RESEARCH PAPER | Geology | Volume : 6 | Issue : 2 | FEBRUARY 2016 | ISSN - 2249-555X

Identification of Potential Groundwater Recharge Zones In Sarabanga Sub Basin, Tamil Nadu, Using Gis-Based Analytical Hierarchical Process (AHP) Technique

KEYWORDS Geographical Information System (GIS), Groundwater Artificial Recharge, Potential Recharge Zone, Analytical Hierarchical Process, Sarabanga Sub Basin, Tamil Nadu

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ABSTRACT *The increasing demands of water extraction pumping rates also increases. The declaiming trend of water level leads to future dements. The management of both surface and subsurface water resources is very urgent need. The present study utilizes the application of Analytical Hierarchical Process (AHP) on geospatial analysis for the exploration of potential zones for artificial groundwater recharge along Sarabanga sub basin in the Salem district, Tamil Nadu, India. The ideal morphology of features such as geology, geomorphology, soil types, land use and land cover, drainage, lineament, and aquifers influence the groundwater recharge in either direct or indirect way. These thematic layers are extracted from IRS P6 LISS IV image, topographical map, and other collateral data sources. In this study, the multilayers were weighed accordingly to the magnitude of groundwater recharge potential zones. The AHP technique is a pair-wise matrix analytical method was used to calculate the geometric mean and normalized weight of individual parameters. Further, the normalized weighted layers are mathematically overlaid for preparation of groundwater recharge potential zone map. The results revealed that 904.55 km2 of the total area are identified as high potential for groundwater recharge zones to construct different types of artificial recharge structures. The gentle slope areas in northeast and southwest and south part have been moderately potential for groundwater recharge zones. Hilly terrains in northeast south and western part are considered as unsuitable zone for groundwater recharge processes.*

INTRODUCTION

The importance of groundwater for domestic, industrial and agricultural uses and its readily and locally available characteristics have lead to indiscriminate extraction of this precious natural resource. Technological development in construction of deep tube wells, water abstraction devices and pumping methods have also contributed to large scale exploitation of groundwater from depths exceeding 300 m below ground level. In many parts of India especially in the arid and semi arid regions, water scarcity has increased tremendously in recent years.

Recent development in remote sensing and GIS techniques allow mapping the spatial distribution of groundwater level and its quality (Brunner et al. 2004; Tweed et al. 2007; Srivastava and Bhattacharya 2006; Krishna Kumar et al. 2011; Magesh and Chandrasekar 2011; Mukherjee et al. 2012; Magesh et al. 2012b; Sarath Prasanth et al. 2012). The results of downscaling analysis of the water resource system and climate change and production of reservoir inflows using statistical method produced significant output for extreme management of water resources (Georgakakos et al. 2011).

Application of GIS merged with analytical hierarchical process (AHP) in demarcating groundwater recharge zones are carried out by few.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 (Chowdhury et al. 2010). However, Machiwal et al. 2011 have used five parameters in AHP process in their study for the identification of groundwater recharge zone but in our study, we have used eleven parameters for better results. The evaluation of the spatial parameters such as geological structure, geomorphic features and hydrological characteristics, among them geomorphology, slope and geology of the area have a great role to identify the groundwater recharge zone from the surface runoff (Vijith 2007).

The application of geostatistical modeling on geospatial layers showed a positive result for demarcating the artificial groundwater recharge sites (Sikdar et al. 2001). Even though most of the researchers have used GIS and remote sensing for delineating the potential groundwater recharge zones in various geographical areas using few thematic layers and successfully predicted the favorable zones. However, the entire analysis depends on assigned weightage to different layers. In the present study, we have used 9 thematic layers for weightage purpose and these layers have been assigned appropriate weights using direct indirect relationship among different layers and AHP analysis. This approach is more reliable in augmenting the potential groundwater recharge zones as this concept deals with systematic allocation of weights through AHP method and weighted overlay analysis technique is GIS platform. Therefore, the present paper deals with AHP coupled with remote sensing and GIS to identify the potential groundwater recharge zone in Sarabanga sub basin, Salem district, Tamil Nadu. Assignments of score value of parameters for scale weight calculation are given in Table.1.

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TABLE -1
ASSIGNMENT OF SCORE VALUE OF PARAMETERS FOR SCALE WEIGHT CALCULATION

Parameters	Lineament	Slope	Soil	Geomorphology	Geology	Drainage	LULC	Aquifer	Rainfall	Scale weight
Lineament	1	0.5	-	1	1	1	0.5	1	1	7
Slope	0.5	1	0.5	1	0.5	1	0.5	0.5	1	6.5
Soil	0.5	0.5	1	0.5	0.5	0.5	1	1	1	6.5
Geo morphology	1	1	0.5	1	0.5	1	1	0.5	1	7.5
Geology	1	0.5	1	1	1	0.5	0.5	1	0.5	7
Drainage	0.5	0.5	0.5	1	0.5	1	1	0.5	0.5	6
LULC	0.5	0.5	0.5	1	0.5	0.5	1	0.5	0.5	5.5
Aquifer	1	0.5	1	0.5	1	1	0.5	1	0.5	7
Rainfall	1	0.5	1	0.5	0.5	1	0.5	1	1	7

STUDY AREA

Sarabanga sub basin located between north latitudes 11°46'00" to 12°09'39" and east longitudes 78°12'27" to 78°36'65" (1178.56 km^2 in area) is laying entirely in the Salem district of Tamil Nadu state, India. Out of the total area, around 715.70 km^2 is covered with forest, 159.69 km^2 with agriculture, and 19.81 km^2 with water bodies. River Sarabanga and its tributaries are the major water sources of this study area. It covers in an areal extent of 1178.56 km^2 and fell entirely in the Salem district. Sarabanga river originate on the western slope of Shevaroy hills at an altitude of 1630 m amsl, it's appears only rainy seasons, people in this region entirely depends on the groundwater resources for their domestic, agricultural and industrial needs. (Fig.1)

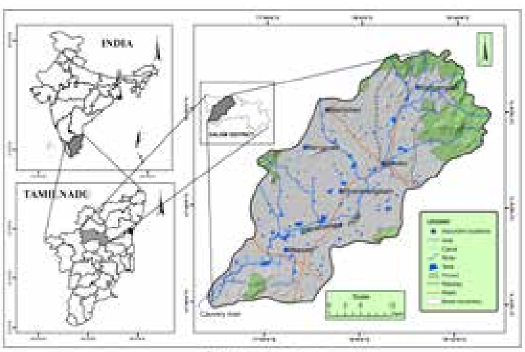

Figure 1: Location of the study area

Figure 2: Geology of the study area

MATERIALS AND METHODS

The multiple parameter analysis for delineating the artificial groundwater recharge sites in the study area has been done by GIS-based AHP technique. In this study, 9 spatial parameters such as geology, geomorphology, slope, land use and land cover, lineament density, drainage density, soil, aquifer thickness and rainfall are analyzed by AHP approach including geometric mean and normalized weight calculation to explore the potential zone for groundwater recharge.

Data collection and preparation of geospatial database

Nine spatial parameters have been used for geospatial database preparation. Using GIS tool, the thematic layers namely geology, geomorphology, slope, land use and land cover, lineament density, drainage density, soil, aquifer thickness and rainfall were prepared from the above data sources and projected with UTM–WGS 84 projection and coordinate system. The geological thematic layer was prepared from the published map of Geological Survey of India using digitizing technique in ArcGIS 10.1 environment. Similarly, the soil maps have been prepared from soil survey of India and the geophysical field survey Vertical Electrical Sounding (VES) has been carried out using SSR-MP-ATS resistivity meter, aquifer thickness are identified up to the depth of 150 m layer thickness maps were prepared and further overlay with various thickness maps finally identified artificial recharge zones. The geomorphology and lineament density layer has been prepared from Landsat IRS P6 LISS IV image using visual interpretation technique and Landuse/land cover map was prepared using supervised classification method in Erdas Imagine 9.1 software. In addition to that, the feature classes of specific parameter have been assigned with suitable weight, geometric mean, and normalized weight in separate column of the attribute table.

Analytical Hierarchical Process

AHP is used to demarcate the potential groundwater recharge zones and this technique was proposed by Saaty (1990). The AHP method allows assessing the geometric mean (Eq. 1), followed by allotting a normalized weight (Eq. 2) to various parameters for finalizing the decision process. In this study, the AHP pair-wise matrix was developed by input values of scale weights of parameters based on direct or indirect relationship shown in Table.2. The influence of different parameters towards groundwater recharge was integrated with each other to form a cluster of relationships. If a parameter has direct influence towards groundwater recharge, then the score was assigned as 1 and for indirect influence the assigned score is 0.5. AHP–Pairwise matrix analysis of parameter's scale weight for geometric mean are given in Table.2

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TABLE - 2
AHP–PAIRWISE MATRIX ANALYSIS OF PARAMETER'S SCALE WEIGHT FOR GEOMETRIC MEAN

Parameters	Lineament	Slope	Soil	Geo Morpho logy	Geology	Drainage	LULC	Aquifer	Rain fall	Total Value	Geo metric mean
Lineament	7/7	7/6.5	7/6.5	7/7.5	7/7	7/6	7/5.5	7/7	7/7	9.5	1.06
Slope	6.5/7	6.5/6.5	6.5/6.5	6.5/7.5	6.5/7	6.5/6	6.5/5.5	6.5/7	6.5/7	8.8	0.98
Soil	6.5/7	6.5/6.5	6.5/6.5	6.5/7.5	6.5/7	6.5/6	6.5/5.5	6.5/7	6.5/7	8.8	0.98
Geomor phology	7.5/7	7.5/6.5	7.5/6.5	7.5/7.5	7.5/7	7.5/6	7.5/5.5	7.5/7	7.5/7	10.19	1.13
Geology	7/7	7/6.5	7/6.5	7/7.5	7/7	7/6	7/5.5	7/7	7/7	9.5	1.06
Drainage	6/7	6/6.5	6/6.5	6/7.5	6/7	6/6	6/5.5	6/7	6/7	14.09	1.57
LULC	5.5/7	5.5/6.5	5.5/6.5	5.5/7.5	5.5/7	5.5/6	5.5/5.5	5.5/7	5.5/7	7.44	0.83
Aquifer	7/7	7/6.5	7/6.5	7/7.5	7/7	7/6	7/5.5	7/7	7/7	9.5	1.06
Rainfall	7/7	7/6.5	7/6.5	7/7.5	7/7	7/6	7/5.5	7/7	7/7	9.5	1.06

Geometric mean
In the first step of AHP analysis, the parameters were rated based on a defined score (0.5–1 scale) for calculating the geometric mean. The geometric mean is derived from the total sum of score of a specific parameter known as total scale weight divided by total number of parameter this is expressed as (after Rhoad et al. (1991). The geometric mean of individual parameters is listed in Table 3.

Normalized weight
The normalized weight is an indicator of multi parameter analysis for groundwater recharge. In the second step of AHP analysis, the normalized weight was derived from the assigned weight of a parameter feature class divided by the corresponding geometric mean. The formula is represented as (after Yu et al. (2002).

The normalized weighted map is an indicator of potential groundwater recharge zone that was classified into very high, high, moderate, low, and unsuitable zone. The class with maximum weight is considered as very high suitable zone and least weighted class is less or unsuitable zone for groundwater recharge.

Assignment of weight to parameters
In the present study, the GIS-based AHP method was applied to integrate different thematic layers based on the assigned weights for suitable site selection. Here, the weight of the feature class of individual parameter was assigned at a scale of 1–10 as per the guidelines of Central Ground Water Board, Government of India (CGWB, 2007). Further, the feature classes of each parameters were quantitatively weighted as poor (weight=1–3), moderate (weight=3–5), high (weight=5–7), and very high (weight=7–9). For example, the layer that has aquifer and more permeable soil type with agricultural land is assigned with the weight as 7, as well as the layer with hard rock with less soil depth and poor permeability is assigned as 1. Similarly, all parameters were assigned with a suitable weight and integrated with geometric mean of corresponding layer to derive the normalized weighted output. The assigned weights and the normalized weights of individual parameters are shown in Table 3.

TABLE - 3
ASSIGNMENT OF WEIGHT FOR THE FEATURE CLASSES OF INDIVIDUAL PARAMETER AND NORMALIZED WEIGHT CALCULATION

Name of parameter	Feature class	Assigned weight (AW)	Geometric mean (G)	Normalized weight (N=AW/G)
Lineament density (km/km^2)	<0.5	8	1.06	7.55
	0.5-1.0	6		5.66
	1.0-1.5	4		3.77
	1.5-2	2		1.89
	>2	1		0.94
Drainage density (km/km^2)	0-0.5	5	1.57	3.18
	0.6-1.0	4		2.55
	1.1-1.5	3		1.91
	1.6-2.0	2		1.27
	2.1-2.5	1		0.64
Slope (in percentage)	0-1%	7	0.98	7.14
	1-3%	6		6.12
	3-5%	5		5.10
	5-10%	4		4.08
	10-15%	3		3.06
	15-30%	2		2.04
	>30%	1		1.02
Aquifer Thickness	<40	7	1.06	6.60
	40-66	5		4.72
	66-86	3		2.83
	>86	1		0.94
Annual rainfall (in mm)	<233	1	1.06	6.60
	233-237	3		4.72
	237-266	5		2.82
	>266	7		0.94

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Soil	Alfisols	6	0.98	6.12
	Entisols	5		5.10
	Inceptisols	4		4.08
	Vertisols	3		3.06
	Miscellaneous Reserve Forest	2		2.04
Land use/ land \cover	Crop land	7	0.83	8.43
	Fallow land	6		7.23
	Land with scrub	5		6.02
	Land without scrub	4		4.82
	Barren Rocky/ Stony Waste	3		3.61
	Buildup Land	2		2.41
	Forest	1		1.20
Geology	Alkaline rocks-Syenite	4	1.06	3.77
	Basic rocks-Dolerite	3		2.83
	Charnockite	5		4.72
	Fissile Hornblende Biotite Gneiss	6		5.66
	Granitic/Acidic rocks	3		2.83
	Ultrabasic Syenite Carbonatite Complex	2		1.89
	Ultramafic / Ultrabasic rocks	3		2.83
Geomorphology	Valley Fill/ filled in valley buried Pediplain	7	1.13	6.19
	Shallow weathered/shallow	6		5.31
	Shallow Flood Plain	5		4.42
	Shallow Buried Pediment	4		3.54
	Pediment/ Valley Floor	5		4.42
	Dome type Residual Hills	1		0.88

RESULTS AND DISCUSSION

The potential zones for groundwater recharge were explored by analyzing the different parameters such as geology, geomorphology, slope, land use and land cover, lineament density, drainage density, soil, aquifer thickness and rainfall through integrated AHP method and geospatial technology.

Geology and Geomorphology

The study area is mainly underlined by Fissile hornblende biotite gneisses, charnockite, granite etc. Fissile hornblende biotite gneisses are the dominant group of rocks covering major parts of the study area, followed by the charnockite rocks. The minor amount of alkaline rocks (syenite) and basic rocks (dolerite) are noticed in south and northeastern part. The younger alluvium formations are seen predominantly in the central part of the study area and are considered as highly permeable. Besides that, the southwest parts of the study area consist of fluvial deposits, which are laid on hornblende biotite gneiss and are considered as good zone for groundwater recharge. (Fig.2). Morphologically, the favorability of groundwater potential flood plain and buried weathered pediplain are good potential zones, Pediment, Pediment inselberg complex, Pediplain buried are moderate potential zones Dome type denudational hill, dome type residual hills and Structural hill are low potential zones. Among these landforms, younger flood plain and debris wash plain have more potential for groundwater recharge, but the structural hills, pediment racks, and steep slope landforms are not suitable for groundwater augmentation.

Aquifer Thickness

Aquifers are water-bearing unconsolidated layer of geological structure of an area. The aquifer thickness is the groundwater storage from the unit of area. The sub surface layer thickness is highly varied place to place. Based on Vertical Electrical Sounding (VES) was carried out at 93 locations using Slumberger configuration with electrode spacing of 150 m to demarcate different layers of aquifers are classified in to low thickness (<19.86), medium thickness (19.86-38.76), high thickness (38.76-60.76) and very high thickness (>60.76) the groundwater potential of the study area. The thickness of the weathered, fractured zone and depth to bed rock were determined from VES data. Due to over exploitation of groundwater in the study area, only fractured layers act as aquifers. (Fig. 3).

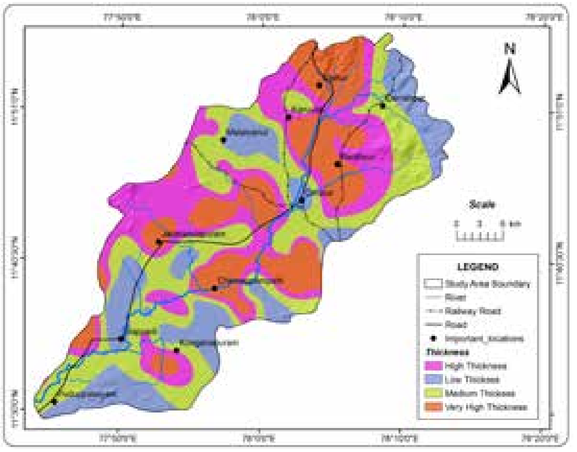

Figure 3: Aquifer thickness of the study area

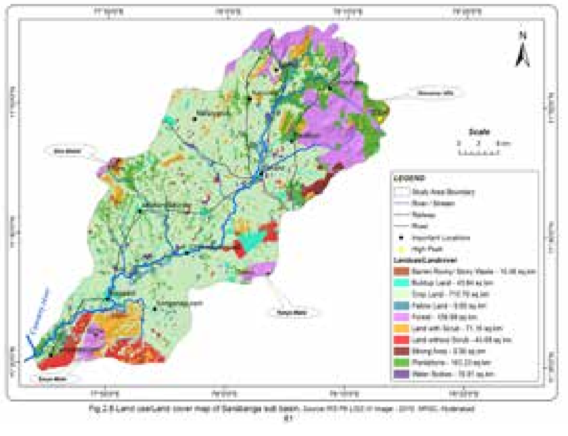

Figure 4: Landuse/Land cover of the study area

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TABLE-4
GEOMETRIC MEAN OF INDIVIDUAL PARAMETERS

Geomorphology	Geology	Slope (in %)	Soil type	Drainage density km/km²	Lineament density km/km²	Aquifer Thickness	Remarks
Valley Fill/ filled in valley buried Pediplain Shallow weathered shallow / Pediplain	Ultrabasic Syenite Carbonatite Complex Granitic/ Acidic rocks Ultramafic / Ultrabasic rocks	1-3%	Alfisols, Entisols	0-0.5	<0.5	>86	Very high suitable zone
Shallow Flood Plain Shallow Buried Pediment	Alkaline rocks Syenite Charnockite Fissile Hornblende Biotite Gneiss	3-10%	Entisols, Inceptisols	0.6-1.5	0.5-1.5	86-66	High suitable zone
Pediment/ Valley Floor	Fissile Hornblende Biotite Gneiss Charnockite	10-15%	Vertisols Miscellaneous Reserve	1.6-2.0	1.5-2	66-40	Moderate suitable zone
Dome type Residual Hills	Charnockite	15-30%	Forest	2.1-2.5	>2	<40	Poor/un suitable zone
Geomorphology	Geology	Slope (in %)	Soil type	Drainage density km/km²	Lineament density km/km²	Aquifer Thickness	Remarks
Valley Fill/ filled in valley buried Pediplain Shallow weathered shallow / Pediplain	Ultrabasic Syenite Carbonatite Complex Granitic/ Acidic rocks Ultramafic / Ultrabasic rocks	1-3%	Alfisols, Entisols	0-0.5	<0.5	>86	Very high suitable zone
Shallow Flood Plain Shallow Buried Pediment	Alkaline rocks Syenite Charnockite Fissile Hornblende Biotite Gneiss	3-10%	Entisols, Inceptisols	0.6-1.5	0.5-1.5	86-66	High suitable zone
Pediment/ Valley Floor	Fissile Hornblende Biotite Gneiss Charnockite	10-15%	Vertisols Miscellaneous Reserve	1.6-2.0	1.5-2	66-40	Moderate suitable zone
Dome type Residual Hills	Charnockite	15-30%	Forest	2.1-2.5	>2	<40	Poor/un suitable zone

Land use and land cover

Land use/land cover is one of the major controlling factors in groundwater recharge processes. The term land use relates to the human activity associated with a specific piece of land, while land cover relates to the type of features present on the surface of the earth. Urban buildings, lakes, residual hills, rocky out crop are all examples of land cover types. Agricultural, afforestation, and mining activities are a few land use categories in the study area. The different types of land use/land cover present in the study area are crop land, plantations, land with shrubs, land without shrubs, buildup land, forest, and water bodies (Fig.4).

POTENTIAL ZONES FOR GROUNDWATER RECHARGE

The systematic analysis of AHP techniques on weighted parameters has produced a suitable groundwater recharge potential zone map in Arc GIS environment. As per the guidelines of CGWB, Government of India, the surface that has characteristics of deep soil depth with high permeability, slope and aquifer thickness associated with agricultural and settlements. It has been prepared from IRS P6 LISS IV satellite image procured from NRSA (Fig.5). Based on this concept, the normalized weighted raster was classified into high, moderate, low, and unsuitable for groundwater recharge (Fig.6). The result reveals that, around 181.20 sq.km of the total area has been identified as very high potential zone are covered central, southern and northwestern part were implement groundwater recharge zone. The high potential zones patches are noticed in groundwater recharge are covered 81.77 sq.km. The zones are comprised Fissile Hornblende Gneissic area moderate potential zones for groundwater recharge it's around 296.68 sq.km. The poor groundwater potential zones are covered 686.80 sq.km. Moreover, these landforms have the lineament density range between 0.5 to 2.0 m/km². The potential zones and its influencing characteristics for groundwater recharge are given in Table 4.

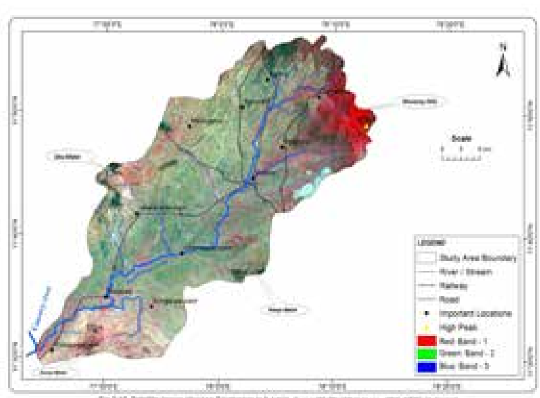

Figure 5: IRS P6 LISS IV image of the study area

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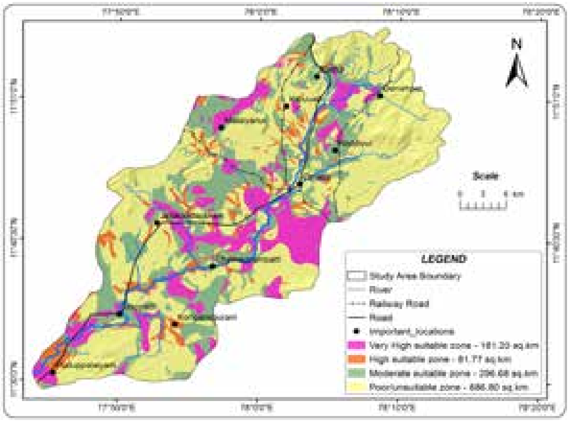

Figure 6: Potential Groundwater recharge zones of the study area

CONCLUSIONS

The application of integrated geospatial technology and AHP has proven to be a better tool for the identification of potential groundwater recharge zones in Sarabanga sub basin. The present study demarcates the potential zones for groundwater recharge zones by analyzing the influencing factors. The result reveals that, around 181.20 sq.km of the total area has been identified as very high potential zone for groundwater recharge zone. From the result, the plain surfaces are developed rural settlements in northwest region and central region followed by southeastern part of the study area which includes rural habitats of Karuvalli, Omalur, Jalakandapuram, Tharamangalam and Idapaddy. The gentle slope in the middle-east and central part of the study area has moderate potential for groundwater recharge. However, hilly terrains in the southern, northern and northeast part are considered as unsuitable zones for groundwater recharge processes. These areas are prioritized for the construction of artificial recharge structures such as check dam, water absorption trench, and farm ponds to store the rainwater and to curb surface runoff. The multi parametric approach carried out using this technique is cost effective and has reduced the workload of a conventional method. This study is a valuable practical tool for the analysis of different types of influencing factors to demarcate the potential groundwater recharge site.

Acknowledgments

The authors are thankful to the University Grants Commission (UGC) Division, Government of India, New Delhi for providing financial support for sanction the "WATER GIS" Major Research Project vide letter reference.F.No.40-301/2011(SR) dated 30.06.2011.

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