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Application of geospatial technology for estimation of groundwater potential zone

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Abstract
Groundwater is an important resource contributing significantly in total annual supply. Assessing the potential zone of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. Groundwater potential zones are demarked with the help of RS and GIS techniques. In this study a standard methodology is adopted to determine groundwater potential. The composite map are generated using GIS tools for identifying the groundwater potential zone such as slope, drainage density, rainfall and land use/land cover. These are integrated with weighted overlay in ArcGIS. Suitable ranks are assigned for each category of these parameters. For the various geomorphic units, weight factors are decided based on their capability to store groundwater and resultant layers are reclassified. The groundwater potential zones are classified into five categories viz very poor, poor, moderate, good and excellent. The use of suggested methodology is demonstrated for a selected study area in Dapoli, Ratnagiri district. Groundwater potential information will be useful for effective identification of suitable locations for extraction of water.

Keywords: RS, GIS, Groundwater, potential zones

Introduction
Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. Water has become an immensely important and dependable source of water supplies because of its several inherent qualities in all climatic regions. Groundwater is a form of water occupying all the voids within a geological stratum. Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storing water. The groundwater occurrence in a geological formation and the scope for its exploitation primarily depends on the formation of porosity. An area of high drainage density increases surface runoff compared to a low drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones. Over the periods the growing importance of groundwater based on increasing need has led to unscientific exploitation of groundwater creating a water stress condition. This alarming situation calls for a cost and time effective technique for proper evaluation of groundwater resources and management planning. A groundwater developing program requires a large volume of data from various sources. Hence, identification of these features is important for generating a groundwater potential model of a study area. Currently groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and low cost of development it requires. Despite the extensive research and technological advancement, the study of groundwater has remained more risky, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters. The different hydrogeological themes can be used to identify the groundwater potential zone of the present area. Aquifers containing groundwater in the sub-surface are highly localized and change spatially. Mukherjee *et al*. (2012) [6], Bagyaraj *et al*. (2013) [1] made an attempt to demarcate the groundwater potential zones. Therefore, researchers are highly interested towards mapping the different potential areas for groundwater.
Remote Sensing and GIS techniques play a crucial role in the assessment of Earth's natural resources. These techniques are highly cost-effective and less time-consuming to understand the groundwater potential of a region the main reason is the availability of satellite data which make the analysis easier compared to the traditional techniques such as ground drilling, geophysical assessment of lineaments and field observations (Das *et al*. 2018) [2]. Moore and Deutsch, 1975 [5] and Saha, *et al*. 2010 [7] used Geographical Information System platform to

generate thematic layers for demarcating groundwater development potential zones.

Groundwater potential mapping is more complex and challenging due to the highly variable geological conditions in the hard-rock region. The demarcation of the groundwater prospect areas in the Deccan Trap region of Maharashtra, covered by basalt, is still not studied well. Hence, an attempt has been made in this study to determine the Groundwater Potential Zones of Dapoli by using Remote Sensing (RS) and Geographic Information System (GIS) and to prepare the groundwater potential maps for future planning, management, utilization and conservation of groundwater resources in Dapoli.

Materials and Methods

Study Area: Dapoli is Geographically, situated 17° 46' 0.12" N latitude and 73° 10' 59.88" E longitude, in Ratnagiri district, Maharashtra, India, encompassing an area about 180 Km^2. The study area lies on 168 m above mean sea level. The rainfall here is around 3109 mm. The averages temperature is 27 °C. Map of Study Area is shown in Fig 2.

Methodology

The methodology of study involved various activities viz. base map preparation, LULC map preparation, digitization and image processing using software and interpretation of the outputs. First stage includes development of spatial data base by using Survey of India (SOI) toposheet on a 1: 50000 scale. GIS and remote sensing technology is applied to prepare various thematic maps with reference to groundwater viz. drainage density, contour and stream length. The second stage involved preparation of digital elevation model (DEM) by interpolating contour map. DEM is used to prepare slope, aspect, flow accumulation and stream order. In the third stage, digital image processing of the satellite data is done for geo-referencing and geometric correction. This is followed by creation of different thematic layers using supervised classification technique. In the fourth stage, all thematic layers are analyzed in overlay and ranking is given to evaluate suitable groundwater potential zone. The methodology is depicted in Fig.1. In the present study, slope, drainage density, Land use and land cover, rainfall and soil are considered for the identification of groundwater potential. All the thematic layers were overlay to find out the final integrated output map of groundwater potential zones.

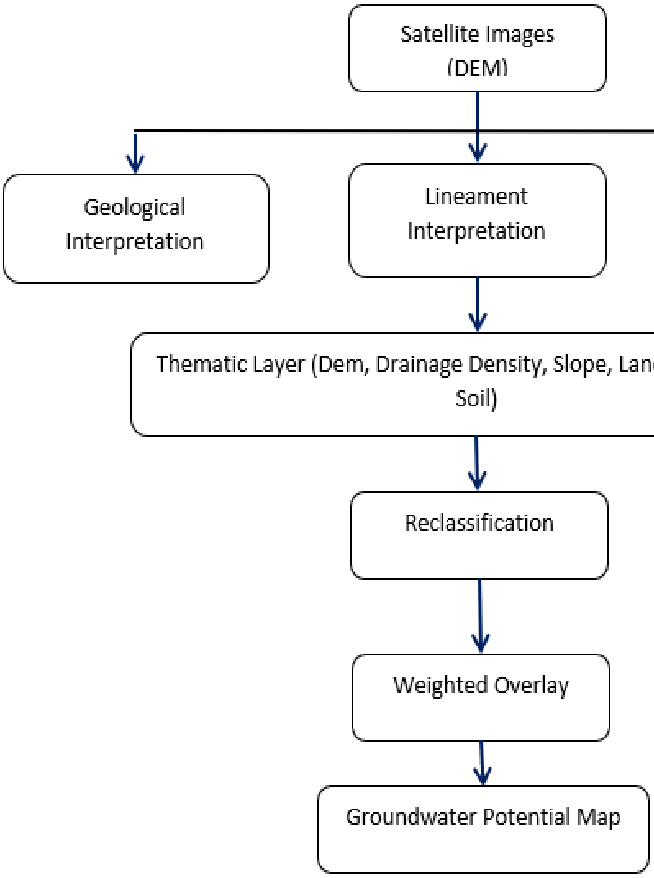

Fig 1: Flow Chart

Factors Influencing Groundwater

Digital Elevation Model (DEM)

A digital elevation model (DEM) is a 3D computer graphics representation of elevation data to represent terrain. A "global DEM" refers to a discrete global grid. DEM are used for digitally produced relief maps is shown in Fig. 3.

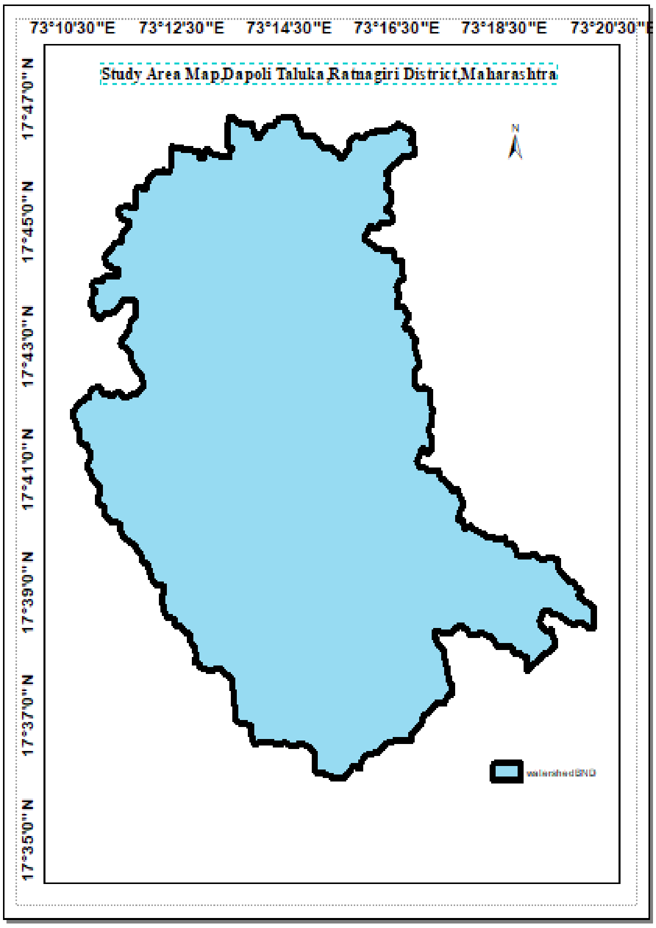

Fig 2: Map of Study Area

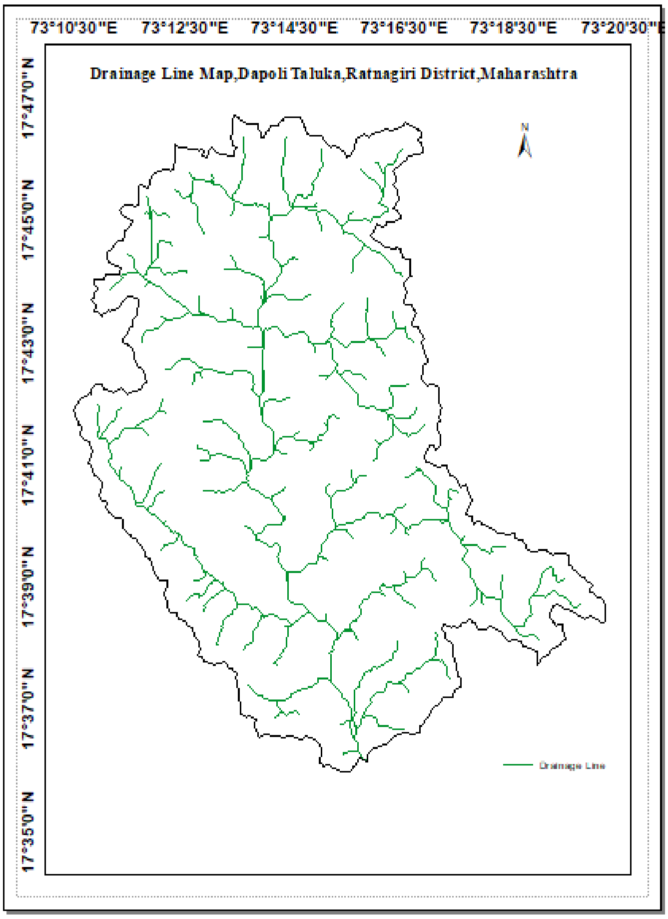

Fig 4: Drainage network Map

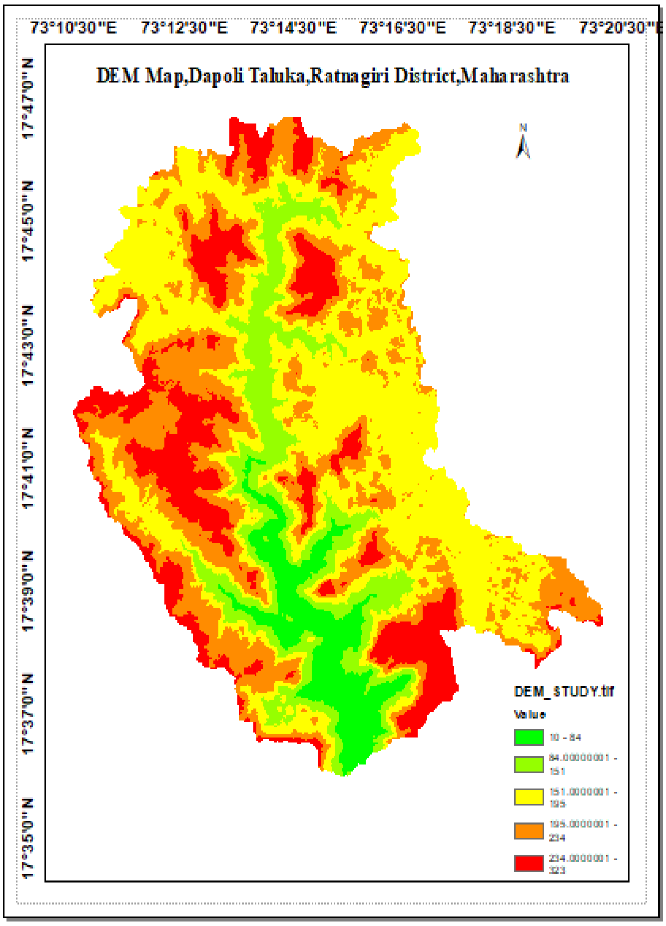

Fig 3: DEM Map

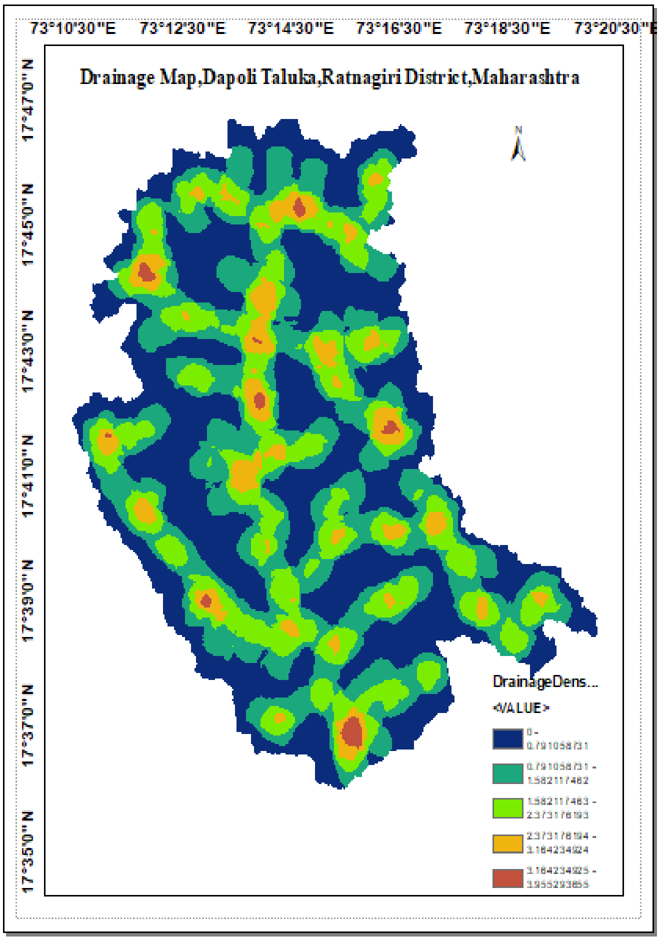

Fig 5: Drainage Density Map

Drainage network: Drainage network Map of study area is shown in Fig 4. Drainage density map was extracted from Drainage network Map. Drainage network helps in delineation of watersheds. Drainage density and type of drainage gives information related to runoff, infiltration relief and permeability. The coarse drainage texture indicates highly porous and permeable rock formations; whereas fine drainage texture is more common in less porous formations. Flow of groundwater along these week zones is an established fact. Drainage pattern reflects surface characteristics as well as subsurface formation.

Drainage Density: Drainage density is the ratio of total stream length of all the orders per unit basin area (Horton 1945).

$$D_d = \frac{\sum_{i=1}^{K}\sum_{i=1}^{N} Lu}{Au}$$

Where,
D_d=drainage density
L_u=Length of stream segments
A_u=basin area, km^2
K=trunk order of the stream segment
N=total no. of streams
The watersheds can be grouped into five categories on the basis of drainage density as Very low (below 0.79 km km^{-2}), Low (0.79 -1.58 km km^{-2}), Moderate (1.58 - 2.37 km km^{-2}) and high (2.37 - 3.16 km km^{-2}) Very High (Above 3.16 km km^{-2}) as shown in Table 1. Drainage density Map of study area is shown in Fig 5. Low drainage density is observed in regions of highly resistant or permeable soil material under dense vegetation cover and low relief. High drainage density is observed in the regions of weak and impermeable subsurface material and sparse vegetation.

Table 1: Drainage Density Category

Class	Km/Km^2	Drainage Density Category
1	0-0.79	Very Low
2	0.791-1.58	Low
3	1.58-2.37	Moderate
4	2.37-3.16	High
5	>3.16	Very High

Slope: The slope is one of the important factors which control the groundwater potential of a region. Rapid run-off occurs in the case of steep slope due to the higher velocity of the water. On gentle slope region, the water becomes stagnant in a particular place for a longer duration which influences water to penetrate into soil layers. Slope is one of the important terrain parameters which are explained by horizontal spacing of the contours. In general, in the vector form closely spaced contours represent steeper slopes and sparse contours exhibit gentle slope whereas in the elevation output raster every cell has a slope value. Here, the lower slope values indicate the flatter terrain (gentle slope) and higher slope values correspond to steeper slope of the terrain. In the elevation raster, slope is measured by the identification of maximum rate of change in value from each cell to neighboring cells. The slope values are calculated either in percentage or degrees in both vector and raster forms. The slope amount derived from digitized contours and spot heights have shown that elevation decreases from the river to flat area.
Slope Map of study area is shown in Fig 6. In the nearly level slope area (0-4) degree, the surface runoff is slow allowing more time for rainwater to percolate and consider good groundwater potential zone, where as strong slope area (20-46) degree, facilitate high runoff allowing less residence time for rainwater hence comparatively less infiltration and poor groundwater potential. The entire slope map is divided into five categories as in Table 2.

Table 2: Slope Category

Class	Degree	Slope Category
1	< 4.20	Very Gentle Slope
2	4.20-8.96	Gentle Slope
3	8.96-14.08	Moderate Slope
4	14.08-20.66	Steep Slope
5	20.66-46.457	Very Steep Slope

Soil: Soil texture and depth are having a major impact on the groundwater potentiality of an area. Soil distribution map of the Dapoli will be prepared from the soil map of Maharashtra.Soil distribution map of the Dapoli was prepared from the soil map of Maharashtra. Soil Map of study area is shown in Fig 7. The major soil texture found in the study area is loam. The thickness of soil varies place to place.

Rainfall: The average annual rainfall is around 3109 mm. The average annual rainfall distribution in the study area is shown in Fig. 8. Monsoon rain occurs from June to September in Dapoli and the rainfall starts decreasing gradually from the October month of the year.

Land Use and Land Cover (LULC): Land use involves an element of human activity and reflects human decisions about its use. Land cover refers to the vegetative characteristics or man-made constructions on the land's surface. Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it and land cover is the observed biophysical cover on the earth's surface.

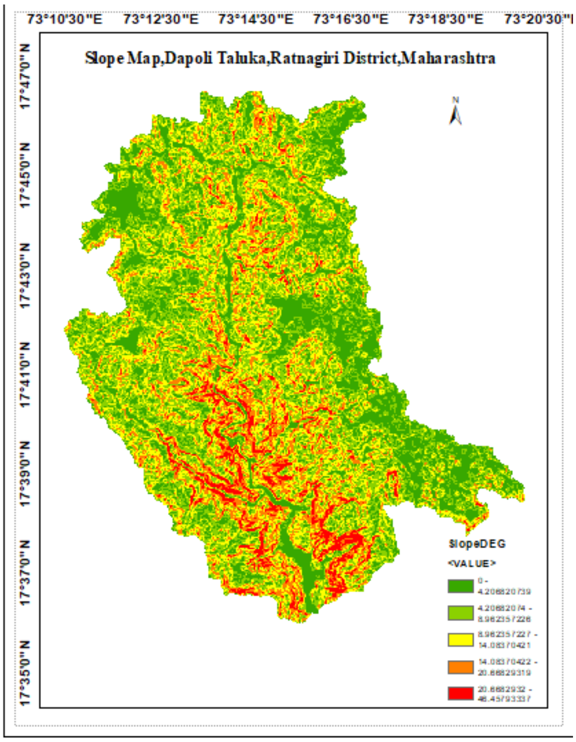

Fig 6: Slope Map

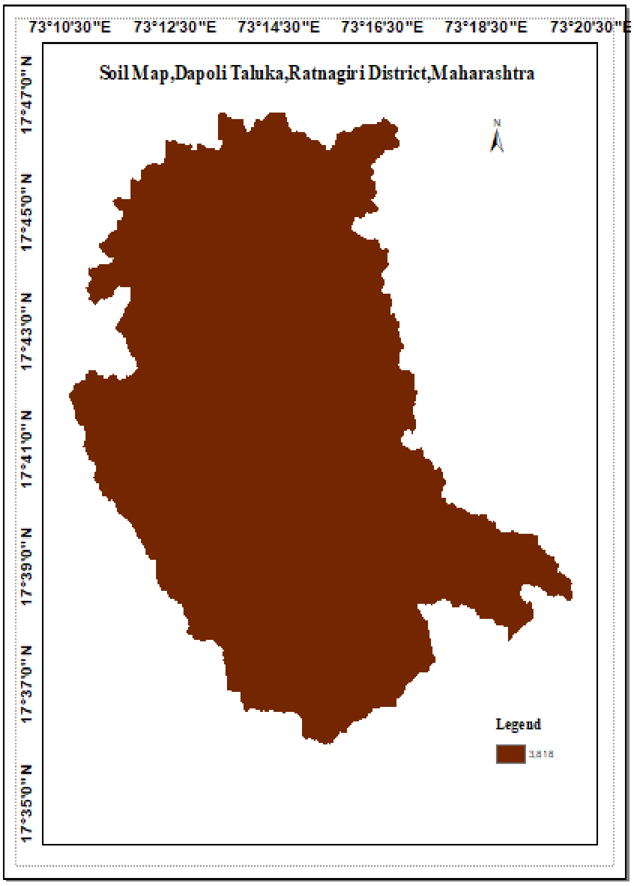

Fig 7: Soil Map

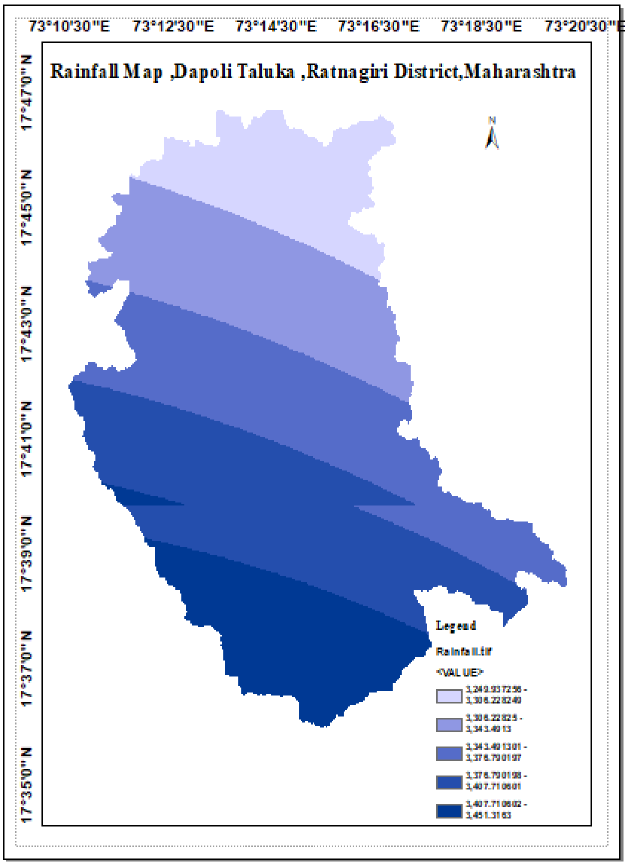

Fig 8: Rainfall Map

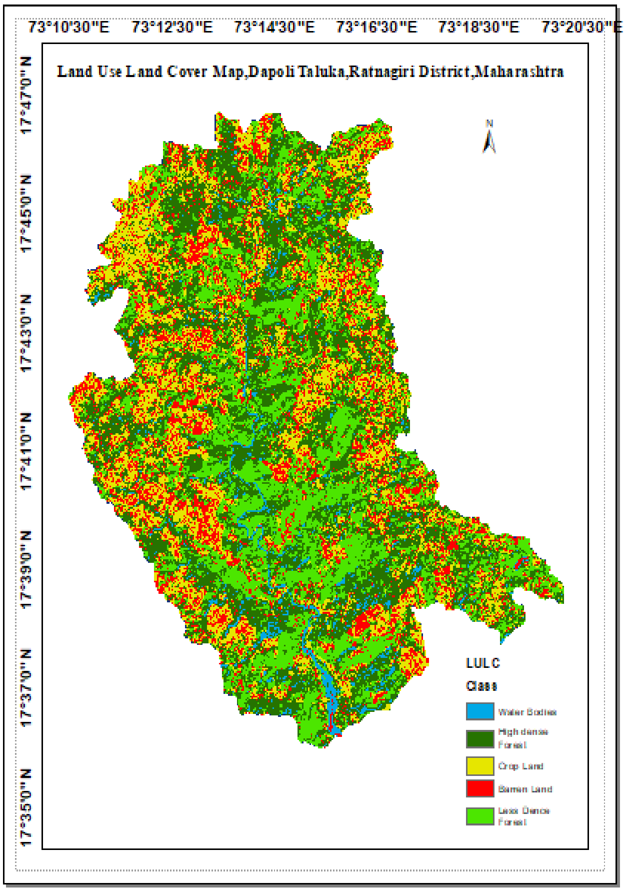

Fig 9: LULC Map

Table 3: Land Use/Land Cover Classification

S. No.	Type of Land	Area (Km^2)	Area (%)
1	Water Bodies	5	2.77
2	High Dense Forest	64	35.55
3	Crop Land	37	20.55
4	Barren Land	29	16.11
5	Low Dense Forest	45	25

Land use/land cover mapping is one of the important applications of remote sensing. Land use plays a significant role in the development of groundwater resources. It controls many hydrogeological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff etc. Surface cover provides roughness to the surface, reduce discharge thereby increases the infiltration. Remote sensing provides excellent information with regard to spatial distribution of vegetation type and land use in less time and low cost in comparison to conventional data. Unsupervised classification of study area shows that major portion in land use is crop land covering area 37 km^2 High Dense Forest land covering area 64 km^2 Barren land covering area 29 km^2, water body covering area 5 km^2 as shown in Table 3 and same depicted in Fig 9.

Assigning Rank and Weight: The groundwater potential zones are obtained by overlaying all the thematic maps in terms of weighted overlay method using the spatial analysis tool in ArcGIS 10.3. During the weighted overlay analysis, the ranks have been given for each individual parameter of each thematic map and the weight is assigned according to the influence of the different parameters. The weights and rank have been taken considering the works carried out by researcher's viz. Krishnamurthy *et al.* (1996) [4], Saraf and Chowdhary (1998).

All the thematic maps are converted into raster format and superimposed by weighted overlay method. The drainage density and DEM were assigned higher weight, whereas the slope and soil were assigned lower weight. After assigning weights to different parameters, individual ranks are given for sub variable. In this process, the GIS layers on slope and drainage density were analyzed carefully and ranks are assigned to their sub variable.

The maximum value is given to the feature with highest groundwater potentiality and the minimum given to the lowest potential feature. The higher rank factors are assigned to low drainage density because the low drainage density factor favors more infiltration than surface runoff. Lower value followed by higher drainage density As far as slope is concerned, the highest rank value is assigned for gentle slope and low rank value is assigned to higher slope. In LULC high rank is assigned to crop land and low value is assigned to barren land. The overall analysis is tabulated in Table 4.

Table 4: Rank and weight for different parameter of groundwater potential zone

Parameter	Classes	Groundwater Prospect	Weight,%	Rank
DEM	10-84	Very Good	30%	5
	84. 0001-151	Good		4
	151. 0001-195	Moderate		3
	195. 0001-234	Poor		2
	234. 0001-323	Very Poor		1
Slope Classes	< 4.21	Very Good	5%	5
	4.21-8.96	Good		4
	8.96-14.08	Moderate		3
	14.08-20.67	Poor		2
	20.67-46.46	Very Poor		1
Land Use/Land Cover	Water Bodies	Very Good	10%	5
	High Dense Forest	Moderate		3
	Crop Land	Good		4
	Barren Land	Poor		2
	Low Dense Forest	Poor		2
Rainfall	3,249.94 - 3,306.23	Very Poor	15%	1
	3,306.24 - 3,343.49	Poor		2
	3,343.5 - 3,376.79	Moderate		3
	3,376.8 - 3,407.71	Good		4
	3,376.8 - 3,407.71	Very Good		5
Drainage Density	0-0.79	Very Good	30%	5
	0.79-1.58	Good		4
	1.58-2.37	Moderate		3
	2.37-3.16	Poor		2
	3.16-3.96	Very Poor		1
Soil	3818	Moderate	10%	3

Delineation of Groundwater Potential Zone

By using remote sensing and GIS, several influencing factors such as Drainage Density, Soil, slope and rainfall were integrated to demarcate groundwater potential zones in Dapoli, Maharashtra. All these factors were grouped, and the weighted overlay was performed using influencing factors and frequency ratio techniques.

Table 5: Groundwater Potential Zone of Study Area

Sr. No	Potential Zone	Area (Km^2)	Area (%)
1	Excellent	1	0.55
2	Good	20	11.12
3	Moderate	68	37.78
4	Poor	82	45.56
5	Very Poor	5	2.77

Depending on the results that came out in ArcGIS, the entire study area was divided into five categories of different groundwater potentials: excellent, high, moderate, low and very low. Fig.10 illustrates the groundwater recharge potential map of the Dapoli through influencing factor technique. The study area is classified as excellent, good, moderate, poor and very poor groundwater potential zones and indicated in Fig.10.

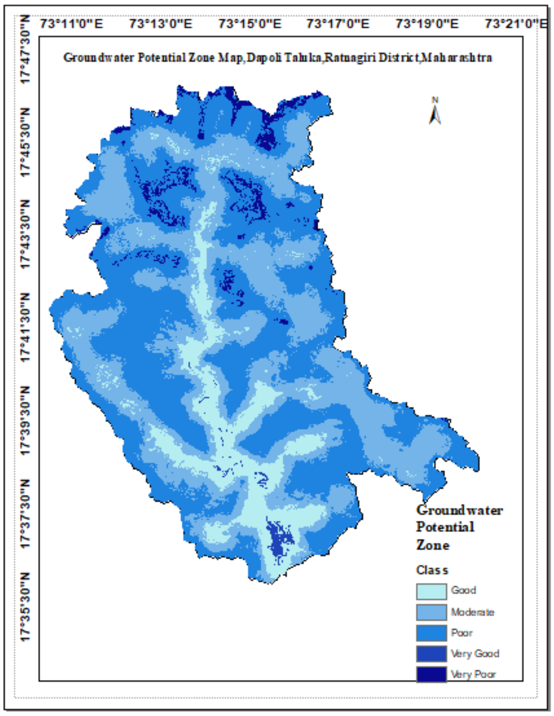

Fig 10: Groundwater Potential Zone of Dapoli

As per Table 4 and 5, it can be seen that area having slope 0 to 4.20, drainage density 0 to 0.79 under High Rainfall and cover with crop land is observed as excellent groundwater potential zone and covers area 1 km2. The area having slope 4.2 to 8, drainage density 0.79 to 1.58, water body and cover with crop land is observed as good groundwater potential zone and covers area 20 km^2. The area having slope 8.9 to 14, drainage density 1.58 to 2.3 and area cover with crop and low dense forest is observed as moderate groundwater potential zone and covers area 68 km^2. The area having slope 14 to 20, drainage density 2.3 to 3.16 and barren land is observed as poor groundwater potential zone and covers area 82 km^2 and the area having slope 20.66 to 46.45, drainage density 3.16 to 3.96 and area cover with barren land is observed as very poor groundwater potential zone and covers area 5 km^2. The study shows that given area is having moderate groundwater potential zone this is because steep slope of area and soil arrangement.

Conclusions

Geographical information system and remote sensing has proved to be powerful and cost effective method for determining groundwater potential in Dapoli district Ratnagiri. The study reveals that integration of six thematic maps viz. drainage density; slope, DEM, Rainfall, Soil and land use/land cover gives first-hand information to local authorities and planners about the areas suitable for groundwater exploration.

By implementing influencing factor, it is observed that about 0.55%, 11.12%, 37.78%, 45.56% and 2.77% areas are falling under excellent, high, moderate, poor and very poor groundwater potential zones, respectively. The central and Southern parts of the study area show good-to-moderate groundwater potentiality as this region shows very gentle slope, high rainfall, low drainage density which influence rapid infiltration process into the sub-surface. Northern Parts of the Dapoli reflects poor groundwater potential as the region is having very steep slope.

This groundwater potential information will be useful for effective identification of suitable locations for extraction of water.

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