# Identification of Groundwater Recharge Potential Zones for Devasugur nala Watershed Using Remote Sensing and GIS in Raichur District, Karnataka

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**ABSTRACT:** Groundwater is considered as the preferred source of water for meeting domestic, industrial and agricultural requirements, due to its longer residence time in the ground, low level of contamination, wide distribution, and availability within the reach of the end user. In this study, nine different thematic layers were generated and used. Among the nine layers, six layers *viz*., geology, soil, land use/cover, watertable fluctuation, depth to bed rock and slope maps were generated from the different data sources. For developing the slope map, ASTER GDEM data was used. For the development of land use/cover map, the IRS R2 LISS-IV digital data was used and by digital image processing technique, totally five different land use and land cover classes were demarcated in the study area. To meet the specific objective, the Multi Criteria Evaluation (MCE) was carried out. Fuzzy logic models were used for the site selection of groundwater recharge zones. The models were evaluated with bore well yield data and it was found that suitable zones demarcated by the Fuzzy logic model were better matched with the bore well yield data. Hence, Fuzzy logic model was selected for the identifying the suitable zones for the recharge. The output of the Fuzzy logic model revealed that 1.04, 36.94, 58.33 and 3.69 percentage of the total areas were occupied by the poor, moderate, good and excellent recharge suitability zones, respectively in the selected watershed. Suitability map revealed that, the good and moderate zones were located in the lower and upper portions of the watershed, respectively.

***Key words:*** *Fuzzy logic; Groundwater; Multi Criteria Evaluation; Suitable*

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## INTRODUCTION

Groundwater recharge refers to the entry of water from the unsaturated zone below the water table surface, together with the associated flow from the water table within the saturated zone. Groundwater recharge occurs when water flows past the groundwater level and infiltrates into the saturated zone. Field investigations help to explain the process of groundwater recharge and evaluate the spatial-temporal difference in the study area. However, these field investigations often focus on a single affecting factor or an indirect site-specific detail for groundwater recharge, reducing the reliability of the investigations. In recent times remote sensing and geographic information system technique is proved to be a cost effective and time saving tool to produce valuable data on geomorphology, geology, land use land cover, slope, lineament density, drainage density, etc. which helps to groundwater recharge potental zones. Narendra *et al.*, (2013) have used remote sensing and GIS techniques for delineation of groundwater potential zones. Binay Kumar *et al.*, (2011), Mondal *et al.*, (2011) have used the remote sensing and GIS technique for generation of groundwater recharge zones map for the improvement and development of groundwater for the region. Subagunasekar *et al.*, (2012) have applied GIS for assessment of the groundwater recharge potential zones. Brema *et al.*, (2012) have used GIS for identification of sites suitable for artificial recharging and groundwater flow modelling. Integrated approach of remote sensing and GIS can provide the appropriate platform for convergent analysis of divergent datasets for decision making in not only mapping and planning of groundwater resources but also management of groundwater resources for its efficient and cost effective use for a region or state. This study is aimed to develop and apply integrated method for combining the information obtained by analysing multi-source remotely sensed data in a GIS environment for better understanding the groundwater resource for a watershed in Raichur district, Karnataka, India.

## MATERIALS AND METHODS

### Site location of study area description

The present study was taken up in the Devasugur nala watershed in Raichur district of Karnataka state. The total area of watershed which is undertaken for the study is 514.43 $km^2$. The watershed lies between 16°08′36″ to 16°22′48″ N latitude and 77°02′24″ to 77°29′24″ E longitude. The physiography on the whole watershed is gently sloping and the total relief is 107 m. Then normal rainfall of Raichur is 621 mm and minimum and maximum temperatures recorded were 15.7$^o$C and 44.25$^o$C, respectively. While the monthly reference evapotranspiration ($ET_o$) was in the range of 120.0 to 245.4 mm. Relative humidity of over 75 per cent is common during monsoon period. Wind speeds exceeding 6-15 km/h are common during the months of June and July.

### Data used

1. Survey of India (SOI) toposheet no. 56H/3, 56H/4, 56H/7 and 56H/8 on scale 1:50000
2. IRS R2 LISS-IV satellite data at the scale 1:50000
3. ASTER GDEM 30 m (USGS/NASA ASTER DEM data available from http:// www.gdem.aster.ersdac.or.jp)

4) Borewells data by field investigations.

First SOI toposheets are geo-coded with the help of known ground control points (GCPs) on it. These geo-coded toposheets are then mosaic to create the boundary map of study area with relevant details, in the form of shape file using QGIS software. Clipping operation is carried out for obtaining required details for study area from the mosaic toposheets. Using map to image registration technique provided by the Geomatica software, the IRS R2 LISS-IV satellite image is geometrically rectified and registered with SOI toposheets on 1:50000 scale. The false colour composite (FCC) generated from red, green and blue spectral bands (4, 3 and 2). To enhance the satellite imagery linear, equalization and root enhancement techniques have been used for better interpretation of the geomorphological, soil, structural and other information for preparation of thematic maps from it. For digitization, editing, and topology creation of various features QGIS software has been used. The most important work of assignment of rank and weightage to different features/themes and classes within theme was carried out and then integration of multi-thematic information is done to identify groundwater potential zones and to generate map for the same (Table 1).

**Spatial Database Building**

QGIS software is used to generate datasets of features, attribute tables, topology/geometric network and other data items in database, which provides various tools. Different thematic maps are created using procedure as below.

1. Digitization of scanned toposheets/maps and editing for elimination of errors
2. Providing map projection system to spatial dataset
3. Extraction of various feature classes for all the layers
4. Assignment of attributes for each layer

**Fuzzy logic model**

Fuzzy logic can be used as an overlay analysis technique to solve traditional overlay analysis applications such as site selection and suitability models. For the site selection of artificial groundwater recharge, nine thematic maps were generated in GIS environment which are: (i) Geomorphology, (ii) Geology, (iii) Soil (iv) Land use and land cover, (v) Slope and (vi) Drainage density, (vii) lineament density, (viii) Watertable fluctuation (ix) Depth to bedrock. To analyze the relationships and interaction between all these thematic layers for the multiple criteria in the overlay model, Fuzzy membership and overlay techniques are used. The membership data was combined based on Fuzzy logic to generate intersecting polygons, in a paired combination according to weightage. The available Fuzzy set overlay techniques which are found to be useful for combining exploration datasets are Fuzzy AND, Fuzzy OR, Fuzzy Algebraic Product, Fuzzy Algebraic Sum and Fuzzy Gamma operator.

a) Fuzzy AND: The minimum of the Fuzzy memberships from the input Fuzzy rasters.
b) Fuzzy OR: The maximum of the Fuzzy memberships from the input rasters.
c) Fuzzy Algebraic Product: It is a decreasive function and it is used when the combination of multiple evidence is less important or smaller than any of the inputs alone.
d) Fuzzy Algebraic Sum: It is an increasive function and is used when the combination of multiple evidence is more important or larger than any of the inputs alone.
e) Fuzzy Gamma: The algebraic product of the Fuzzy Sum and Fuzzy Product, both raised to the power of gamma.

Fuzzy algebraic product is defined as:

$$\mu_{\text{Combination}} = \prod_{i=1}^{n} \mu_i \qquad \text{--- (1)}$$

Where,

$\mu_{\text{combination}}$ is each unit value in output map

$\mu_i$ is the Fuzzy membership values of $i^{th}$ map and

i=1,2,3……n

In Fuzzy algebraic product operator as a t-norm, the weight of compositional layer in the multi- layer intersection is equal to their products and for other sections is zero. Using this overlay analysis a new composite map is generated which is integration of various features from these thematic maps and this is the final composite map for artificial groundwater recharge zones.



**Data integration through GIS**

Various favourable groundwater thematic maps have been integrated into a single groundwater prospect zone with the application of GIS techniques. Data integration required steps as below

1. Assignment of ranks to various features in different themes of spatial data.
2. Integration by overlay of various thematic maps in QGIS environment.
3. Assignment of weightage to different themes in overlay analysis in GIS environment.
4. Generation of groundwater recharge potential zones map

**Spatial Analysis**

The process of study of locations of geographic phenomena together with their dimensions and attributes, classification, polygon classification, rank and weightage assignment to individual class and feature class respectively, is significant and important. The thematic maps of (i) Slope, (ii) Geomorphology, (iii) Land Use and Land

Cover, (iv) Soil (v) Drainage density and (vi) Lineament density, (vii) Geology (viii) Watertable fluctuation (ix) Depth to bedrock map along with well locations data obtained through GPS receiver spread over the study area, have been prepared on the scale 1:50000 using remote sensing data, and field investigations data, using QGIS software. From ASTER DEM 30 m, a thematic percent slope map has been generated. These thematic layers, such as geomorphology, soil, land use land cover and slope map, etc., are used for multi-criteria or weighted overlay analysis by intersecting polygons. Using weighted overlay analysis a new integrated map indicating groundwater recharge potential zones is generated, which is integration of various feature classes from different thematic maps and combining all these features from various thematic maps into one map. Thus final composite map for groundwater recharge potential zones is obtained showing class wise groundwater recharge potential for a watershed of the study area. According to their respective influence or prominence on groundwater recharge, various themes have been considered in assigning the final weightages to the layers in the form of polygons, during weighted overlay analysis, to integrate various thematic maps. Weighted overlay analysis is a GIS technique to be applied for divergent input themes to bring them into the unique convergent output. The groundwater recharge potential zones map has been generated through this weighted overlay analysis and has been categorized into four zones *viz*., excellent, good, moderate and poor suitable from groundwater recharge potential point of view.



## RESULTS AND DISCUSSION

### Geology

The detailed analysis revealed that there are four types of geological classes *viz*., amphibolites hornblende and chlorite schist, dolerite and amphibolites dyke, granodiorite and granite, gray and pink granite. The majority of the area is under gray and pink granite and occupying 372.23 km$^2$ (72.36%), while least area is under dolerite and amphibolites dyke, which is distributed in the small patch in the western side of the study area. It accounted hardly 0.44 km$^2$ (0.09%). The granodiorite and granite occupied 53.93 km$^2$ (10.48%). The geological formations like amphibolites hornblende and chlorite schist is under 87.83 km$^2$ (17.07%) and considered better than the other geological formation for the recharge occurrence.

### Geo-morphology

Geo-morphology of an area can give indirect information about the groundwater potential. It is also helpful in selecting the artificial recharge sites. The list of geomorphic units encounter in study area are buried weathered pediplain, pediplain eroded, flood pediplain, pediment inselbergs complex and residual hill/settlement. It reveals that buried weathered pediplain accounted 464.99 $km^2$ (90.39%) followed by residual hill/settlement 17.85 $km^2$ (3.47%), pediplain eroded 12.47 $km^2$ (2.43%), pediment inselbergs complex 11.74 $km^2$ (2.28%) and flood pediplain/water body mask 7.38 $km^2$ (1.43%). The residual hill/settlement is located in the western, northern and southern eastern boundaries, while buried weathered pediplain covers the maximum portion of the watershed. Further, on recharge point of view, buried weathered and eroded pediplain are favourable, while residual hills are least favourable.

**Soil map**

The major part of the study is covered by fine montmorillonitic soils (black cotton clay) and remaining part is with loamy soils. There are, however, variations in the type of soil *viz*., fine montmorillonitic, fine loamy mixed (sandy clay loam), loamy skeletal mixed (gravelly sandy loam) and sandy skeletal mixed (loamy sand). The scrutiny of the data reveals that montmorillonitic soil group covers 396.86 $km^2$ (77.15%) of the total study area, followed by fine loamy mixed soil covering of 63.49 $km^2$ (12.34%) of the watershed. The fine montmorillonitic soils are present in the western middle and northern side of the watershed. On artificial recharge point of view, sandy and loamy skeletal mixed soil is considered better than the fine montmorillonitic soil groups.



**Land use land Cover map**

The supervised classification was done using some training sets. The results obtained under this were very close to the ground truth data. According to supervised classification, the watershed is having agricultural land, built up land, waste land, water bodies and other land area occupying 453.09 $km^2$ (88.08%), 19.87 $km^2$ (3.86%), 22.22 $km^2$ (4.32%), 16.55 $km^2$ (3.22%) and 2.70 $km^2$ (0.52%), respectively. For classifying using supervised method, the selected areas were identified by some ground truth values.

**Slope map**

The detailed procedure of generating slope map from the ASTER GDEM data is explained in the material and methods chapter. The DEM of the study area is shown in Fig.4.7. The major part of the area is having gently slope (Less moderate). However, variations in the slope (0 to 11.33%) was made to group the entire area into four slope classes *i.e*. 0-1, 1-3, 3-5 and > 5 per cent. On south-eastern and north-western sides, small residual hills are appearing and where the slope is more than 5 per cent, and occupying 48.62 $km^2$ (9.45%) of the total area. Whereas, major part of the study area is with gentle slope occupy

291.24 km$^2$ (56.62%) of the watershed. While, at the foot of the watershed, slope is less than 1 per cent and accounted 82.43 km$^2$ (16.02%) of the total area. About 92.14 km$^2$ (17.91%) area falls in the range of 3 to 5 per cent slope. The areas having slope 0-1 and 1-3 per cent were assigned higher values and the areas, which are having slope more than 3 per cent were considered as the moderate in view of the groundwater recharge.

**Lineament density map**

In the study area, the lineament density was in the range of 0 to 2.55 km/km$^2$. Hence, for the analysis they were grouped into four classes *viz*., < 0.5 (low), 0.5 to 1 (less moderate), 1 to 1.5 (moderate), and >1.5 (high) km/km$^2$, respectively. It reveals that most of the lineaments are concentrated along the drainage network; the density is high in western direction compared to the other area. The identified lineament trend was south-eastern and south-western directions. Further, it shows that 61.58 per cent of the total area, the lineament density was low *i.e*., less than 0.5 km/km$^2$. In the remaining 33.99, 3.55 and 0.88 per cent of the area, it is moderate; 0.5-1, 1-1.5 and 1.5 km/km$^2$, respectively.

Further, for recharge point of view, more weightage was given was given where lineament density was higher than 1.5 km/km$^2$, whereas, low weightage was given where the lineament density was lower than 0.5 km/km$^2$.



**Drainage density map**

The drainage density map reveals that density values ranges from 0 to 5.72 km/km$^2$. For the analysis purpose, they were re-grouped into four categories, *i.e*. high (> 3.5), moderate (2-3.5), less moderate (1-2) and low (0-1) km/km$^2$. The high drainage density was observed in Western and followed by Eastern sides of the watershed. A major portion of the region has less moderate 215.42 km$^2$ (41.88%) to moderate 192.55 km$^2$ (37.43%) drainage density. While, high and low drainage densities were 62.11 km$^2$ (12.07%) and 44.35 km$^2$ (8.62%), respectively.

Considering groundwater recharge point of view, more weightage was assigned to low drainage density regions, whereas low weightage assigned to high drainage density regions.

**Watertable fluctuation**

The fluctuation was in the range of 0 to 5.28 mbgl. In the 58.59 per cent of the study area, the fluctuation was in the ranges of 1-3 mbgl, while in 4.16 per cent of the area it was in the range of 3-5 mbgl. In 36.48 and 0.77 per cent of the areas the fluctuation was minimum (< 1 mbgl) and maximum (> 5 mbgl), respectively.

For selecting artificial recharge sites, the maximum weightage was assigned to the regions with watertable fluctuation more than 3 mbgl, whereas less weightage was given where fluctuation was less than 3 mbgl.

**Depth to bedrock map**

The depth to bedrock was in the range of 15 to 90 m. For the analysis purpose the depth to bedrock are re-grouped into four classes *viz*., <15 m, 15 - 30 m, 30 - 45 m and >45 m. In the major portion of region, the depth is the in the range of 35 to 55 m, while in some pockets *i.e*., at eastern and middle portion of the watershed, it is maximum and minimum, respectively. It reveals that more than 67.82 per cent of the area falls in the range of 30 - 45 m. Whereas, maximum (> 45 m) and minimum (15-30 m) dept to bedrock were recorded in 30.54 and 1.64 per cent of the total area.

For the assigning weightage for groundwater recharge zone selection, the regions with depth to bedrock more than 30 m was given high weightage, whereas, for the less than 30 m depth given the low weightage .

**Overlay analysis**

Overlay analysis is a multi-criteria analysis wherein analysis can be carried out with complex things for finding out certain theme with the help of assignment of rank to the individual class of feature and then assigning weightage to the individual feature considering its influence over theme. All the thematic maps were converted into raster format and superimposed by weighted overlay method, which consists of rank and weightage wise thematic maps and integration of them through GIS. Integration of thematic maps for carrying out multi-criteria or overlay analysis in GIS environment was done using QGIS software. According to Fuzzy logic model; excellent, good, moderate and poor suitable sites were 18.98 $km^2$ (3.69%), 300.06 $km^2$ (58.33%), 190.05 $km^2$ (36.94%) and 5.34 $km^2$ (1.04%), respectively found.

**CONCLUSIONS**

The thematic maps were geology, geo-morphology, soil, land use/land cover, slope, lineament, drainage, watertable fluctuation and depth to bedrock maps can be successfully used to their classifications and to identify the groundwater recharge zones. Multi Criteria Evaluation (MCE) based integrated models with Fuzzy logic models may be used successfully to locate suitable sites for the artificial recharge. According to Fuzzy logic model; excellent, good, moderate and poor suitable sites were 18.98 $km^2$ (3.69%), 300.06 $km^2$ (58.33%), 190.05 $km^2$ (36.94%) and 5.34 $km^2$ (1.04%), respectively found.

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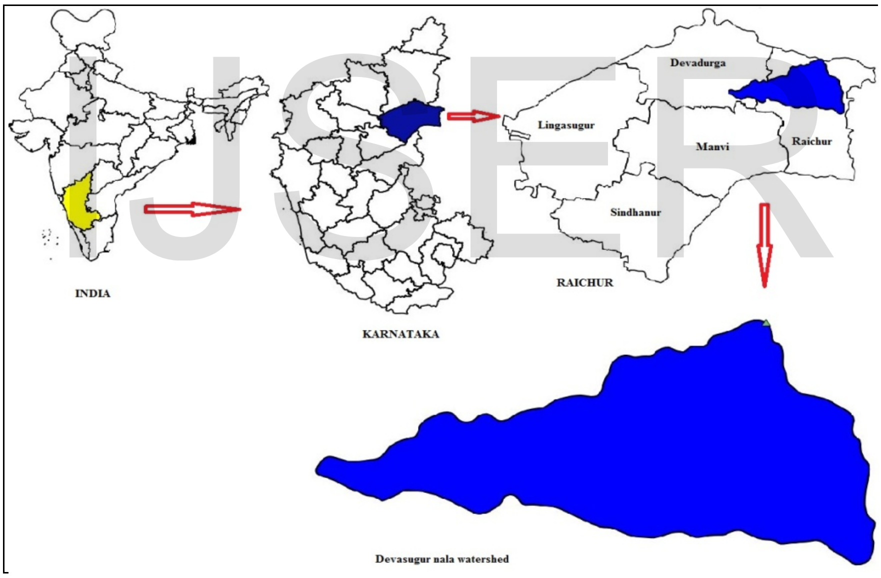


**Fig. 1 The location map of the study area of Devasugur nala watershed**

**Table 1 The criteria classes/units and weightages applied for the selection of sites for artificial recharge**

| Sl. No. | Criteria/Factor | Criteria classes/units | Class/ rank | Weightage factor | Score |
|---|---|---|---|---|---|
| 1 | Geo-morphology | Buried weathered pediplain | 4 | 16 | 64 |
| | | Pediplain eroded | 3 | | 48 |
| | | Flood pediplain/water body | 2 | | 32 |

| | | | | | |
|---|---|---|---|---|---|
| | | mask | | | |
| | | Pediment inselbergs complex | 1 | | 16 |
| | | Residual hill/settlement | 1 | | 16 |
| 2 | Soils | Sandy skeletal mixed | 4 | 14 | 56 |
| | | Loamy skeletal mixed | 3 | | 42 |
| | | Fine loamy mixed | 2 | | 28 |
| | | Fine montmorillonitic | 2 | | 28 |
| 3 | Geology | Amphibolites hornblende and chlorite schist | 2 | 12 | 24 |
| | | Dolerite and amphibolites dyke | 1 | | 12 |
| | | Granodiorite and granite | 1 | | 12 |
| | | Gray and pink granite | 1 | | 12 |
| 4 | Slope | Low (0 to 1 per cent) | 4 | 12 | 48 |
| | | Less moderate (1 to 3 per cent) | 3 | | 36 |
| | | Moderate (3 to 5 per cent) | 2 | | 24 |
| | | High (> 5 per cent) | 1 | | 12 |
| 5 | Lineament density | High (> 1.5 km/km$^2$) | 4 | 12 | 48 |
| | | Moderate (1 to1.5 km/km$^2$) | 3 | | 36 |
| | | Less moderate (0.5 to 1km/km$^2$) | 2 | | 24 |
| | | Low (0 to 0.5 km/km$^2$) | 1 | | 12 |

Contd...

| Sl. No. | Criteria/Factor | Criteria classes/units | Class/ rank | Weightage factor | Score |
|---|---|---|---|---|---|
| 6 | Land use and land cover | Agricultural land (Deep soil) | 4 | 10 | 40 |
| | | Agricultural land (Medium soil) | 3 | | 30 |
| | | Permanent plantation(Orchard) | 3 | | 30 |
| | | Summer crops | 2 | | 20 |

| | | | | | |
|---|---|---|---|---|---|
| | | Water body | 2 | | 20 |
| | | Waste land | 2 | | 20 |
| | | Settlement/built-up | 1 | | 10 |
| 7 | Watertable fluctuation | High (> 5 m) | 4 | 9 | 36 |
| | | Moderate (3 to 5 m) | 3 | | 27 |
| | | Less moderate (1 to 3 m) | 2 | | 18 |
| | | Low (< 1m) | 1 | | 9 |
| 8 | Depth to bedrock | > 45 m | 4 | 8 | 32 |
| | | 30 to 45 m | 3 | | 24 |
| | | 15 to 30 m | 2 | | 16 |
| | | < 15 m | 1 | | 8 |
| 9 | Drainage density | Low (< 1 $km/km^2$) | 4 | 7 | 28 |
| | | Less moderate (1 to 2 $km/km^2$) | 3 | | 21 |
| | | Moderate (2 to 3.5 $km/km^2$) | 2 | | 14 |
| | | High (> 3.5 $km/km^2$) | 1 | | 7 |