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Groundwater Potential Recharge Zonation of Bengaluru Urban District - A GIS based Analytic Hierarchy Process (AHP) Technique Approach

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Abstract: As fresh water resource groundwater has greater significance in major portion of world. It is one of the major components of the entire water supply for drinking and irrigation purposes. The key issues regarding groundwater are its exploration, appraisal and management.The present work deals with the utilization of GIS based analytical hierarchy process (AHP) technique for identification of the groundwater potential recharge zones in Bengaluru urban district, Karnataka, India.Various factors that influence the occurrence, movement, yield and quality of groundwater in an area are Lithology, Geomorphology, Drainage density, Lineaments density, Soil, Elevation, Slope, Lu/Lc and Rainfall. These thematic layers were extracted from Liss III imagery, CartoDEM, topographical map, and other secondary data sources using software such as Arc GIS 10.2, Erdas Imagine 9.2 and Google Earth. Because of the different weightage of influence on various themes and their feature on the presence of groundwater recharge potential zones in an area AHP technique is introduced to allocate weightage.Weighted overlay sub module from ArcGIS environment was used to integrate these thematic layers to prepare the groundwater recharge potential zones of the study area. The zones thus obtained were divided into five categories, viz., Very good, Good, Moderate, Poor and Very poor zones based on the availability of groundwater.

Keywords: AHP, Bengaluru Urban District, GIS, Groundwater Potential recharge Zone, Remote Sensing.

I. INTRODUCTION

In the global scenario, the over exploitation and lack of ground water management reduces the availability of groundwater as a fresh water resource. Inadequacy of the available surface water resource also increase the demand of groundwater. In order to overcome this global issue it is very much necessary to safeguard the groundwater resources and improve the groundwater level in national, regional and local scale. There are several research study were conducted on different perspective of groundwater such as study on physical and chemical properties of ground water [1],[2]. Study on the ground water level fluctuation using temporal water depth data [3]. Study on potential ground water zone using GIS and Remote Sensing technique [4].

There are various conventional methods for groundwater investigation such as Dowsing, preliminary surveys (look at the site and meeting with the chief or head of the village to ask about well location, springs, place where vegetation is greenest and remain green during the dry season and location where existing water resource have higher outflow in all seasons), geophysical method like electrical resistivity method, magnetic methods like Slingram and VLF methods.

The interpretation of satellite data in conjunction with sufficient ground truth information make it possible to identify various geological structures, geomorphic features and their hydrologic characteristics [5], it may serve as indicators of the occurrence of groundwater. The use of Remote sensing data from aircraft or satellite is become an acceptable tool for understanding subsurface water condition [6]. The study conducted by [7], [4], [8] proved that GIS and Remote Sensing technique are suitable to identify groundwater potential recharge zones. The occurrence and movement of groundwater in an area is affected by several factors such as topography, lithology, geological structures, extent of fractures, secondary porosity, soil, drainage pattern, land forms, Land use land cover, and climate condition and inter relationship between the factors [9],[10].

In most of the study personal judgment has been used for assigning weightage for different thematic layer and their feature. But studies on GIS based AHP technique approach in identifying groundwater potential recharge zone are carried out by few.

II. OBJECTIVES OF THE STUDY

The specific aim of the present study entitled as Groundwater potential recharge zonation of Bengaluru urban district - A GIS based Analytic Hierarchy Process (AHP) technique approach were,

1) Application of Remote Sensing & GIS along with AHP technique to prepare various thematic maps for demarcating Groundwater Potential Recharge Zone of Bengaluru Urban District as

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- Elevation map
- Slope map
- Drainage density map
- Land use Land cover map
- Hydrologic Soil Groups map
- Lithology map
- Geomorphology map
- Lineament density map
- Rainfall map

2) Recognition of Groundwater potential recharge zones of the study area by means of AHP technique and weighted overlay sub module in Arc GIS environment.

III. STUDY AREA

The current project, Ground water potential recharge zonation was carried out on The Bengaluru Urban District. Figure 1 shows the study area selected.

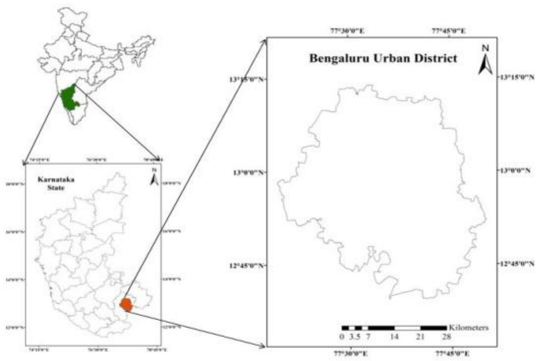

Fig. 1. Study area (Bengaluru Urban District)

In a development point of view Growth of Bengaluru urban district is tremendous, and radialy with respect to the city centre. The rate of increase of population is also in an exponential way. So the source of water for industrial, agricultural, and domestic use are escalating day by day. Water resources and water demand are unevenly distributed spatially and temporally. Water shortage has recently become a significant issue. Water consumption was increased by the continuous progress of the economy, and has accordingly resulted in shortages of surface water. Therefore, the dependency of groundwater resources has increased, leading to the excess utilisation of groundwater, and causing ecological troubles such as decrease in groundwater levels, water pollution, water exhaustion and deterioration of water. These cause severe problems and threaten to both people's livelihoods and overall national development. Therefore, it is significant to systematically understand the groundwater resources of Bengaluru in order to enhance the efficiency and performance of their planning, utilization, administration, and management.

Bengaluru Urban District is bounded by the Dharmapuri district of Tamil Nadu on the south and Bengaluru Rural district on the north, east and west. The district has four taluks. It is having an areal extent of 2190 sq.km and is situated between the North latitude 12˚ 39' 32" : 13˚ 14' 13'' and East longitude 77˚ 19' 44'': 77˚50'13". Total population of this district is 95, 88,910 and the mean annual rainfall for Bengaluru is 1049mm according to central ground water board report of 2012.

IV. METHODOLOGY

A. Data Collected & Software Used

Various data such as Remote Sensing data and existing map from various departments are collected for the successful completion of project. Remote Sensing data composed of CartoDEM of 2.5m resolution and IRS P5 LISS-III satellite data of 23.5 m resolution, which are freely downloadable from Bhuvan website (http://bhuvan.nrsc.gov.in) of National Remote Sensing Centre (NRSC). Existing map include spatial data such as lithology, geomorphology, lineaments and hydrologic soil groups and non spatial data such as rainfall data. The lithology, Geomorphology, lineaments maps in 1:50,000 scale for the study area was collected from Geological Survey of India, Bengaluru. Hydrologic Soil Group map in 1: 50,000 scale and annual average rainfall data were collected from Nation Beuro of Soil Survey, Bengaluru and India Meteorological Department, Bengaluru respectively. For the preparation of various thematic layer ArcMap version 10.2, ERDAS Imagine version 9.2 and Google earth version 7.1 were used.

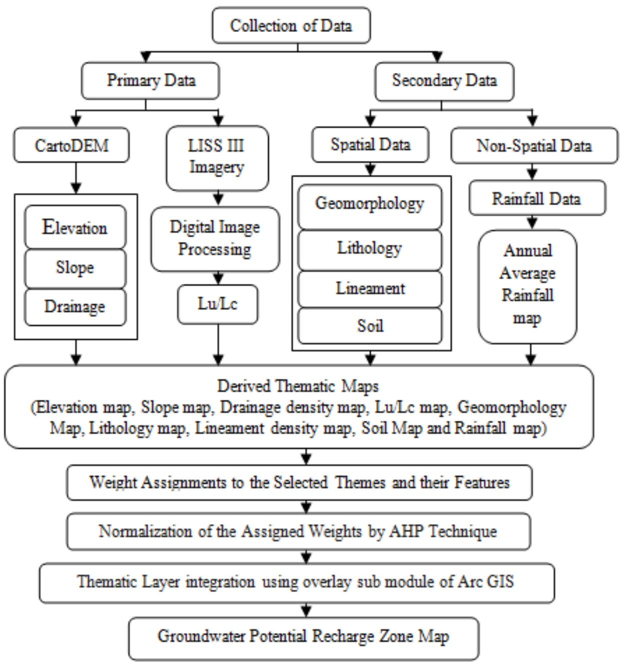

Fig. 2. Flowchart for Identification of groundwater Potential Recharge zone by integrated GIS, RS and AHP techniques

B. Methodology

The occurrence and the opportunity of exploration of groundwater in a geological formation primarily depend on the characteristics such as porosity and permeability.

The nine Factors that have significant influence in groundwater distribution and occurrence were used for integration to delineate potential groundwater recharge zones in an area are Lithology, geomorphology, soils, land use/land cover, drainage pattern, elevation, slope, lineaments and rainfall.

Integrated remote sensing and GIS techniques were applied for generating new thematic data layers as well as existing data for demarcating potential groundwater recharge zone. All the Prepared layers were spatially arranged in the GIS environment with the same resolution and coordinate system. All thematic maps were reclassified and given proper weight based on their importance to groundwater potentiality. The Satty's analytical hierarchical process has been used to rank the weight of each parameter.

By integrating different thematic maps in GIS software using weighted overlay analysis, the groundwater potential recharge zone was found out and classified. The methodology adopted for the identification of groundwater potential recharge zones was illustrated in Figure 2.

V. RESULT AND DISCUSSION

For the successful completion of project, Groundwater potential recharge zonation of Bengaluru urban district - A GIS-based Analytic Hierarchy Process (AHP) technique Approach, nine thematic maps were prepared as mentioned in the methodology such as,

- Elevation Map
- Slope Map
- Drainage density Map
- Land use Land cover Map
- Hydrologic Soil Group Map
- Lithology Map
- Geomorphology Map
- Lineament density Map
- Rainfall Map

The detailed discussion of each parameter was following

A. Elevation

For the present study elevation data shaped from CartoDEM of 2.5 m spatial resolution. A Digital Elevation Model (DEM) indicates a digital geographic dataset of elevations in three dimensions. Water is always preferred to stay at lower topography than the higher topography. If Higher the elevation lesser will be the ground water potential and vice versa. Elevation map of Bengaluru urban district is shown in Figure 3. In Bengaluru Urban District it is clear from the map that elevation of topography was in the range between 609m and 902m from mean sea level. Most of the region is in the range between 780m to 845 m. Lower elevation were identified at south west part and western part of the study area.

B. Slope

Slope map provide an idea about the gradient or steepness of the terrain. Figure 4 shows the slope map of the study area developed by using CartoDEM in spatial analyst module of Arc GIS, which reveals four slope classes based on percent rise: **(1)** Nearly Level (0-5), **(2)** Gently sloping (5-15), **(3)** Moderately sloping (15-35) and **(4)** Strongly sloping (35-70). Slope is inversely proportional to the ground water recharge. A high sloping region causes more runoff and less infiltration result in poor groundwater contribution compared to the low slope region. Most of the area of Bengaluru urban district comes under nearly level and gently sloping terrain.

C. Drainage Density

The drainage density means the whole length of drainage per unit area. The drainage density of an area and permeability are inversely associated. The less permeable a rock, less infiltration of rainfall which tends to be concentrated in surface run off, resulting a well developed drainage system. In relation with surface runoff and permeability, the drainage density indicates the unsuitability of groundwater recharge of an area. The drainage density map of Bengaluru urban district was shown in Figure 5. The maximum value of drainage density identified in the Bengaluru urban district is 1.14 km/km^2.

D. Land Use Land Cover

Land use indicates how people utilize the landscape whether for development, conservation, or mixed uses. Land cover depicts how much of a region is covered by forests, barren land, agriculture, and other land and water types. For groundwater investigation the land use land cover study was necessary because the surface covered by vegetation like forests, plantation and cropland traps and holds the water in root of plants whereas the built-up and barren land use affects the recharge of groundwater by increasing runoff during the rain. The LISS III imagery of 23.5 m spatial resolution has been used for finding out land use land cover of the study area. The supervised classification carried out on satellite image classified the whole study area into six different classes such as Built up area, Forest, Cropland, Plantation, Barren land and Water body. The prepared Land use Land cover map of Bengaluru Urban was shown in Figure 6. Most of the area of Bengaluru Urban district is cropland and central part concentrated with built up area.

E. Hydrologic Soil Groups

Soils were originally assigned to hydrologic soil groups based on measured rainfall, runoff, and infiltrometer data [11]. Based on the surface runoff characteristics the hydrologic soil groups are classified in ascending order such as Group A, Group B, Group C and Group D.

The Hydrologic Soil groups' map of Bengaluru Urban district was prepared using the map available from NBSS, Bengaluru and is shown in Figure 7. The southern part and some of the northern part of the district were concentrated by Group B hydrologic soil and eastern part of district was filled with Group C hydrologic soil. Group A hydrologic soil were founded in middle and western part of the district.

F. Lithology

The lithology of a rock unit is a description of its physical characteristics visible at outcrop, in hand or core samples or with low magnification microscopy, such as colour, texture, grain size, or composition. It may be either a detailed description of these characteristics or be a summary of the gross physical character of rock [12].

The character of the rock will affects the movement of groundwater both quantitatively and qualitatively. The weathering property of rocks has indirect effect on infiltration ability. Lithology is an indication of porosity-permeability of the geological formation. Figure 8 shows the Lithology map of Bengaluru Urban district. For Bengaluru urban district there is mainly three type of rock formation are distributed such as Granite, Migmatite and granodiorite and ultramafic schist. In which migmatite and granodirite and ultramafic schist have almost equal amount of permeability character and granite is comparatively lesser permeable. About 90% of total area of Bengaluru urban district lithologicaly migmatite and granodiorite indicate higher permeability in those regions.

G. Geomorphology

Geomorphologic map give an indication of origin and evolution of topographic and bathymetric features on earth surface. By weathering, erosion and dissection the primary porosity-permeability characteristic gets modified to secondary porosity - permeability. Figure 9 shows the Geomorphology map of Bengaluru urban district and was prepared from the map available from the Geological Survey of India, Bengaluru. Various type of geomorphological feature identified in the study area were Denudation hill, structural hill, pediplain, flood plain and settlement. Based on the importance of particular geomorphological feature on groundwater potential recharge weigtage were assigned to each. From the map prepared it was clear that a vast area in Bengaluru urban district was covered geomorphologicaly by pediplain and central region are by settlements.

H. Lineament

Lineaments are the linear fractures of tectonic origin. They visible as linear to curvilinear shapes on the satellite and are often marked by the presence of moisture, alignment of vegetation, straight streams or river courses, alignment of tanks or ponds, etc [13]Lineament density of an area reveal the groundwater potential, since the presence of lineaments usually indicates the permeability of that area [14]. Areas with high lineament density are good for groundwater potential zones [15]. Figure 10 Show Lineaments map of Bengaluru Urban district. A maximum of 1.46 km/km^2 of lineament density were identified at the western region of the study area.

I. Rainfall

Rainfall is one of the prime sources of groundwater and is expressed as the depth of precipitation in millimetre, measured by rain gauge for preferred periods of time. The association of rainfall to groundwater occurrence is modified by factors like topography, vegetation and surface geology. All these factors affect the quantity of water that gets underground. With respect to diverse surface condition which influence the amount of water that percolate to the ground, annual rainfall should be taken in order to average the amount of water that goes in to the ground in spite of surface condition. Rainfall map shown in figure was prepared from the annual average rainfall data (non spatial data) obtained from India Meteorological Department, Bengaluru. From the available data from the year 2000 to 2014 the annual average rainfall was found out for different stations and the values were interpolated by Inverse Distance Weight (IDW) method to prepare the rainfall map of Bengaluru urban district. Figure 11 shows the map prepared and from it was clear that the rainfall in the study area between 628mm to 1078mm

J. Analytical Hierarchy Process (AHP) Technique

Expert advises from number of previous literature reviews and local field experience for the relative importance of Table I shows the procedure of assigning weightage for each parameter and classes with in the parameter based on the importance of it. From centre towards the right side thevalue increase from 1 to 9 and towards the left side the value decrease from 1 to 1/9. Based on these weightage criteria each parameter in the study has been classified.

K. Weighted Overlay Analysis

After the weightage of each main parameter has been determined (Table II), the weightage for the sub class of main parameters have been assigned as mention in Table III Overlay analysis was performed by the tool 'Weighted Overlay' in Overlay sub module of Spatial Analyst Tools in ArcGIS. The weighted overlay tool overlays several raster using a common measurement scale and weight each according to its importanse (ESRI). The result of overlay analysis has been classified based on the availability of groundwater into five classes as very good, good, moderate, poor and very poor (Figure 12). From the result of classification it has been found that, 58.25 km^2 area are having very good, 1333.67 km^2 area are having good, 478.8 km^2 area having moderate, 287.24 km^2 area having poor and 14.37 km^2 area having very poor potential recharge zone of ground water. The study also depicts that a vast area of the district is coming under good ground water potential recharge and the western region of the district has higher groundwater availability.

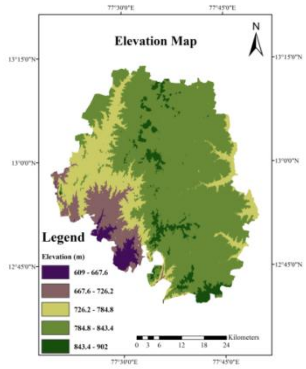

Fig. 3. Elevation map of Bengaluru Urban District

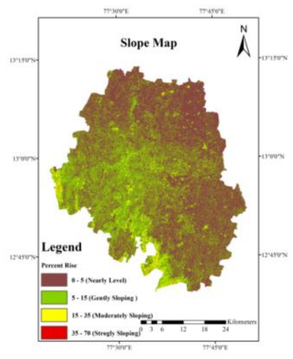

Fig. 4. Slope map of Bengaluru Urban District

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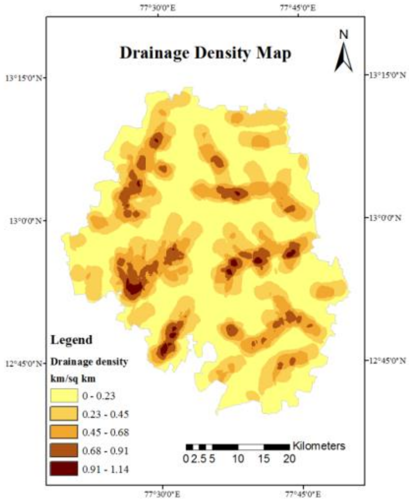

Fig. 5. Drainage Density map of Bengaluru Urban District

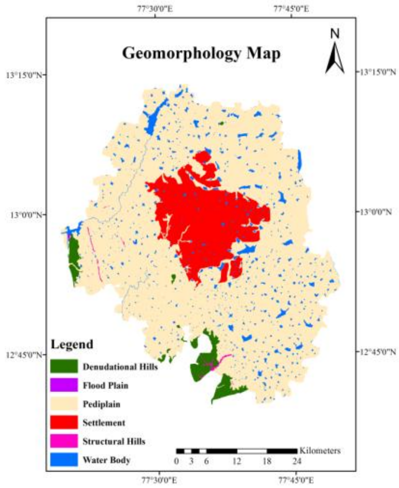

Fig. 8. Elevation map of Bengaluru Urban District

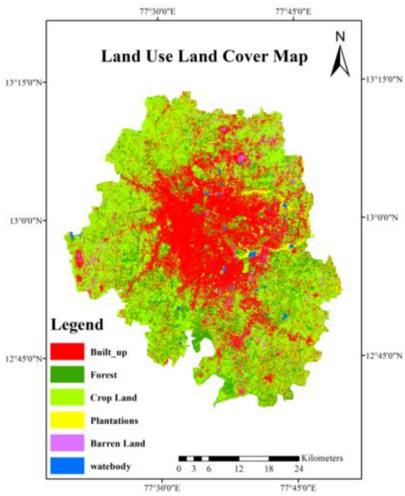

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Fig. 6. Lu/Lc map of Bengaluru Urban District

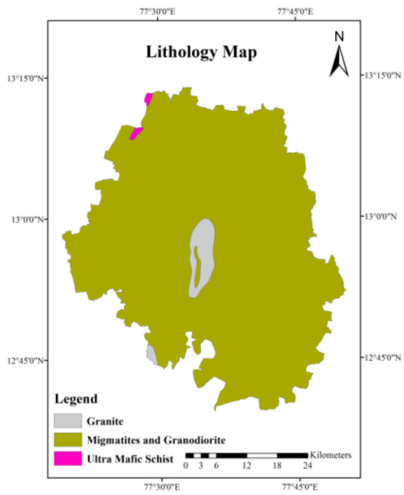

Fig. 9. Lithology map of Bengaluru Urban District

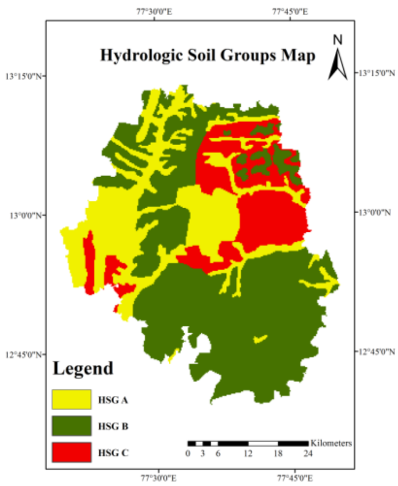

Fig. 7. Hydrologic Soil Group map of Bengaluru Urban District

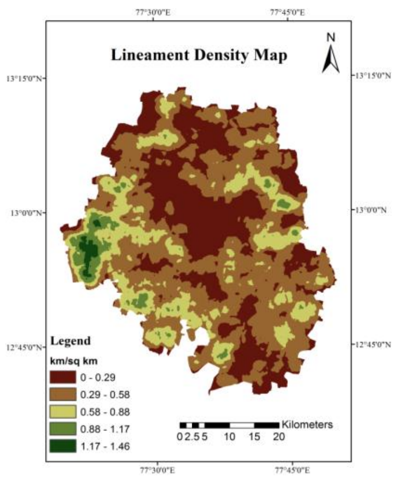

Fig. 10. Lineament Density map of Bengaluru Urban District

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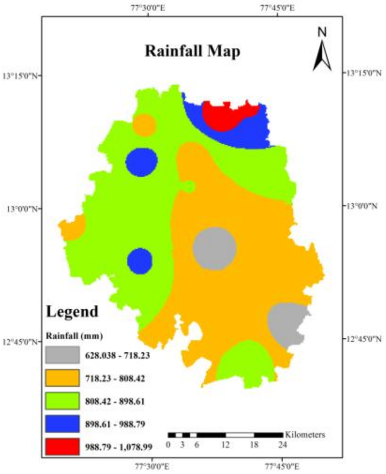

Fig. 11. Rainfall map of Bengaluru Urban District

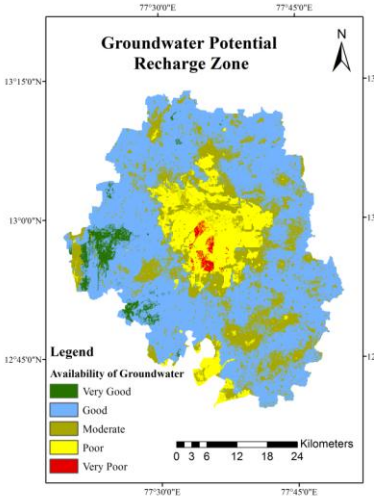

Fig. 12. Groundwater Potential Recharge Zone map of Bengaluru urban district.

Table I: Rating scale of Satty's Analytical Hierarchical process

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equaly	Moderately	strongly	Very strongly	extremely
Less important ←				Equal	→ More important			
Note: 1/8,1/6,1/4,1/2,2,4,6,8 can also be used if more number of classes exist								

Table II : Percentage of Influencing factor based on Satty's Analytical Hierarchical process

Sl no.	Influencing Factor	Value	Satty's scale (in Frac.)	Satty's scale (in Deci.)	%Influence = (Satty's scale/sum)*100	Relative influence value
1	Lithology	High	1	1	35.58	35
2	Geomorphology		1/2	0.5	17.79	18
3	Lineament density		1/3	0.33	11.74	12
4	Drainage density		1/4	0.25	8.89	9
5	HSG		1/5	0.2	7.11	7
6	Slope		1/6	0.16	5.69	6
7	Rainfall		1/7	0.14	4.98	5
8	Lu/Lc		1/8	0.12	4.27	4
9	Elevation	Low	1/9	0.11	3.91	4
				Sum = 2.81		

Table III: Assigned weight according to Satty's Analytical Hierarchical process

Sl no.	Influencing factor	Class Interval	Ground water availability	Satty's scale (in frac.)	Satty's scale (in deci.)	%weight = (Satty's scale/sum)*100	Relative weight
1	Elevation	609-667.6	Very high	1	1	56.17	56
		667.6-726.2	High	1/3	0.33	18.53	19
		726.6-784.8	Moderate	1/5	0.2	11.23	11
		784.8-843.4	Low	1/7	0.14	7.86	8
		843.4-902	Very low	1/9	0.11	6.17	6
					Sum=1.78		

2	Slope	0-5	Very high	1	1	59.88	60
		5-15	High	1/3	0.33	19.76	20
		15-35	Moderate	1/5	0.2	11.97	12
		35-70	Low	1/7	0.14	8.38	8
					Sum=1.67		
3	Drainage density	0-0.23	Very high	1	1	56.17	56
		0.23-0.46	High	1/3	0.33	18.53	19
		0.46-0.69	Moderate	1/5	0.2	11.23	11
		0.69-0.92	Low	1/7	0.14	7.86	8
		0.92-1.15	Very low	1/9	0.11	6.17	6
					Sum=1.78		
4	Lu/Lc	Forest	Very high	1	1	43.85	44
		Cropland	High	1/2	0.5	21.92	22
		Plantation	High	1/3	0.33	14.47	14
		Water body	Moderate	1/5	0.2	8.77	9
		Built up	Low	1/7	0.14	6.14	6
		Barren land	Very low	1/9	0.11	4.82	5
					Sum=2.28		
5	HSG	A	High	1	1	65.35	65
		B	Moderate	1/3	0.33	21.56	22
		C	Low	1/5	0.2	13.07	13
					Sum=1.53		

6	Lithology	Migmatite and granodiorite	Moderate	1/3	0.33	38.37	38
		Ultramafic schist	Moderate	1/3	0.33	38.37	38
		Granite	Low	1/5	0.2	23.25	24
					Sum=0.86		
7	Geo morphology	Pediplain	Very high	1	1	52.91	53
		Flood plain	High	1/3	0.33	17.46	17
		Water body	Moderate	1/5	0.2	10.58	11
		Settlement	Low	1/7	0.14	7.4	7
		Denudation hill	Very low	1/9	0.11	5.82	6
		Structural hill	Very low	1/9	0.11	5.82	6
					Sum=1.89		
8	Lineament density	0-0.28	Very low	1/9	0.11	6.17	6
		0.28-0.58	Low	1/7	0.14	7.86	8
		0.58-0.86	Moderate	1/5	0.2	11.23	11
		0.86-1.15	High	1/3	0.33	18.53	19
		1.15-1.44	Very high	1	1	56.17	56
					Sum=1.78		
9	Rainfall	628.038-718.23	Very low	1/9	0.11	6.17	6
		718.23-808.42	Low	1/7	0.14	7.86	8
		808.42-898.61	Moderate	1/5	0.2	11.23	11
		898.61-988.79	High	1/3	0.33	18.53	19
		988.79-1078.99	Very high	1	1	56.17	56
					Sum=1.78		

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VI. CONCLUSION

A. Summary of Work Done

In this study, a standard methodology for demarcating groundwater potential recharge zonation map using a GIS based Analytical Hierarchy Process technique approach has been proposed. The proposed methodology has been carried out by evaluating the groundwater potential of Bengaluru urban district, Karnataka, India. The present study identifies the potential recharge zone of groundwater by analyzing the influencing factors. Satellite data, CartoDEM, Conventional maps and Rainfall data were used to prepare the thematic layers of nine parameters namely Elevation, Slope, Drainage, Land use Land cover, Hydrologic Soil Group, Lithology, Geomorphology, Lineament and Rainfall. The chosen nine thematic layers and their featusres were assigned suitable weights on the Saaty's scale according to expert advice from previous literature reviews and local field experience. The assigned weights of the thematic layers and their features were then normalized by using analytic hierarchy process (AHP) technique. These Thematic layers were integrated in the GIS environment by weighted overlay sub module to demarcate groundwater potential recharge zones in the study area.

B. Conclusions and Recommendations

A map has been derived showing groundwater potential recharge zones namely, 'Very good', 'Good', 'Moderate', 'Poor' and 'Very poor', which cover 3%, 61%, 22%, 13% and 1% of the study area respectively. The results indicate that most effective Groundwater recharge potential zonation was located outside of the city area in the district. In this region hydrologic soil group, pediplain and cropland have high infiltration ability. Also very good ground water availability was found out in the western part of the district due to the presence of high concentration of lineaments. The central region of study area were least susceptible to groundwater recharge mainly due to its less lineament density, higher elevation and presence of built up areas.

Overall result demonstrates that the integrated RS & GIS technique offer powerful tool to study groundwater resource and propose a suitable exploration plan for recharge of groundwater in a study area. Compared to conventional technique of groundwater inquiry remote sensing data which provide accurate spatial information can be utilise cost effectively. Satty's AHP is one of the appropriate methods for assigning the weigtage for the groundwater study. The multiparameter approach carried out by means of GIS and an AHP technique was economical and stress free work method.

The work result can be useful to the concerned engineers, planners and water managers for various purposes like recognition of location of artificial recharge structures (check dam, water absorption trench and farm pond), location of favourable area for well establishment for the goodwill of the society. Also it is supportive to formulate effective groundwater investigation strategies for the study area so as to assure long term sustainability of this vital and fragile resource. More fascinatingly the methodology was cheap and more appropriate for rising and low income countries where satisfactory and good quality hydrgeologic data were often wanting for groundwater investigation by data intensive technique.

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