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Geospatial Modeling for Demarcation of Groundwater Potential Zone Using WIO and CIS Techniques in Kallar Watershed, South India

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Abstract:

Water plays a vital role in the development of activities in an area. The spatial variation in the recharge due to distributed land-use, soil type or texture, slope, groundwater level, meteorological conditions. The present study attempts to delineate groundwater potential zones for the assessment of groundwater availability in the Kallar watershed, South India using remote sensing and GIS technique. Integration of remote sensing data and the geographical information system (GIS) for the exploration of groundwater resources has become a breakthrough in the field of groundwater research, which assists in assessing, monitoring, and conserving groundwater resources. IRS-IC LISS III satellite data have been used in the present study to prepare various thematic maps such as geological, geomorphological, drainage density, lineament density, land use / land cover and soil permeability. On the basis of relative contribution of each of these maps towards groundwater potential, the weight of each thematic map has been selected. Further, within each thematic map ranking has been made for each of the features. All the thematic maps have been integrated step by step using the Weighted Index Overlay (WIO) analyses method in GIS based on Composition Suitability Index (CIS). On the basis of this final weight and ranking, the ground water potential zones have been delineated. Thus from the present study it is observed that an integrated approach involving remote sensing and GIS technique can be successfully used in identifying potential groundwater zones in the study area. Three categories of groundwater potential zones, viz., good, moderate and poor have been demarcated. Major portions of the study area has “moderate” as well as “poor” prospect while a few scattered areas have good prospect. The result depicts the groundwater potential zones in the study area and found to be helpful in better planning and management of groundwater resources.

Keywords: Groundwater potential zones; South India; remote sensing; Geographic information system

1. Introduction

Groundwater plays a fundamental role in human well-beings, as well as that of some aquatic and terrestrial ecosystems. At present, groundwater contributes around 34% of the total annual water supply and is an important fresh water resource. Groundwater is gaining more and more importance in India owing to the ever increasing demand for water supplies, especially in areas with inadequate surface water supplies. More than 85% of rural and nearly 50% of urban population depend on the groundwater for drinking purposes, while, it accounts for nearly 60% of the total irrigation in the country. According to Central Ground Water Board (CGWB, 2007) out of total number of 5723 blocks/ watershed assessed in the country, 839 are categorized as over exploited, 226 as critical and 30 are infested with saline groundwater. So, an assessment for this resource is extremely significant for the sustainable management of groundwater systems. GIS and remote sensing tools are widely used for the management of various natural resources (Krishna Kumar et al., 2011; Magesh et al., 2011).

Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data, has made it easier to establish the base line information for groundwater potential zones (Tiwari and Rai, 1996; Das et al., 1997; Thomas et al., 1999; Harinarayana et al., 2000; Muralidhar et al., 2000; Chowdhury et al., 2010). Remote sensing not only provides a wide-range scale of the space-time distribution of observations, but also saves time and money (Murthy, 2000; Leblanc et al., 2003; Tweed et al., 2007). In addition it is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones (Sener et al., 2005). Teeuw (1995) relied only on the lineaments for groundwater exploration and others merged different factors apart from lineaments like drainage density, geomorphology, geology, slope, land-use, rainfall intensity and soil texture (Sander et al., 1996; Das, 2000; Sener et al., 2005; Ganapuram et al., 2008). The derived results are found to be satisfactory based on field survey and it varies from one region to another because of varied geo-environmental conditions. One of the most accepted method is weighted index overlay (WIO) for assigning weights and relative ranks based on the multicriteria evaluations for decision making (Pratap et al. 2000; Javed and Wani, 2009; Nagarajan and Singh, 2009; Subba Rao, 2009; Jha et al. 2010). Therefore, the present study focuses on the identification of groundwater potential zones in Kallar watershed, Tamil Nadu using the advanced technology of remote sensing.

2. Study area

Kallar watershed is one of the sub-watersheds in the Cauvery River; it is categorized under semi critical area based on existing groundwater development condition. Kallar watershed located in Salem district west, central, southern and eastern part of Perampalur and Cuddallor districts and small portion in Viluppuram district in Northern part . It is well connected by roads and railways with rest of the cities in Tamil Nadu. It is lying in between 78^0 38’ 58” to 79^0 20’ 19” Eastern longitudes and 11^0 20’ 38” to 11^0 32’ 10” Northern latitudes (Fig.1). The total area of block is 545 sq. km. There are eight blocks fall within the block. The Kallar is known for aggressive agricultural practices, such as tapioca cultivation and sago industry. Semi arid climatic condition prevailing in the watershed without much variation, the annual average rainfall in the block is about 842 mm, which much lower than the state average rainfall. The Kallar watershed is mostly covered by pediments and pediplain with extensive coverage of black cotton soil, which normally have low infiltration. At present, the agricultural practices are mostly oriented towards the availability of groundwater resource in the watershed. Charnockite and hornblende biotite gneiss is the major rock types present mostly in the northern and southern part of the Kallar watershed. The metamorphosed gneissic rocks foliated and weathered compare to charnockitic rocks. However, lineaments associated with joints and fractures control high weathered condition irrespective rock types. Both dug wells and bore wells catering groundwater requirement in gneissic terrain.

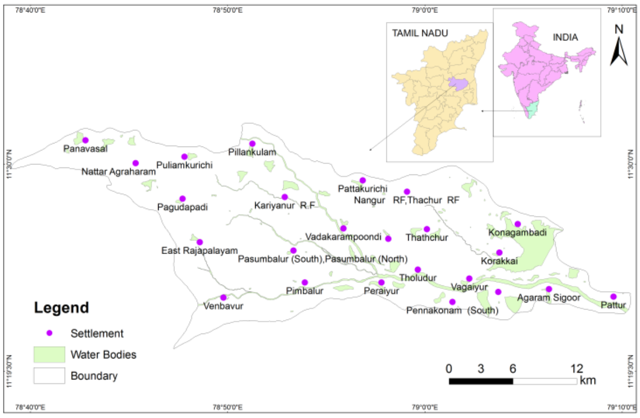

Fig.1: Location map of the study area

3. Methodology

The base map of Kallar watershed was prepared based on Survey of India topographic maps ona 1:50,000 scale. The drainage network for the study area was scanned from Survey of India (SOI) toposheets and digitized in ArcGIS 9.3 platform. The drainage density and lineament density maps were prepared using the line density analysis tool in ArcGIS. Satellite images from IRS P6 LISS-III have been used for delineation of thematic layers such as land-use, lineament, and soil types. The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 9.3. During weighted overlay analysis, the ranking was given for each individual parameter of each thematic map, and weights were assigned according to the weighted index overlay analysis based on Composition Suitability Index (CIS). Each thematic map was assigned a weight (Table 1) depending on its influence on the movement and storage of groundwater (Nag, 2005; Dinesh Kumar et al. 2007; Avtar et al. 2010; Preeja et al. 2011). Relative ranking of each thematic unit in a theme were assigned as knowledge based hierarchy using Spatial Analyst tool of ArcGIS. The resultant map is classified into good, moderate and poor groundwater prospective zones.

3.1. Geology

The study area comprises of Precambrian crystalline rocks viz: hornblend biotite gneiss, charnockite, migmatite gneiss, sand and silt and clay. Charnockite and hornblende-biotite gneiss covers major part. Ranks were assigned to each geological unit on the basis of their porosity and permeability. Since Charnockite posses high porosity and permeability, a rank of 2 is assigned similarly a rank of 1 to hornblende biotite gneiss , 5 to clay and 3 to migmatite gneiss. By multiplying theme weight (10) with feature rank (Wi), factor scores were derived (Table 1). The derived score ranges from maximum of 70 to a minimum of 10 (Fig.2).

3.2 Geomorphology

The word landform denotes the structure, process and stage that shape the earth surface features. Therefore, study of landforms help in understanding the material with which they are made up of, the processes responsible for their genesis and the stage of their evolution. In such a broader sense, the knowledge of landforms lends clues for the evaluation of resource potential, including the ground water in an area. Thus, geomorphology assumes significance in ground water studies. The various geomorphological units discussed are the result of different geomorphologic processes especially the fluvial activities that have been operated in the area (Harikrishna, K. et. al., 2013). The Indian Remote sensing satellite IRS-P6, LISS III (March., 2012) digital data was analyzed through image processing software (ERDAS imagine 9.1) and Arc GIS 9.3 software. The various geomorphic features were delineated and digitization. Field investigations were made for ground verification before finalizing the geomorphic map. In this study, six geomorphological units have been delineated by standard visual interpretation techniques. These are deep, moderate and shallow buried pediment, linear ridge and valley floor. The rank and weightages are given based on their hydrogeomorphic condition in the watershed.

Table 1 Themes and feature classes of groundwater potential zones

Themes	Features	Weight -age	Rank
Geology	Charnockite Fissile hornblende biotite gneiss Migmatite gneiss Clay Sand and silt	10	2 1 3 5 7
Geomorphlogy	Linear Ridge Shallow burried pediment Moderate burried pediment Deep burried pediment Eroded Pediplain Valley Floor	10	1 3 5 6 7 9
Drainage density	Low Moderate High	20	9 5 2
Lineament Density	Low Moderate High	25	2 5 9
Land use / land cover	Agriculture Water bodies Built-up Forest Wastelands	10	7 10 1 5 3
Soil (Based on permeability)	High Moderate Low Mis/forest	25	10 7 4 1

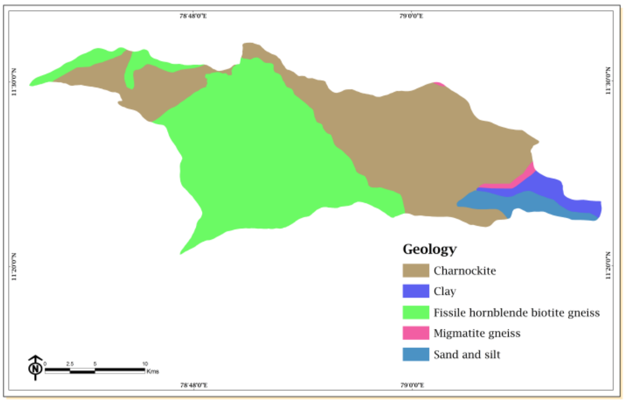

Fig.2: Geology of the Kallar watershed

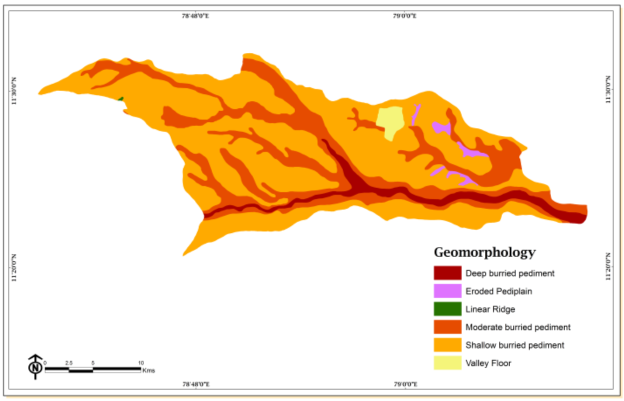

Fig.3: Geomorphological features of the study area

3.3 Drainage

Drainage was derived from Survey of India toposheet using ArcGIS 9.3 (Fig.4). Drainage density is defined as the ratio of total channel segment lengths within a watershed/basin to the watershed/basin area. Drainage density of the study area was prepared by dividing the area into 1 km/1 km grids. The density of these unit cells was then interpolated by Inverse Distance Weight (IDW) method to generate drainage density map (Fig.5). The values obtained and the respective theme weight and class rank assigned to them are given in Table 1. Drainage density is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. This gives origin to a well developed and fine drainage system. High drainage density indicates less infiltration and hence acts as poor groundwater prospect compared to low drainage implying an inverse relation between the two. Low network of drainage course indicates presence of highly resistant and permeable rock, while a high drainage course indicates highly weak and impermeable rocks (Karanth 1999). A higher ranking was attributed to low drainage density zones and a lower ranking to a high drainage density zones.

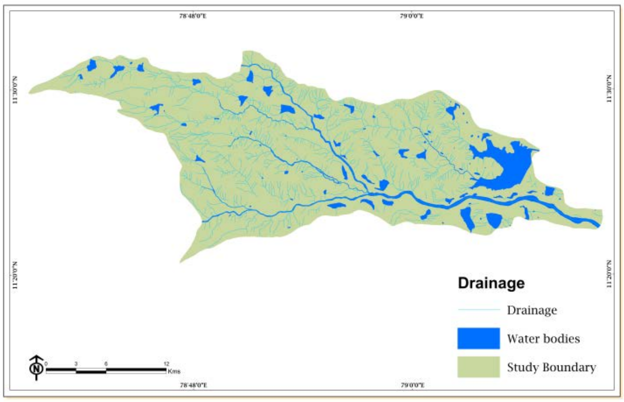

Fig.4 Drainage map of the study area

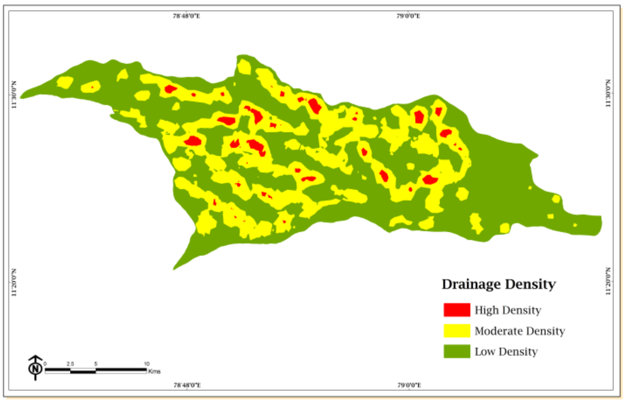

Fig.5 Drainage density map of the study area

3.4 Lineaments

Lineament is defined as a large scale linear feature, which express itself in terms of topography of the underlying structural features. The linear features can be measured and created quantitatively like measurements of other geological properties, but it is necessary to use formal static's that reflect the circular nature of the directional data. These provide the path way for ground water movement and are hydro-geologically very important. In the present study the lineaments are mapped from satellite imagery of IRS P6 LISS III data, which is shown in Fig. 6. Majority of the lineaments are disturbed due to various anthropogenic activities. A major lineament with the trend of E-W direction is parallel to the nearby denudational hill. This phenomenon reflects that the lineament area is a major valley, which is structurally controlled. A reservoir over this lineament was constructed at Wellington with a view to supply water to the Perampalur urban dwellers. Moderate to low lineament density are identified over the plains, which are characterized by urban sprawl (Fig.7). The major lineaments reflect structural instability and also these are occupied by major drainage. These lineaments can act as conduits and therefore unsuitable for landfill site.

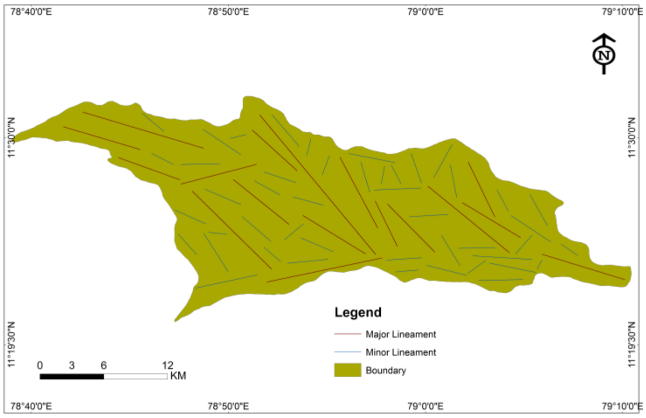

Fig.6 Lineament map of the study area

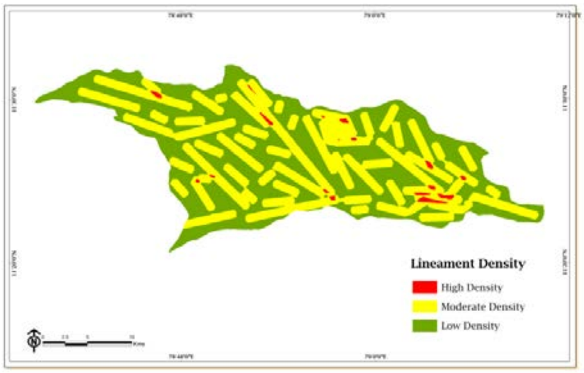

Fig.7 Lineament density map of the study area

3.5 Land use / Land cover

Land use describes how a piece of land is used whereas land cover describes the materials present on the surface (Sabin, 1987). Monitoring, mapping and assessment of land use/land cover in temporal sequence are essential for planning and development of land resources. A sudden change in land use/land cover may be indicative of change in terrain character. The land use pattern and land management of an area reveal indirectly the conditions of the people of the area their economic status and resources. The satellite data of IRS P6 LISSIII have been used in the analysis. The present study area covers different types of land use/Land cover categories. Five types of land use/Landover categories have been identified in the study area. They are built up land, agriculture land, forest, wastelands and water bodies (Fig.8). All the categories are mentioned in table1.

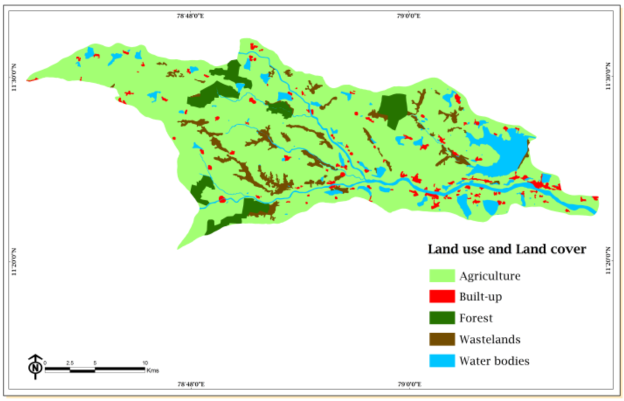

Fig.8 Land use / land cover map of the study area

3.6 Soil

The term soil has specific connotation to different groups involved with soil survey and mapping (Lille sand and Keifer 1987). Soil is a major component of land system and an important ingredient of primary production system. The soil map helps to know the qualities and characteristics of soils of the area to understand their problems, potentials and management needs for their potential use. Traditionally, soil mapping is carried out by field traversing procedures which are tedious, slow, subjective and limited to accessible areas only. Application of remote sensing helps to overcome the shortcomings of the traditional system. Soil mapping is accomplished either by field survey or by application of aero-space remote sensing. Field survey methods are slow, tiresome and prone to subjectivity hazards. Present study area covers alfisols, entisols, inceptisols, and vertisols (Fig.9).

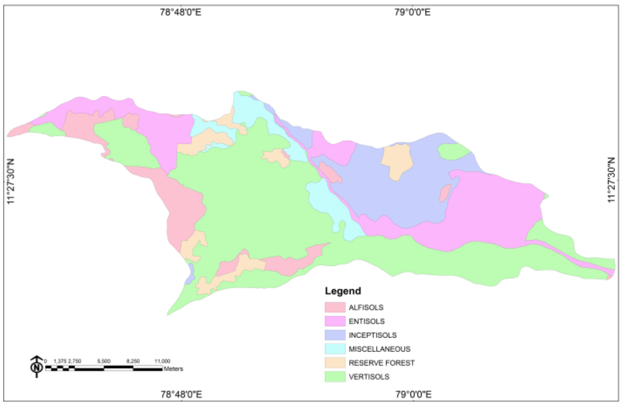

Fig.9 Soil types of Kallar watershed

3.7 Weight Assignment

Thematic layers viz., geology, geomorphology, lineament density, drainage density, land use /land cover and soil maps have been considered for site suitability analysis. Based on the available knowledge on the role of each of these parameters in controlling the occurrence, storage and distribution of groundwater, weightages of 10, 10, 20, 25, 10 and 25 were assigned for geology, geomorphology, lineament density, drainage density, land use /land cover and soil respectively. Again each of these layers has further been classified into different classes. Each of the classes, based on its ability to facilitate water infiltration has been given ranks from 1 to 10. Finally, scores have been calculated as the product of the weightage and rank e.g. under the class geomorphology (wt. 10), valley fills have been assigned the rank 4 (wt. 40). The final score has been calculated by the multiplication of the rank and weightage of the class (Table 1).

The thematic layers were integrated with one another through GIS using the weighted aggregation method. The following order of sequence was adopted to derive the final integrated map.

Geology (I1)	+ Geomorphology (I2)	=	WIO1
WIO1	+ Lineament density (I3)	=	WIO2
WIO2	+ Drainage density (I4)	=	WIO3
WIO3	+ Land use / land cover (I5)	=	WIO4
WIO4	+ Soil (I6)	=	
WIO5			

Where I1, I2… and WIO1, WIO2… input and output layers respectively

In the first step, geology (I1) and geomorphology (I2) layers were integrated by the intersect option. The integrated output layer (WIO1) comprises polygons of the geology layer and polygons of the geomorphology layer and after union it resulted in new polygons having attributes of both the layers. Adding these two layers derived the weight of each polygon in the integrated layer (O1). In the next step, the WIO1 layer was intersected with the lineament density layer (I3). In this step, the integrated layer WIO2 was generated by adding geology, geomorphology and lineament density and so on. The polygons in the integrated layer contain the composite detail of all the thematic layers together numerically having maximum weight of 855 and minimum weight of 205 with standard deviation 117.

Grouping of polygons of high ranks of all the thematic layers has helped in delineating the sites that are excellent for groundwater potential. Based upon the standard deviation, the polygons were grouped into classes suited for groundwater potential zones. A Composite Suitability Index (CSI) has been calculated for each composite unit by multiplying weightage with rank of each parameter and summing up the values of all the parameters. Categorization of the CSI is achieved by ranging the CSI into five classes.

Class I: Maximum	$>CSI\geq 4\sigma$
Class II:	$4\sigma>CSI\geq 3\sigma$
Class III:	$3\sigma>CSI\geq 2\sigma$
Class IV:	$2\sigma>CSI\geq 1\sigma$
Class V:	$1\sigma>CSI>$ Minimum

Where σ Standard deviation

Those polygons, having cumulative weight 205 to 421 (205 to 1s) in the final integrated layer were classified as poor potential. The polygons classified as moderate category have the cumulative weight 422 to 637, whereas good category has the weights 638 to 855.

4. Results and Discussion

Depending upon the overlay of these thematic layers in the study area these were assigned with a particular weightage number and multiplied to obtain a map which is used for further analysis. In the same way depending upon their levels of concentrations of the groundwater zones were also assigned with a particular weightage and multiplied to obtain maps which as used for overlay analysis of all these parameters along with drainage of the study area to obtain groundwater zones.

To demarcate the different groundwater prospective zones, all the thematic layers such as geology, geomorphology, lineament density, drainage density, land use/land cover and soil are integrated through Spatial Analyst in ArcGIS. The groundwater potential map (Fig. 10) was generated on the basis of weights and ranks assigned to different features of the thematic layers in GIS, which was classified into groundwater prospect zones based on the decision as good (20% of the area), moderate (46% of the area) and poor (34% of the area). The maximum area is characterized by moderate to good potential zone that occupies 66% of total area. The map indicates that the stream courses and burried pediments with associated lineaments are identified as good prospective zones, while, the compact lithology and high drainage density are classified as poor prospective areas.

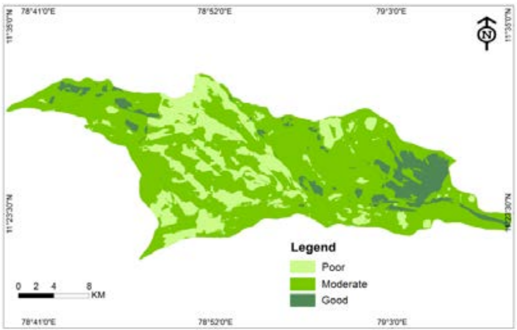

Fig.10 Groundwater potential map of Kallar watershed

5. Conclusions

The site suitability modeling for locating the groundwater potential zones using GIS analysis has an added advantage over conventional survey. The mapping of groundwater resources has assumed importance in recent years because of increased demand for water. Utilization of remote sensing and GIS is a powerful tool for water resources management. It plays an important role in integrating all the data to generate various thematic maps for preparing groundwater potential map. The geomorphic units' buried pediment and water bodies are good prospective zones for groundwater exploration. Presence of high lineament density, low drainage density and low slope indicate the occurrence of groundwater. The resultant maps of the study revealed that about sixty six percent of the Kallar watershed comes under the category of good to moderate groundwater prospective zones, while, the remaining area falls in the poor zone. The integrated groundwater potential map, thus, could be useful for development of sustainable scheme for groundwater development in the area.

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