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Research Article

Identification of Potential Zones for Groundwater Recharge in Kosigi Mandal, Kurnool District, using Remote Sensing and GIS

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Abstract

Ground water, the major source of rural domestic water requirements in India is depleting fast in many areas due to its large scale withdrawal. To tackle the hazardous de-saturation of aquifer zones and consequent deterioration of ground water quality, there is an urgent need to recharge the groundwater resources through suitable watershed management interventions. In this study, Kosigi which is one of drought prone mandal of Kurnool district was taken up to identify potential zones for groundwater recharge using GIS techniques. There are 26 villages covering an area around 420 km^2 predominantly by black cotton soils and nearly flat terrain surface with small isolated hillocks. By considering suitability of terrain surface, soil and its depth; thematic maps such as geomorphology, drainage density, lineament density, and land use / land cover were prepared for Weighted Overlay Analysis (WOA) using ArcGIS 10.2 desktop software. The weights of selected themes were computed using Analytic Hierarchy Process (AHP) method. From the results, the groundwater potential zones with poor (34.76 km^2), moderate (227.91 km^2), good (117.02km^2), very good (36.37 km^2), and excellent (5.20 km^2) prospective zones were identified.

Keywords: *Groundwater Recharge, Potential Zones, Remote Sensing, GIS, AHP, Weighted Overlay, ArcGIS*

1. Introduction

The rapid development of ground water resources for varied usage has contributed in expansion of irrigated agriculture, overall economic development and in improving the quality of life in India. Ground water, which is the source for more than 85 percent of rural domestic water requirements of the country, is depleting fast in many areas due to its large-scale withdrawal. The significant contribution made for Green Revolution and also as primary reliable source of irrigation during drought years has further strengthened the people's faith in utilization of ground water as dependable source (CGWB, 2013).

The speedy and uncontrolled usage of ground water has also created many problems. In order to determine the location of aquifer, quality of groundwater, physical characteristics of aquifers, etc., in any basin, test drilling and stratigraphy analysis are the most reliable and standard methods. However, such an approach for groundwater investigations is very costly, time-consuming and requires skilled manpower (Sander *et al*, 1996). In contrast, Remote Sensing and GIS with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has emerged as a very useful tool for the assessment, monitoring and management of groundwater resources (Jha *et al*, 2007).

2.Scenario of Ground Water in India

India is a vast country with varied hydrogeological situations resulting from diversified geological, climatological and topographic set up. The rock formations, ranging in age from Archaean to recent, control occurrence and movement of ground water. Similarly rainfall pattern also shows region wise variations. Various rock types occurring in the country have been categorized as unconsolidated, semi-consolidated, and hard rock / consolidated formations.

2.1 Unconsolidated Formations

The sediments comprising alluvium are important repositories of ground water. These are essentially comprised of clay, sand, gravel and boulders etc. The aquifer materials vary in particle size, roundness and sorting. Consequently, their water yielding capabilities vary considerably.

2.2 Semi-consolidated Formations

The semi-consolidated formations mainly comprise shale, sandstones and limestone. The sandstones form

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highly potential aquifers locally, particularly in Peninsular India. These sediments normally occur at narrow valleys or structurally faulted basins. Though these formations have been identified to possess moderate potential, the physiography of the terrain, normally restricts development.

2.3 Hard Rock / Consolidated Formations

The consolidated formations occupy almost two thirds of the country. From the hydrogeological point of view, the consolidated rocks are broadly classified into Igneous and metamorphic rocks, volcanic rocks, and carbonate rocks. These formations control the ground water availability and scope for augmentation and artificial recharge.

2.3.1 Igneous and Metamorphic Rocks

The most common types of rocks are granites, gneisses, charnockites, khondalites, quartzites, schist and associated phyllite, slate, etc. These rocks possess negligible primary porosity but are rendered porous and permeable due to secondary porosity by fracturing and weathering.

Crystalline hard rock reveals the existence of lineaments along deeply weathered and fractured zones, locally forming potential aquifers. These lineament zones are found to be highly productive for construction of bore wells. These in turn offer good scope for recharge through suitable techniques. In most of the granite / gneiss area, the weathered residuum serves as an effective ground water repository.

2.3.2 Volcanic Rocks

The basaltic lava flows are mostly horizontal to gently dipping. Ground water occurrence in this hard rock is controlled by the contrasting water bearing properties of different lava flows. The topography, nature and extent of weathering, jointing and fracture pattern, thickness and depth of occurrence of vesicular basalts are the important factors which play a major role in the occurrence and movement of ground water in these rocks. Basalts or Deccan Traps usually have medium to low permeability depending on the presence of primary and secondary porosity.

2.3.3 Carbonate Rocks

Carbonate rocks include limestone, marble and dolomite. Among the carbonate rocks, lime stones occur extensively. In carbonate rocks, solution cavities lead to widely contrasting permeability within short distances. Potential limestone aquifers are found to occur in Rajasthan and Peninsular India in which the yields range from 5 to 25 lps. Large springs exist in the Himalayan Region in the limestone formations.

3. Review of Literature

In a study by Amaresh *et al*, (2004) to identify groundwater potential zones in Nagar block of Mirzapur district, Uttar Pradesh, IRS 1C, LISS III data, geo-electrical data and litho-log data have been used by integrating various thematic maps such as Hydrogeomorphology, Lineament, slope, drainage maps etc. These maps are integrated after assigning weight factors to the identified features in each thematic map depending upon their infiltration characteristics.

An attempt made by Basavaraj *et al*, (2011) to delineate possible groundwater potential zones in the Ghataprabha sub basin of Krishna river, Karnataka. The thematic layers considered in this study are lithology, landform, drainage density, recharge, soil, land slope and surface water body, which were prepared using the Google Earth imagery and conventional data. All these themes and their individual features were then assigned weights according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on the Saaty's analytical hierarchy process.

In many research studies, the commonly used thematic layers are lithology, geomorphology, drainage pattern, lineament density, soil and topographic slope (Binay Kumar *et al*, 2011; S Sahid *et al*, 2000, S. Saravanan, 2012, SumitDabra *et al*, 2013). All the studies have been carried out in India; the majority of which focus on soft rock and hard-rock terrains.

4. Study Area

Kosigi watershed is lies between 15.79490^0 to latitude and 77.14188^0 to 77.32040^0 longitude in Kurnool district of Andhra Pradesh, India. It is bounded by Mantralayam mandal in the east, the Tungabhadra River in the north, Peddakadubur mandal in the south and Kowathalam mandal in the west. In general, the study area is a plain terrain with slight undulation and with structural hills. There are 26 villages covering an area of 420 km^2 predominantly by black cotton soils.

5. Methodology

Various thematic maps like drainage density, land use/land cover, slope and geomorphological maps have been generated to identify the ground water potential zones in a series of steps as follows:

a) Determination of the basic resource information required for the production of various thematic maps
b) Preparation of district, mandal, and village boundary maps.
c) Delineation of watershed map from Digital Elevation Model (DEM) data.
d) Preparation of drainage network map
e) Preparation of slope map
f) Preparation of elevation map
g) Preparation of drainage density maps using Neighborhood tools from ArcGIS Spatial Extension.
h) Preparation of geomorphology map by digitizing WMS layer available at ISRO's Bhuvan website.

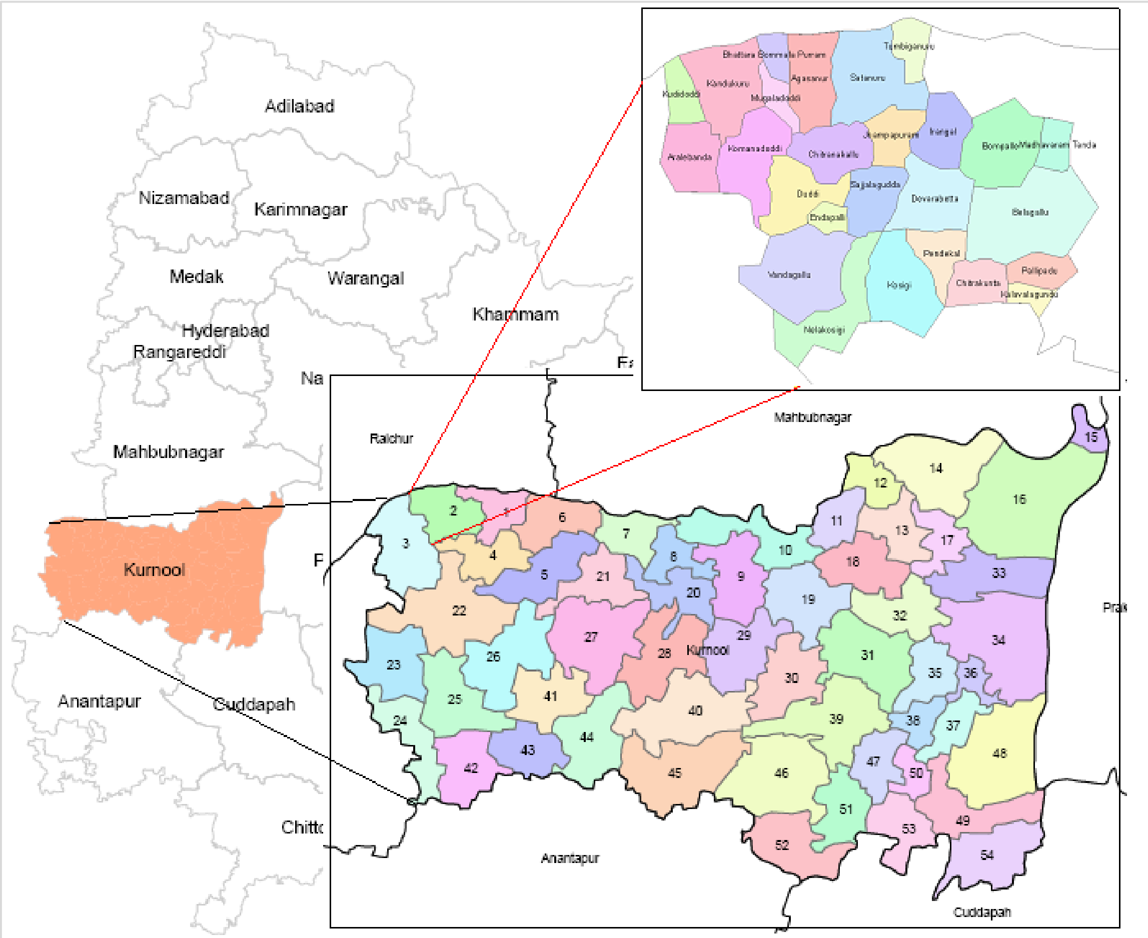

Fig. 1 Location Map of Kosigi Mandal

i) Preparation of land use / land cover map of the year 2011 by digitizing WMS layer available at ISRO's Bhuvan website.

j) Preparation of lineament map by digitizing WMS layer available at ISRO's Bhuvan website.

k) Preparation of lineament density map from lineament map data.

l) Assigning of weights according to their relative importance in groundwater occurrence and the corresponding normalized weights are obtained based on the Saaty's analytical hierarchy process.

m) The thematic layers are finally integrated using ArcGIS desktop software to yield a groundwater potential zone map of the study area. Thus, three different groundwater potential zones are identified, namely excellent, very good, good, moderate, and poor.

6. Data used

Various types of data from different sources are used to prepare the required thematic maps are given below:

a) Toposheets (57E series) of scale 1:50,000 from Survey of India

b) LISS III Data from open data archive of ISRO's Bhuvan website for Land Use / Land Cover map.

c) CartoDEM data having horizontal resolution of one arc-second (30 meters) downloaded from Open Data Archive of ISRO's Bhuvan website

d) Google Maps

e) ArcGIS Server Base Maps such as World Imaginary, World Street Map, World Topographic Map

f) Thematic maps such as Land use / Land cover, Geomorphology maps from ISRO's Bhuvan WMS Server

g) Manuals of Central Ground Water Board of India.

7. Software used

a) ArcGIS 10.2 Desktop software used to prepare thematic maps and Weighted Overlay Analysis to identify Groundwater Potential Zones.

b) Google Maps API to view data online

c) Google Fusion Tables to store data online

d) ASP.NET for web application

8. Factors Influencing Ground Water

Roads and Rail Tracks have not been considered as they have little bearing on water resources identification. The most of the region of Kosigi watershed is buried pediplains with black cotton soils. Black cotton soils have good potential is highly favorable for ground water exploration and development. Geologically, the area consists of Achaean age and Alluvium deposit of recent age. Alluvium occurs along the river course and the thickness of alluvial aquifer ranges from 10-15 m. It consists of unconsolidated materials composed of various proportions of sand, silt and clay, which forms fertile soil strata that support agriculture. This deposit forms very good water bearing horizon.

Slope plays an important role in ascertaining the land capabilities and suit abilities for different land uses and groundwater hydrology. Greater the slope, more runoff and lesser gradient tend to spread the overland flows thus favoring the infiltration and ground water prospects. The study area is havingless than 3% of slope and is excellent from the point of occurrence of ground water.

By considering the suitability of soil and slope, in the present study, the following thematic maps have been generated and considered for Weighted Overlay Analysis:

a) Drainage Density map
b) Land use / Land Cover map
c) Lineament Density map
d) Geomorphology map

8.1 Drainage Density Map

Drainage density is an inverse function of permeability. In the present study, since the drainage density can indirectly indicate the groundwater potential of an area due to its relation to surface run-off and permeability, it was considered as one of the indicators of groundwater occurrence. The area is classified into four categories as very good, good, moderate, and poor. The drainage density map for the study area is shown in Figure 2.

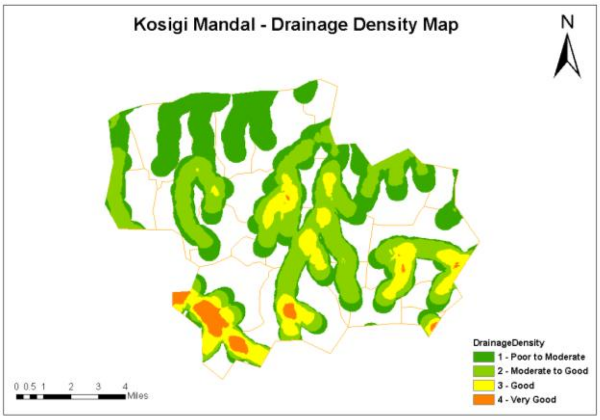

Fig. 2 Drainage Density Map

8.2 Land Use / Land Cover Map

The fundamental approach to any watershed planning is to determine the present situation of land use / land cover pattern. Different land use / land cover patterns obstruct the run-off, reduce evaporation of surface and ground water and hence have an impact on groundwater resources. Land use / land cover map has been obtained from ISRO's Bhuvan website through the WMS services. The same has been digitized and nearly five major categories are prepared as shown in Table 6.

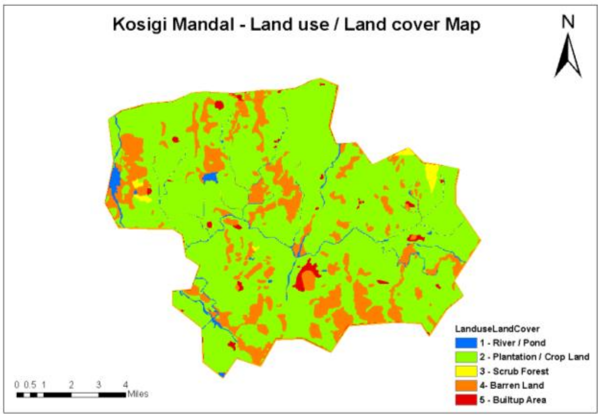

Fig. 3 Land Use / Land Cover Map

8.3 Lineament Density Map

Lineament is defined as topography of the underlying linear structural features. Lineaments provide the pathways for ground water movements and are hydro geologically very important. The lineaments intersections are considered as good ground water potential zones. The most important function of fractures in relation to the groundwater is that they act as conduits for percolation of water to deep sources. Only lineaments could acts as better conduits for descent and ascent of groundwater through any form of opening in the rocks. Well-developed fractures intersecting with each other may hold appreciable quantity of groundwater.

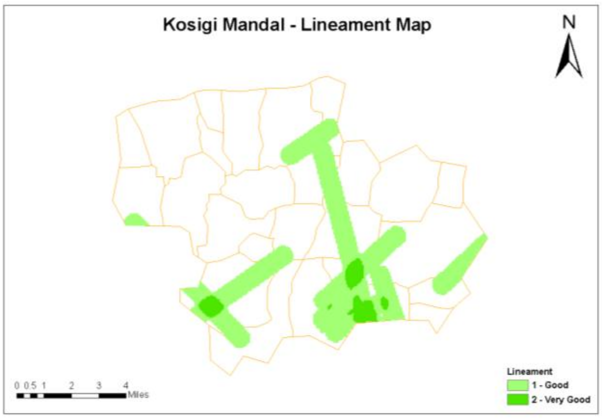

Fig. 4 Lineament Density Map

8.4 Geomorphology Map

Geomorphology is the scientific study of the nature and history of the landforms on the surface of the Earth and other planets, and of the processes that create them.

Geomorphology is the highly influencing parameter of groundwater occurrence. The hydrogeomorphological units like flood plains, valley fills, buried channels and lineaments are very good sources for groundwater. On the contrary, structural hills, pediment zone and gullied lands are poor potential zones. The study area geomorphic features have been observed and listed below.

a) Denudational Hills
b) Denudational Pediplains

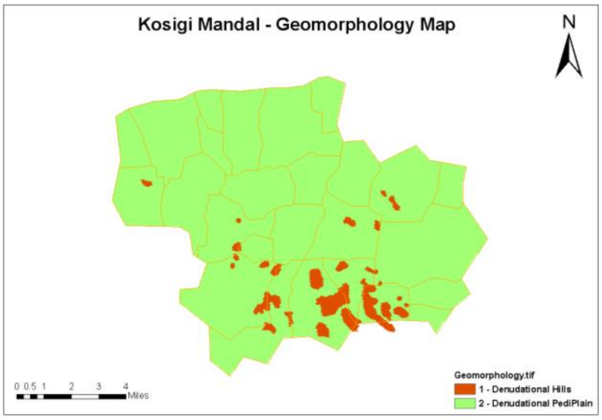

Fig. 6 Geomorphology Map

9. Weighted Overlay Analysis

In many earlier studies of Weighted Index Overlay Analysis (WIOA), different thematic layers have been assigned weights arbitrarily for ground water potential assessment. Since the weights forms the governing criteria, their variation can affect the accuracy of the map generated. In this research, specific weighing scheme has been adopted as Analytic Hierarchy process.

In this study, thematic layers identified for weighted overlay analysis were Drainage Density, Lineament Density and Land use / Land Cover. Subclasses in every thematic layer were derived through reclassification method which is based on natural breaks in data. Relative importance of each individual class within the same thematic map was compared with each other by pairwise comparison method using continuous rating scale developed by Saaty in 1977.

9.1 Deriving the weights using AHP

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. ANP is an extension of AHP for decision making in which a problem is divided into various parameters, arranging them in a hierarchical structure, making judgments on the relative importance of pairs of elements and synthesizing the results (Saaty 1999). In short, AHP is a method to derive ratio scales from paired comparisons. The input can be obtained from subjective opinion such as satisfaction feelings and preference. AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value.

The methodology for deriving the weights to the thematic layers and their corresponding classes using ANP and AHP respectively, involves following steps (Agarwal *et al*, 2013):

Step 1: The problem should be clearly defined and then decomposed into various thematic layers containing the different feature/classes of the individual themes so that form a network of the model.

Step 2: The relative importance values are determined with Saaty's 1–9 scale (table 1), where a score of 1 represents equal importance between the two themes, and a score of 9 indicates the extreme importance of one theme compared to the other one (Saaty 1980).

Table 2 shows a matrix for comparing the classes in order to achieve the priority. A pairwise comparison matrix is derived using Saaty's nine-point importance scale based on thematic layers used for delineation of groundwater potential. Because we have five thematic layers, thus we have 4 by 4 matrix. The diagonal elements of the matrix are always 1 and we only need to fill up the upper triangular matrix. Based on the judgment value by comparing one thematic layer with other upper triangle matrix is filled. To fill the lower triangular matrix, we use the reciprocal values of the upper diagonal. If $\mathbf{a_{ij}}$ is the element of row **i** column **j** of the matrix, then the lower diagonal is filled using this formula

$$a_{ij} = 1/ a_{ji}$$

Thus now we have complete comparison matrix as shown in table2.

Step 3: Having a comparison matrix, now we would like to compute priority vector, which is the normalized Eigen vector of the matrix. The procedure is as given below:

a) Write 4 by 4 reciprocal matrix which is derived from pair comparison
b) Sum each column of the reciprocal matrix
c) Then we divide each element of the matrix with the sum of its column, we have normalized relative weight. The sum of each column is 1.
d) Calculate the normalized principal Eigen vector by averaging across the rows.
e) The normalized principal Eigen vector is also called priority vector. Since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the things that we compare.

Table 1 Saaty's 1-9 scale of relative importance

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal Importance	Weak	Moderate Importance	Moderate Plus	Strong Importance	Strong Plus	Very Strong Importance	Very, Very Strong	Extreme Importance

Table 2 Complete Comparison Matrix

	Drainage Density	Land Use / Land Cover	Lineament Density	Geomorphology
Drainage Density	1.00	2.00	2.00	0.50
Land Use / Land Cover	0.50	1.00	0.50	0.33
Lineament Density	0.50	2.00	1.00	0.50
Geomorphology	2.00	3.00	2.00	1.00
Σ of Column Matrix	**4.00**	**8.00**	**5.50**	**2.33**

Table 3 Normalized Score Table

	Drainage Density	Land Use / Land Cover	Lineament Density	Geomorphology	Σ	Eighen Vector	%
Drainage Density	0.25	0.25	0.36	0.21	1.08	**0.27**	**27**
Land Use / Land Cover	0.13	0.13	0.09	0.14	0.48	**0.12**	**12**
Lineament Density	0.13	0.25	0.18	0.21	0.77	**0.19**	**19**
Geomorphology	0.50	0.38	0.36	0.43	1.67	**0.42**	**42**
Total	**1**	**1**	**1**	**1**	**4**		

Table 4 Saaty's ratio index for different values of n

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Table 5 Calculation of Principal Eigen Value

Thematic Map	**Σ of Column Matrix(1)**	**Eighen Vector(2)**	**(1) x (2)**
Drainage Density	4.00	0.27	**1.08**
Land Use / Land Cover	8.00	0.12	**0.97**
Lineament Density	5.50	0.19	**1.06**
Geomorphology	2.33	0.42	**0.97**
Principal Eigen value, λ_{max}			**4.08**

Step 4: The AHP captures the idea of uncertainty in judgments through the principal eigenvalue and the consistency index (Saaty 2004). Principal Eigen value, λ_{max}, is obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix. Saaty gave a measure of consistency, called Consistency Index (CI) as deviation or degree of consistency using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where λ_{max} is the Principal Eigen value of the pairwise comparison matrix and **n** is the number of classes. Consistency Ratio (CR) is a measure of consistency of pairwise comparison matrix and is given by equation

$$CR = \frac{CI}{RI}$$

where RI is the Ratio Index. The value of RI for different n values is given in table 4.

If the value of CR is smaller or equal to 0.1, the inconsistency is acceptable. If CR is greater than 10%, we need to revise the subjective judgment.

CI = (4.08-1) / (4-1) = 0.026
CR = CI / RI = 0.026 / 0.89 = 0.0292 or 2.92% < 10%.
Hence, it is acceptable

Further, different units of each theme were assigned knowledge-based hierarchy of ranking from 1 to 5. On the basis of their significance with reference to groundwater prospects, where 1 denotes poor prospects and 5 denotes excellent prospect of groundwater. The final weightages and rank of thematic layers and its individual features are shown table 6.

Table 6 Ranks and Weightages for various parameters for Groundwater Potentiality

Priority	Thematic Layer	Weights (%)	Individual Features	Rank	Ground Potentiality
1	Drainage Density	42	Class 1	3	Poor to Moderate
			Class 2	5	Moderate to Good
			Class 3	7	Good
			Class 4	9	Very Good
2	Geomorphology	27	Denudational Hills	1	Poor
			Denudational Pediplains	9	Good
3	Lineament Density	19	Class 1	5	Good
			Class 2	9	Very Good
4	Land Use / Land Cover	12	Built-up Area	1	Poor
			Barren Land	3	Moderate
			Scrub Forest	5	Good
			Plantation / Crop Land	7	Very Good
			River / Pond	9	Excellent

After arriving the above weightages and ranks, groundwater potential zones are obtained using Weighted Overlay Tool of Spatial Analyst Extension. Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. The output map thus arrived by cumulating weightage factors of all the themes shown in seven ground potential zones. To avoid more number of sub categories, several small regions are recoded and are integrated to the nearby broad potential zones. The final map has shown with five groundwater potential zones such as excellent, very good, good, moderate, and poor are shown in Figure 8.

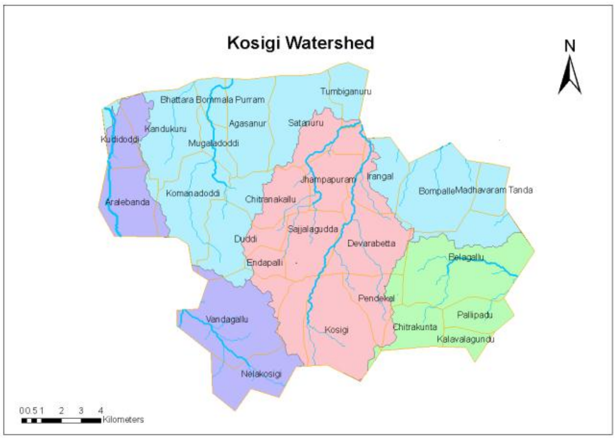

Fig. 7 Kosigi Watershed

Conclusions

Remote Sensing and Geographic Information System (GIS) approach is very constructive. All the thematic maps were converted into grid (raster format) and analyzed by weighted overlay method (rank and weightage wise thematic maps). From the results, the groundwater potential zones with poor (34.76 km^2), moderate (227.91 km^2), good (117.02km^2), very good (36.37 km^2), and excellent (5.20 km^2) prospective zones were identified.

Table 7 Groundwater Potential Zones

Zone	Area in km^2	%
Poor	34.76	8.25%
Moderate	227.91	54.10%
Good	117.02	27.78%
Very Good	36.37	8.63%
Excellent	5.20	1.23%

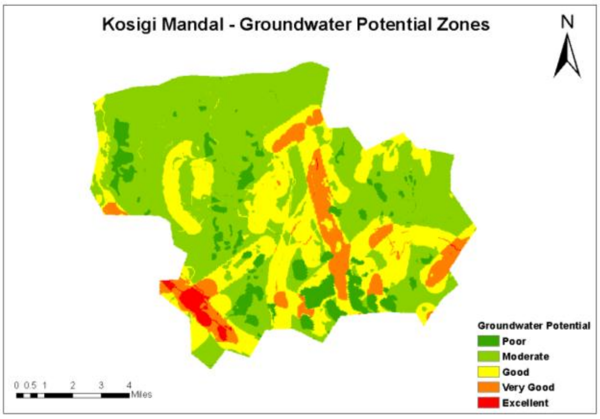

Fig. 8 Ground Potential Zones

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