclassified into 8 classes of land use/land cover namely water body, agriculture-crop land, agriculture-fallow, built-up-urban, built-up-mining, scrub-land, barren-uncultivable and forests. The classes are level1/level 2 classification system in accordance with NRSC (2006).

The methodology used for the present study is shown in fig.2.

The thematic layers and their classes are shown in Fig. 3 and Fig. 4.

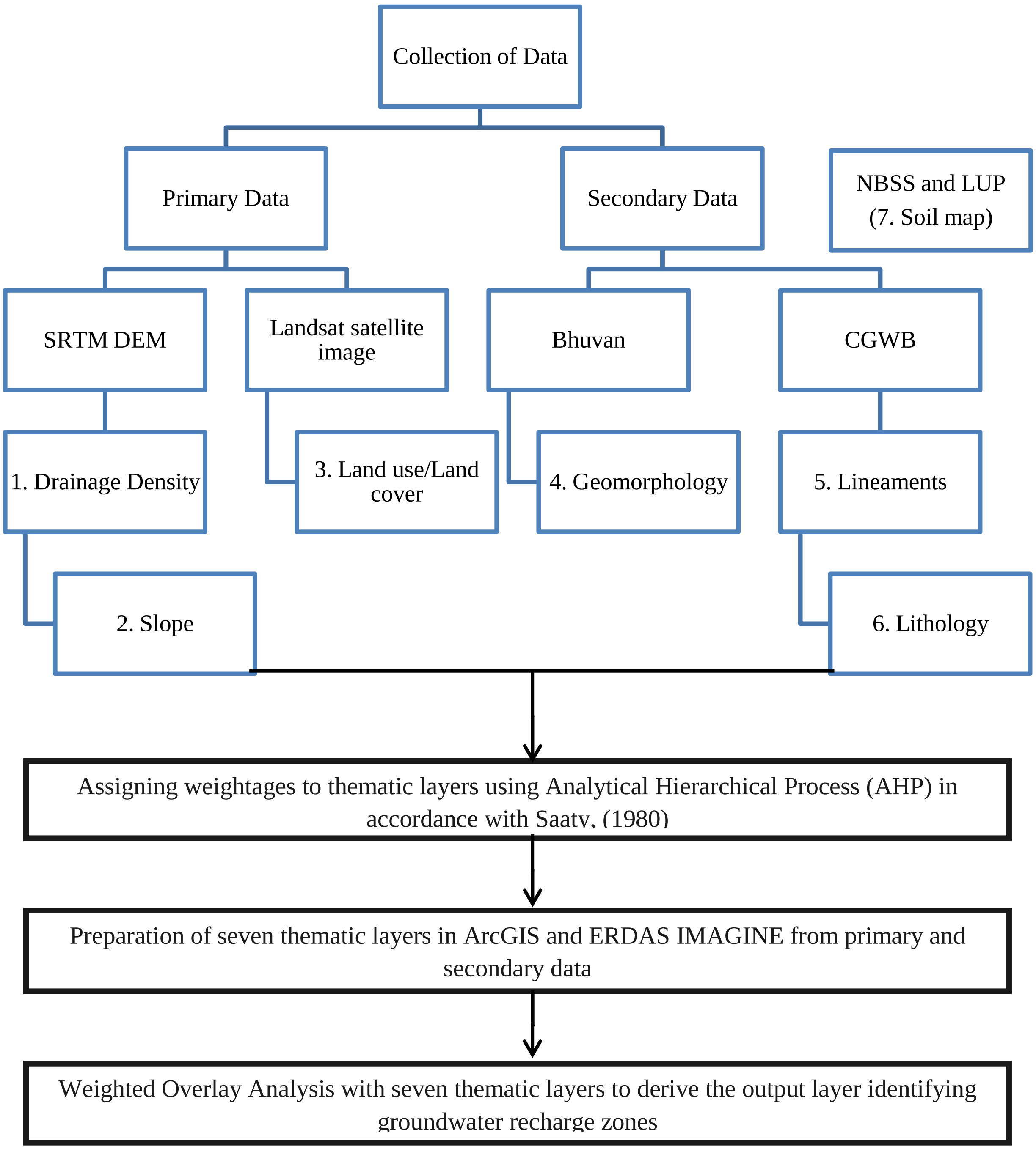

Fig.2 Flow Chart shows the methodology

Table 3: Weights and Scale Values/Ranks for thematic layers and their classes.

Sl No	Thematic layer	Classes	Scale Value	% Weightage
1	**Land use/Land cover**	Water Body	9	12
		Forest	7	
		Agriculture, Crop Land	7	
		Scrub Land	5	
		Agriculture, Fallow	3	
		Built up, Mining	1	
		Barren, Uncultivable	3	
		Built up, Urban	1	
2	**Slope**	$0\text{-}1^o$	9	8
		$1^o\text{-}3^o$	7	
		$3^o\text{-}5^o$	5	
		$5^o\text{-}10^o$	3	
		$10^o\text{-}56^o$	1	
3	**Lithology**	Banded Gneissic Complex	5	6
		Intrusive Acidic Rock	3	
4	**Lineament Density**			23
	(km/km^2)	1.44-1.62	9	
		1.26-1.44	9	
		1.08-1.26	7	
		0.90-1.08	7	
		0.72-0.90	5	
		0.54-0.72	5	
		0.36-0.54	3	
		0.18-0.36	1	
		0-0.18	1	
5	**Stream Density**	0-0.25	9	4
	(km/km^2)	0.25-0.50	7	
		0.50-0.75	5	
		0.75-1.00	3	
		1.00-1.25	3	
		1.25-1.50	1	
		1.50-1.75	1	
		1.75-2.00	1	
		2.00-2.26	1	
6	**Geomorphology**	Pediment - Pediplain	9	32
		Denudational-Low	5	
		Denudational-Moderate	3	
		Structural - Low	3	
		Structural -Moderate	1	
		Anthropogenic Origin	7	
7	**HSG**	A	9	15
		B	5	
		C	3	
		D	1	

Total weightage = 100%

Analytical Hierarchical Process (AHP) to assign weights to thematic layers

Analytical Hierarchical Process (AHP) tool has been adopted in the present study to arrive at unbiased decision in assigning weights to different thematic layers so as to evaluate their relative importance. AHP is a structured tool for analysing and organizing complex management decisions based on mathematics and psychology (Palaka and Sankar, 2015). As each thematic layer namely geomorphology, lithology, land use/land cover, slope, lineament and drainage influence the groundwater infiltration, movement and storage, the output layer depends on the relative importance assigned to each thematic layer.

For the current study, a 7 X 7 comparison matrix has been formed, the factors of relative importance between thematic layers in the pair-wise comparison matrix are chosen from the rating scale shown in Table 4. The lower triangular matrix is filled by taking the reciprocal of the corresponding importance factors of the upper triangular matrix. Example: If a_{jk} is one of the entries in upper triangular matrix, then the corresponding factor in the lower triangular matrix will be $\frac{1}{a_{jk}}$. i.e. $\mathbf{a_{kj}}=\frac{1}{a_{jk}}$ (Saaty,1987).

The pair-wise comparison matrix ***F (n)*** for the present study is shown in Table 5.

Table 4: Rating Scale of Saaty's Analytical Hierarchical process (Aneesh and Deka, 2015)

9	**7**	**5**	**3**	**1**	**1/3**	**1/5**	**1/7**	**1/9**
Extreme	Very Strong	Strong	Moderate	Equal	Moderate	Strong	Very Strong	Extreme
More Important				Equal	Less Important			

Note: 2,4,6,8 can also be used if more classes exist.

Table 5: Pair-wise Comparison Matrix of thematic layers

No	Thematic Layers	Land use/Land cover	Slope	Lithology	Lineament Density	Stream Density	Geomorphology	HSG
1	Land use/Land cover	1	3.00	3.00	0.33	5	0.33	0.33
2	Slope	0.33	1	3.00	0.33	3	0.20	0.33
3	Lithology	0.33	0.33	1	0.20	3	0.33	0.33
4	Lineament Density	3.00	3.00	5.00	1	5	0.33	3.00
5	Stream Density	0.20	0.33	0.33	0.20	1	0.20	0.33
6	Geomorphology	3	5	3.00	3	5	1	3
7	HSG	3.00	3.00	3.00	0.33	3.00	0.33	1
	Column total =	10.87	15.67	18.33	5.40	25.00	2.73	8.33

The pair-wise comparison matrix ***F (n)*** of above table is,

$$F\ (n) = \begin{vmatrix} 1 & 3 & 3 & 1/3 & 5 & 1/3 & 1/3 \\ 1/3 & 1 & 3 & 1/3 & 3 & 1/5 & 1/3 \\ 1/3 & 1/3 & 1 & 1/5 & 3 & 1/3 & 1/3 \\ 3 & 3 & 5 & 1 & 5 & 1/3 & 3 \\ 1/5 & 1/3 & 1/3 & 1/5 & 1 & 1/5 & 1/3 \\ 3 & 5 & 3 & 3 & 5 & 1 & 3 \\ 3 & 3 & 3 & 1/3 & 3 & 1/3 & 1 \end{vmatrix}$$

The normalized matrix is derived from pair-wise comparison matrix by adding the entries in each column of comparison matrix and then dividing each entry a_{jk} with the sum of the entries of the corresponding column Σa_{jk} of the comparison matrix. The sum of normalized entries in each column will be equal to 1 (Trick, 1996). The normalized matrix derived is shown in Table 6.

Table 6: Normalized Matrix

LULC	Slope	Lithology	Lineament Density	Stream Density	Geomorphology	HSG	Total	Eigen Vector (Average)	Consistency Measure
0.09	0.19	0.16	0.06	0.20	0.12	0.04	0.87	0.12	7.67
0.03	0.06	0.16	0.06	0.12	0.07	0.04	0.55	0.08	7.59
0.03	0.02	0.05	0.04	0.12	0.12	0.04	0.43	0.06	7.20
0.28	0.19	0.27	0.19	0.20	0.12	0.36	1.61	0.23	8.19
0.02	0.02	0.02	0.04	0.04	0.07	0.04	0.25	0.04	7.54
0.28	0.32	0.16	0.56	0.20	0.37	0.36	2.24	0.32	8.09
0.28	0.19	0.16	0.06	0.12	0.12	0.12	1.05	0.15	8.18
1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00		

Table 7: Values of Random Index (RI) for number of thematic layers (n)

n	1	2	3	4	5	**6**	7	8	9	10
RI	0	0	0.58	0.9	1.12	**1.24**	1.32	1.41	1.45	1.51

The Principal Eigen Value, Consistency Measure and Consistency Ratio are calculated and shown in Table 8. In accordance with BUNRUAMKAEW (2012), the consistency ratio for the present study is 0.0985 which is below 10%. Hence the weightages assigned to thematic layers are consistent.

Weighted overlay analysis for seven thematic layers in ArcGIS:

Weighed overlay analysis, a GIS technique wherein different thematic layers with diverse features are input to derive unique convergent output, has been adopted in the present study. Weighted overlay analysis for the seven

Table 8: Parameters of AHP to check consistency of the weightages assigned to thematic layers

AHP parameters	Formula	Values	Remarks
Consistency Measure	$\frac{[[\text{Row of Comparison Matrix}]\text{X}\,[\text{Eigen Vector}]]}{\text{Corresponding Eigen Vector of the row}}$	Table 4	Last column of the Normalized Matrix
Principal Eigen Value	$\lambda_{\max}$	7.78	Average of the column of Consistency Measure
Consistency Index (CI)	$\frac{\lambda_{\max} - n}{n - 1}$	0.1299	n is number of thematic layers equal to 7
Consistency Ratio (CR)	$\frac{\text{CI}}{\text{RI}}$	0.0985	RI is Random Index equal to 1.32 from Table 7.

thematic layers of the current study are conducted in ArcGIS 10.2. The weights and scale values or ranks are assigned to each class within each thematic layer as per Table 3. The class within each thematic layer that has highest groundwater potential has been assigned a scale value of 9 and the class with least groundwater potential the scale value assigned is 1. The output layer of weighted overlay analysis that demarcate ground water potential and recharge zones are reclassified into 5 classes, in accordance with the capability of groundwater potential and recharge, with scale value 5 considered as very good, 4 as good, 3 as moderate, 2 as poor and 1 as very poor.

RESULTS AND DISCUSSION

The seven thematic layers of lithology, lineament, stream density, geomorphology, land use/land cover, HSG and slope have given vital inputs of groundwater potential and recharge zones.

The geomorphology of Arkavathy river basin in Fig. 3 show presence of large area of pediment-pediplain area in the northern and central region, structural hills in the southern part and denudational hills in south and south-western part of the basin. According to (Patil and Mohite, 2014) presence of pediment-pediplain is conducive for groundwater recharge. The lineament density reveals the groundwater potential across its higher density that indicates higher level of permeability of groundwater (Aneesh and Deka, 2015). The higher lineament density in Arkavathy river basin is found to be located North and North-West region of the basin. Investigation of lithology reveals that Arkavathy river basin is underlain by Banded Gneissic Complex to the extent of 64% and the rest of 36% area is underlain by Intrusive Acidic Rock. It is noticed that no part of the Arkavathy river basin is deposited with alluvium or limestone or dolomite or basalt or sandstone. During weighted overlay analysis in ArcGIS, higher rank or scale value is attached to Banded Gneissic Rock ahead of Intrusive Acidic Rock. Higher drainage density is observed in south Arkavathy river basin where mountainous relief is large compared to the north region of the basin close to Doddaballapura and Nelamangala. Large part of the basin, excluding the North-Eastern tip of the basin comprising Nandi Hills and structural/denudation hills in the South and South-West portion of the basin, are flat. Therefore, these regions of the basin are conducive for infiltration of rainfall and hence groundwater recharge. As on 2014, Arkavathy river basin in the north is pre-dominantly agriculture with both crop land and fallow land interspersed. But the notable feature is the growing signature of built-up areas in the basin that will cause reduced infiltration and groundwater recharge potential in the future. A large part of the basin is underlain by HSG B type of soil which possesses moderate infiltration and runoff capacity. HSG A possessing higher infiltration and low runoff potential is confined to stream network.

The output thematic layer of Arkavathy river basin, derived using weighted overlay analysis is shown in Fig. 4. The area of the ground water potential and recharge zones derived from weighted overlay analysis are shown in Table 9.

Table 9 Area of the ground water potential and recharge zones

Scale Value	Criteria	Area of Groundwater Recharge Zones (km^2)
5	Very Good	214.03
4	Good	1693.20
3	Moderate	1552.11
2	Poor	229.65
1	Very Poor	440.34

From the output layer (Fig. 4), it can be seen that very good groundwater potential and recharge zones are located across the lineaments and adjoining regions in the northern part of Arkavathy river basin and regions where Hydrological Soil Group A is dominant. The regions with lithology consisting of banded gneissic complex, flatter slope, agriculture land, HSG-A and dominated by pediment-pediplain complex offers scope for recharge of groundwater in the Arkavathy river basin. The built-up areas across Bengaluru metropolitan area possess moderate ground water potential.

The best groundwater potential and recharge zones are located north of the Arkavathy river basin around the region of Doddaballapur and Nelamangala, particularly regions with lineaments and soil group A. These areas are largely pediplain, dominated by agriculture crops, lineaments, soil group A and flat terrain. This is very conducive for infiltration particularly across the lineaments. The poor zones are confined to southern part of Arkavathy river basin where structural and denudation hills are dominated i.e. close to Kanakapura and Ramanagara taluks. These zones have higher drainage density indicating the nature of higher runoff and Soil Group C and D that aid runoff with lesser infiltration capacity. The region around Bengaluru metropolitan region possesses moderate ground water potential because of the presence and expansion of built-up area.

Groundwater potential and recharge zones in Arkavathy river basin are identified using RS and GIS. RS and GIS techniques have facilitated weighted overlay analysis using various thematic layers of lithology, land use/land cover, slope, lineament density, stream density, HSG and geomorphology in the Arkavathy river basin. RS and GIS techniques have served as quicker and cost-effective tools in identifying groundwater recharge zones and in estimation of the area of each zone. If the water resource in Arkavathy basin in harvested and conserved in accordance with the regions identified by this study, it will help in easing water stress in the basin as well as better utilization of investment on water and conservation activities. It will also help in overcoming chronic water scarcity and enable sustainable water management in the basin.

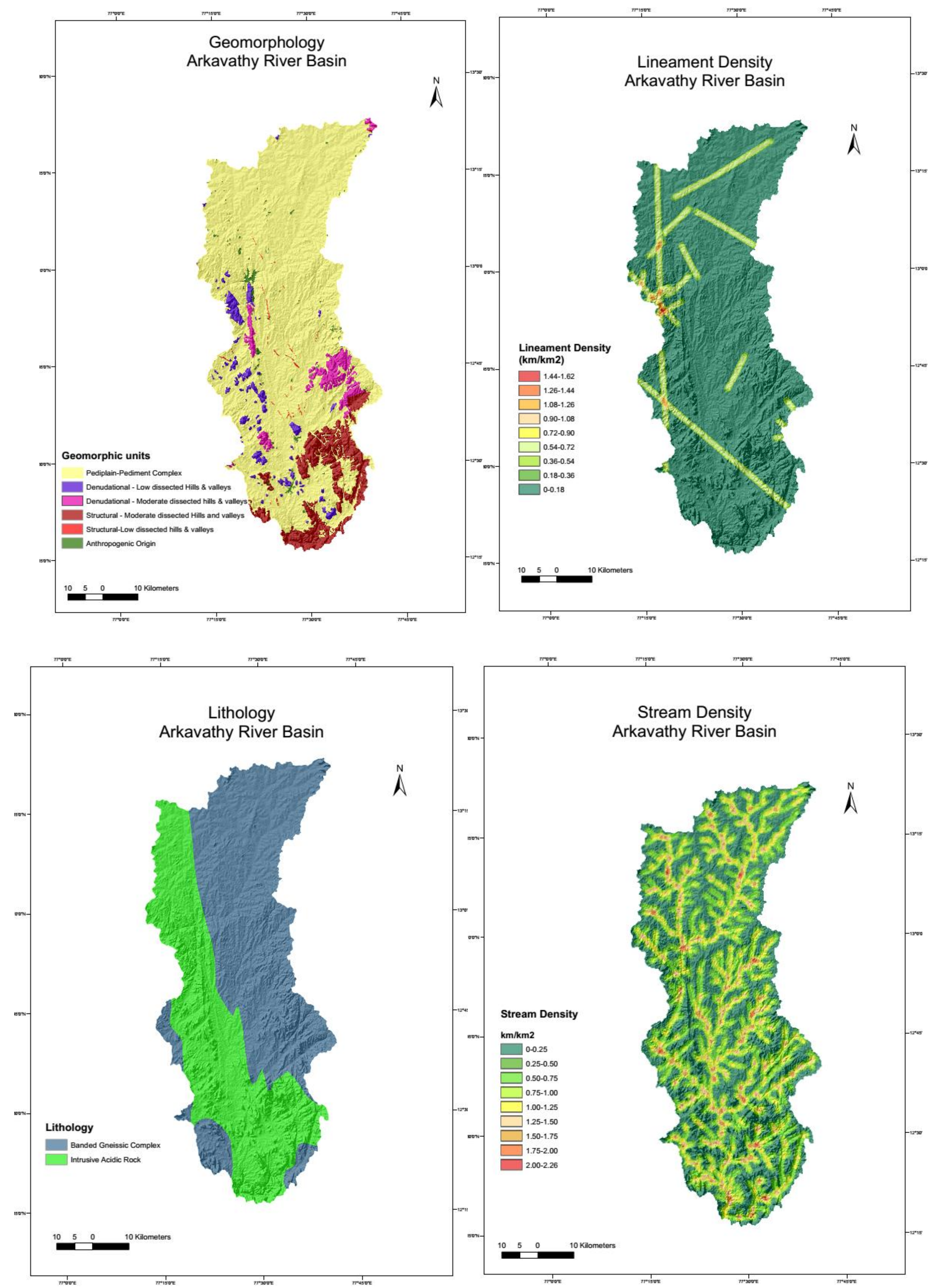

Fig 3: Thematic Layers: Geomorphology, Lineament Density, Lithology and Stream Density

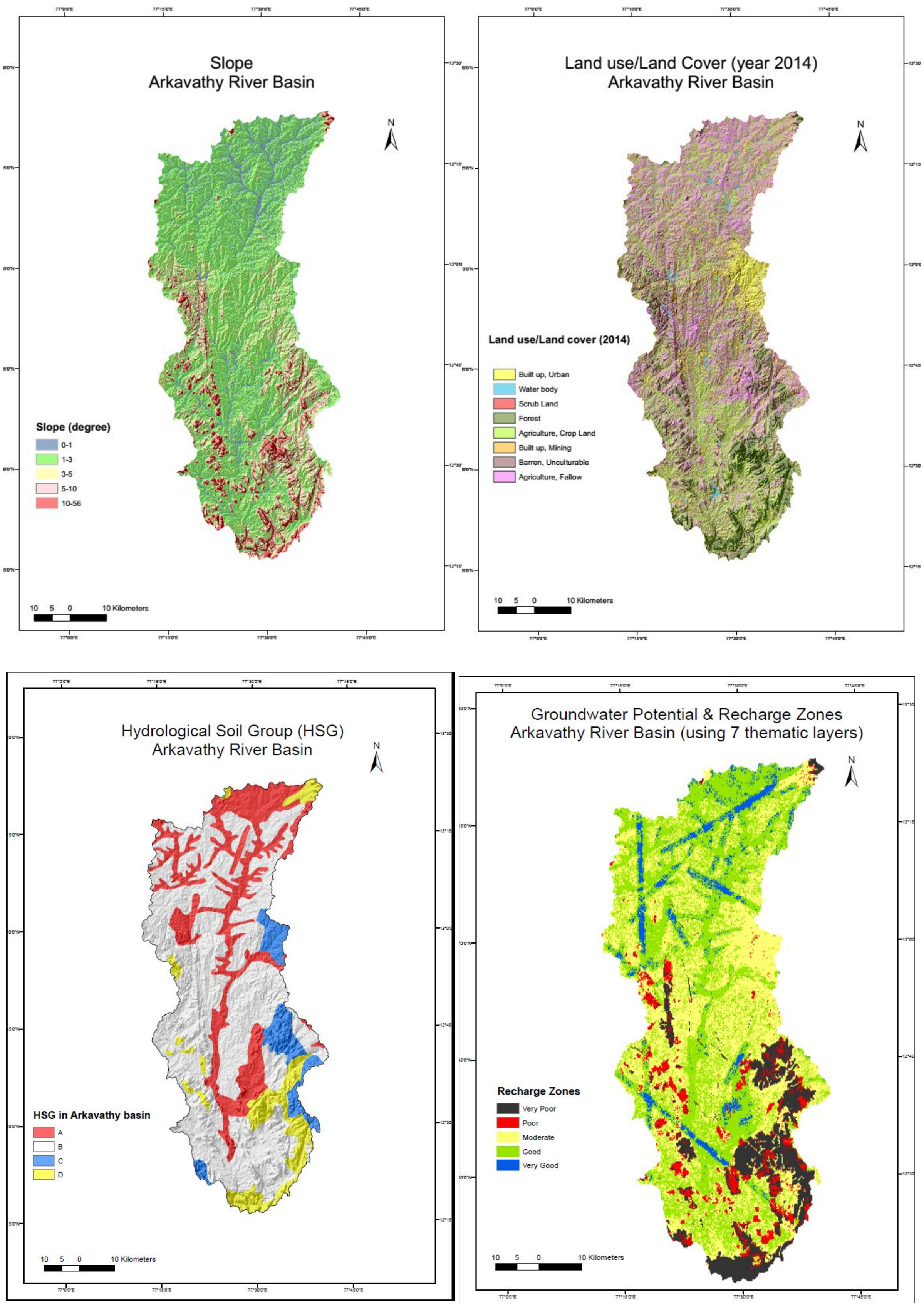

Fig 4: Thematic Layers: Slope, Land use/Land cover and Hydrologic Soil Group (HSG) and output layer showing groundwater potential and recharge zone.

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