Delineation of Groundwater Recharge Potential Zones Using Geo-Spatial Technique

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Abstract - *Water is one of the basic needs of any region for sustainable economic development and progress. There are various limitations regarding availability of surface and subsurface water, hence exploration of groundwater becomes inevitable. This study is aimed to trace the new water resources using Geo-spatial technique. The thematic layers considered in this study are geomorphology, soil, land use land cover, slope, drainage density and rainfall using satellite data and ancillary data. The thematic layers were digitized from satellite imagery supported by ancillary data such as toposheets. Finally the thematic layers were integrated using ArcGIS software to generate a map showing groundwater recharge potential zones in the study area. Groundwater recharge potential zones were identified, namely 'good', 'moderate' and 'poor' using multi-criteria weighted overlay analysis by knowledge based assigned weightage and ranked influence factors. The results obtained based on geo-spatial technique are verified using field conditions of the study area. It is concluded that the geospatial technique is very efficient, time and cost effective and useful for identification of groundwater potential zones for exploration.*

Key Words: groundwater, potential zones, Recharge, geo-spatial, multi-criteria analysis

1.INTRODUCTION

Groundwater is one of the most valuable natural resources, which supports human health, economic development, and ecological diversity. The prevention of contamination of groundwater and managing its use will ensure the quality does not get affected as it is an essential part of ecological cycles and human needs. The frequency of groundwater flow is influenced by two properties of the rock: porosity and permeability. Rainfall in India is erratic, uneven, and uncertain due to which groundwater recharge becomes unpredictable and uncontrolled Groundwater occurrence is in pockets/zones of hard rock terrains, and it is therefore necessary to locate such zones and increase the quantum of groundwater recharge Need to identify the trend of distribution of groundwater recharge on watershed scale using advanced technology like Geospatial techniques Remote Sensing and Geospatial techniques are innovative tools available to the researchers for scientific study of distribution of groundwater recharge on watershed scale. Proper planning and efficient management for groundwater recharge is of utmost importance.

2. LITERATURE REVIEW

In recent times, many researchers such as Meijerink et al. (1996), Scanlon et al. (2002), Yeh et al. (2009 & 2015), Patil et al. (2014 & 2019), Sharma (2016) and Tripathi (2017) have used the approach of remote sensing and GIS for identification of groundwater prospect zones and delineating the potential recharge for the selected area. Vidhya and Vinay Kumar (2018) have used the GIS technique for identification of groundwater potential zones using nine parameters and then to delineate groundwater potential zones. Devanatham et al. (2020), Derdour (2022), Patil et al. (2014), Yeh et al. (2009) have used GIS to delineate groundwater potential zones. Patil et al. (2019) have applied remote sensing and GIS for processing and identification of groundwater potential recharge zones and identification of sites for artificial recharge structures.

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 methods for combining the information obtained by analysing multi-source remotely sensed data in a GIS environment for better understanding the groundwater resource for a micro watershed, designated by Groundwater Surveys and development Agency (GSDA), Govt. of Maharashtra, in Pune district, Maharashtra, India.

STUDY AREA

The study area is a watershed in the Pune district of Maharashtra, covering about 120 sq. km, which lies in between latitudes 18° 25' 0'' to 18° 27' 30'' N and longitudes 74° 15' 0'' to 73° 17' 30'' E. The location map of the study area is shown in the Figure 1. The study area is surrounded by hills, plateau and valleys. Geologically majority of area is falls under the Deccan Trap Basalt. Temperature in the study area ranges from 10° C (minimum) to 40° C (maximum). Average annual rainfall in the study area is 500 to 700 mm. Humidity ranges from 30 % as low in summer to 75 % high in rainy season. Wind ranges from light to moderate during dry season.

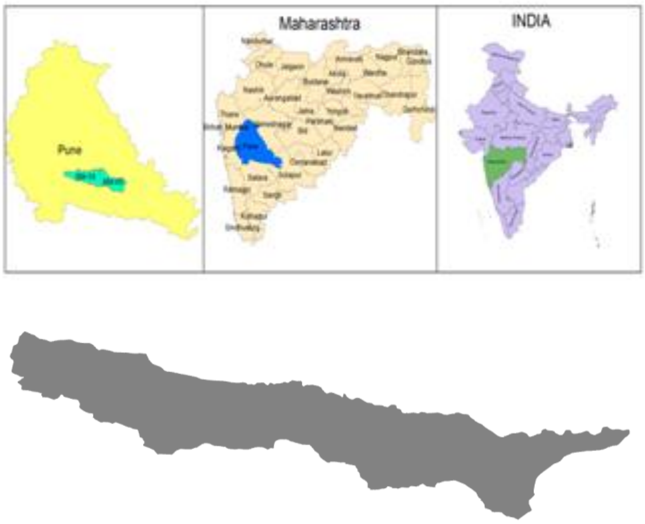

Figure 1: Location Map of the Study Area

Methodology

Methodology adopted in the present study is given in the Figure 2. Survey of India's toposheets are first geocoded with the help of known ground control points (GCPs) and mosaiced all the four toposheets. The boundary map of study area created using ArcGIS software based on watershed boundary. Mosaiced toposheets were clipped using boundary map. The IRS P6 LISS-III satellite data was registered with SOI toposheets on 1:50000 scale using ArcGIS software through map to image registration technique. The standard False Colour Composite (FCC) was generated for better visualization and delineation of thematic layers. Linear, equalization and root enhancement techniques were applied to enhance the satellite imagery for better interpretation of the geomorphological, soil, structural, land use land cover and other information.

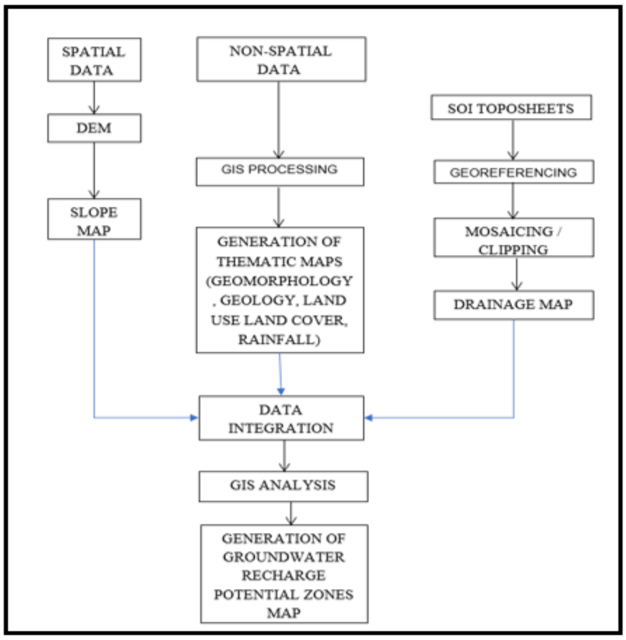

Figure 2: Overall Methodology of the Study

Data

1) Survey of India toposheets
2) LandSat 9 spatial data acquired
3) ASTER GDEM 30 m (USGS/NASA ASTER DEM data available from the website as below: http:// www.gdem.aster.ersdac.or.jp)

The thematic maps of (i) Geomorphology, (ii) Soil, (iii) Land Use Land Cover, (iv) Drainage Density, (v) Slope and (vi) Rainfall were prepared at 1:50000 scale using remote sensing and ancillary data. From Aster DEM 30 m, thematic slope map was generated. Survey of India toposheets and LandSat 9 satellite imagery were used to prepare various thematic maps in ArcGIS environment. ArcGIS software was used for digitization, editing, and topology creation of various features/layers. The groundwater recharge potential zones map was generated using Multi-Criteria Analysis i.e. overlay analysis tool provided in the ArcGIS software. Spatial analysis and knowledge based ranks and weightages to different features for delineating groundwater recharge potential zones are described below:

Spatial Analysis

This is a significant process using study of locations of geographic phenomena together with their dimensions and attributes, classification, ranking and weightage assignment to individual and feature classes respectively. All thematic maps, such as geomorphology, soil, slope and land use land cover map, drainage density and rainfall map have been prepared and duly assigned rankings for individual class and weightages to themes depending upon its influence on groundwater occurrence and movement. Each theme such as geomorphology, soil, land use-land cover, soil, rainfall and slope map provide certain clue regarding groundwater occurrence and movement in the study area, which is evident from the initial study. These thematic layers are used to generate thematic maps for conducting multi-criteria analysis by intersecting polygons. Using weighted overlay analysis, groundwater recharge potential zones map is generated which is integration of various feature classes from different thematic maps. Weighted overlay analysis is a technique to be applied for various divergent input themes to bring them into the unique convergent output. The groundwater recharge potential zones map (Figure10) was generated through overlay analysis and broadly categorized into three types viz. good, moderate and poor, from groundwater prospecting point of view.

Results and Discussion

1. Results

i. Geomorphology

Geomorphological mapping involves the identification and characterisation of various landforms and structural features. Many of these features are favourable for occurrence of groundwater and are classified in terms of groundwater potentiality. Geomorphic units are delineated based on the image characteristics such as tone, texture, shape, colour and associations.

(Fig. 3) shows geomorphology map of the study area, as below.

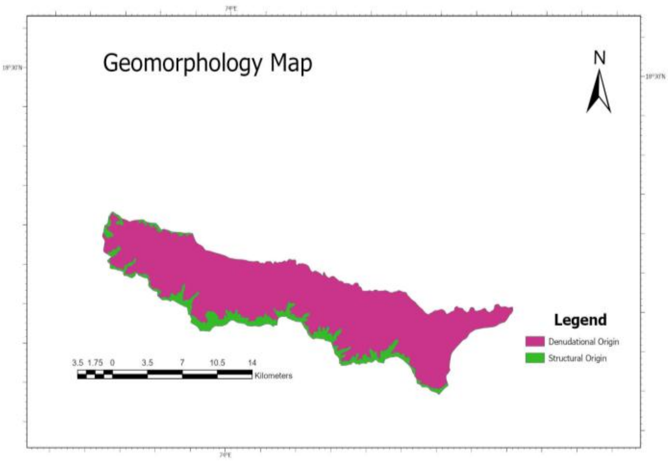

Figure 3. Geomorphology map

The rankings were assigned to the individual landform, according to their respective influence of groundwater holding, as shown in (Table 1).

Table 1: Rankings for geomorphologic units

Influence Factor	Sub-Class	Ranking (In Word)	Ranking (In Number)
Geomorphology	Structural Origin	Poor	3
	Denudational Origin	Good	1

ii. Soil

The study area is prominently consisting in the basaltic region of Maharashtra and falls partly in the hills and partly in regur and alluvium soil. By extraction of various classes of soil types, a thematic map for soil is generated as shown in (Fig. 4).

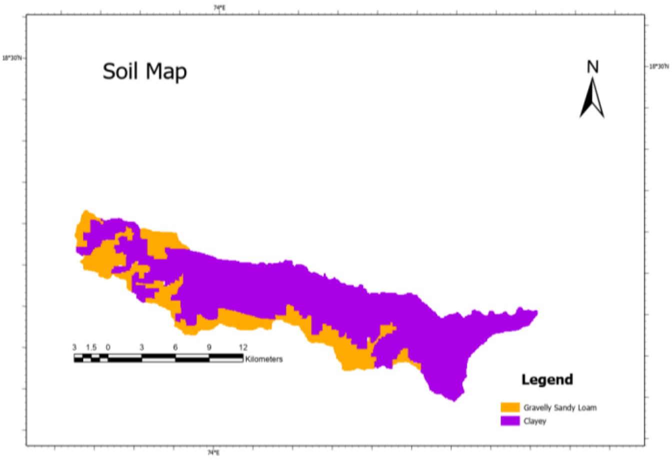

Figure 4. Soil map

The rankings are assigned to the individual landform, according to their respective influence of groundwater holding as shown in (Table 2).

Table 2: Rankings for soil

Influence Factor	**Sub-Class**	**Ranking (In word)**	**Ranking (In number)**
Soil	Gravelly Sandy Loam	Good	1
	Clayey	Moderate	2

iii. Slope

Slope of any terrain is one of the factors controlling the infiltration of groundwater into subsurface or in other words recharge. In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas, steep slope area facilitates high runoff allowing less residence time for rainwater to percolate and hence comparatively less infiltration. The slope map of the study area is derived from ASTER DEM 30 m and slope of the study area is classified into five classes as shown in (Fig. 5).

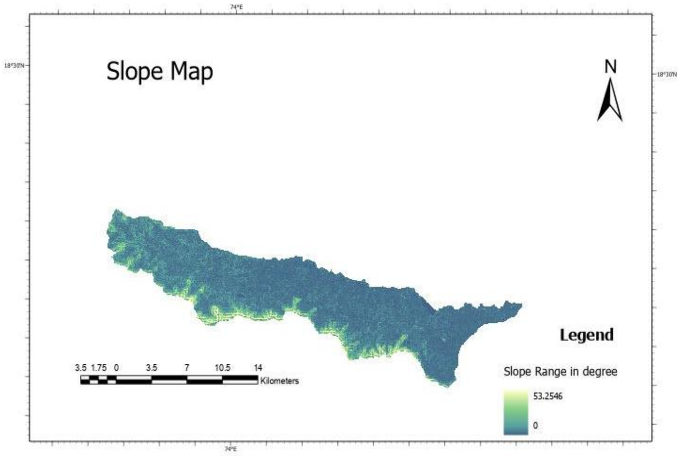

Figure 5. Slope map

(Table 3) shows rankings assigned to the individual slope class, according to their respective influence of groundwater holding.

Table 3: Rankings for percent slope

Influence Factor	Sub-Class	Ranking (In word)	Ranking (In number)
Slope (In Degrees)	0 - 20	Good	1
	20 - 35	Good	1
	35 - 45	Moderate	2
	45 - 55	Poor	3

iv. Land Use Land Cover (LULC)

Land use land cover features control the occurrence of groundwater with variety of classes among itself. Remote sensing data and techniques provide reliable, accurate baseline information for land use land cover mapping, which plays vital role in determining land use pattern and changes therein on different times. The effect of land use land cover is manifested either by reducing runoff and facilitating, or by trapping water on their leaf. Water droplets trapped in this way go down to recharge groundwater. Land use land cover plays important role in the groundwater management. Land use land cover map is shown in (Fig. 6).

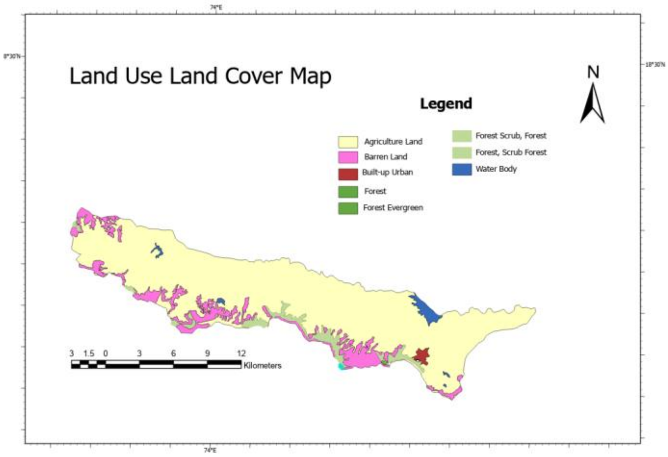

Figure 6. Land use land cover map

The rankings are assigned to the individual land use land cover type, according to their respective influence of groundwater holding, as shown in (Table 4).

Table 4: Rankings for land use land cover

Influence Factor	**Sub-Class**	**Ranking (In word)**	**Ranking (In number)**
Land use land cover	Agricultural land	Good	1
	Barren land	Poor	3
	Urban Built up	Very Poor	5
	Forest Evergreen	Moderate	2
	Scrub Forest	Poor	3
	Water body	Good	1
	Forest	Moderate	2

v. Drainage Density

Drainage density acts as important parameter for analysis of a drainage basin. Drainage density also has a bearing on the permeability of the rocks. Using grids, drainage density map for the study area was prepared, which is divided into three classes. The area of very high drainage density represents more closeness of drainage lines and vice-versa. The higher the drainage density, thus less infiltration and more surface runoff.

By extraction of drainage density features, a thematic map is generated, classified into four zones according to their respective drainage density, as shown in (Fig. 7).

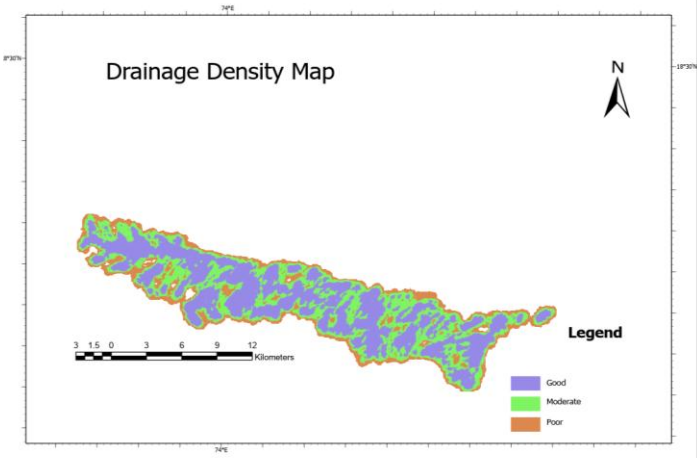

Figure 7. Drainage density map

The rankings are assigned to the drainage density class, according to their respective influence of groundwater holding as shown in (Table 5).

Table 5: Rankings for drainage density

Influence Factor	Sub-Class	Ranking (In word)	Ranking (In number)
Drainage density (In km/sq. km.)	0 – 0.01	Good	1
	0.01 - 1000	Moderate	2
	1000 - 2000	Poor	3

vi. Rainfall

Rainfall is the main source for groundwater recharge and have major impact over groundwater regime and plays important role in the groundwater development, exploration and management. The study area falls under rain-shadow region, having average annual rainfall upto 750 mm; which is below the average annual rainfall of 1100 mm for Pune district. Rainfall map generated is shown in (Fig. 8).

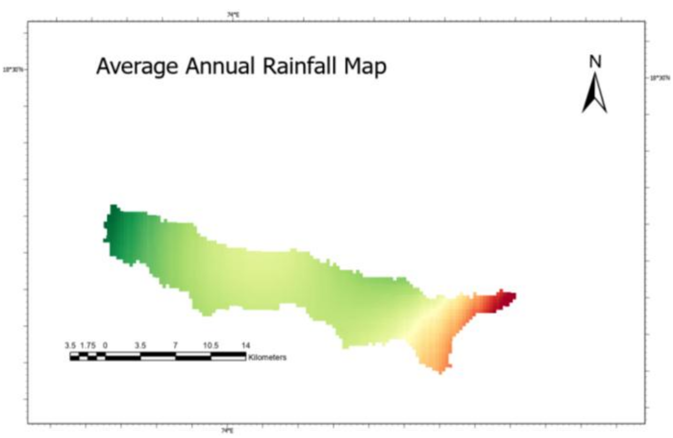

Figure 8 Drainage density map

The rankings are assigned to the rainfall class, according to their respective influence of groundwater holding as shown in (Table 6).

Table 6: Rankings for rainfall

Influence Factor	Sub-Class	Ranking (In Word)	Ranking (In Number)
Rainfall (Average Annual- in mm)	500 - 620	Poor	3
	620 - 700	Moderate	2
	700 - 750	Good	1

Multi-Criteria Analysis (Weighted Overlay)

Overlay analysis is multi-criteria analysis where analysis is carried out with complex things for finding out certain theme with the help of assignment of ranking to the individual class of feature and then assigning weightage to the individual feature considering its influence over theme.

Overlay analysis was carried out, using ArcGIS software, to integrate various thematic maps viz. geomorphology map, soil map, slope map, land use land cover map, drainage density map and rainfall map, which are being very informative and plays important role in the study of occurrence and movement of groundwater for delineation of groundwater recharge potential zones for the study area.

All the thematic maps have been converted into raster format and assigned different weightages of numerical values as shown in (Table 7). Thematic raster maps have been integrated in the GIS environment and derived the groundwater prospect zones based on different ranking and weightages. The groundwater prospect zones map has been categorized into three major types viz. poor to good groundwater potential zones (Figure 9).

Table 7: Rankings and Weightages for Influence Factors

Sr. No	Influence Factor	Sub-Class	Ranking (In Word)	Ranking (In Number)	Weightage (%)
1	Land use land cover	Agriculture Land	Good	1	15
		Barren Land	Poor	3	
		Urban Built-Up	Very Poor	4	
		Forest Evergreen	Moderate	2	
		Scrub Forest	Poor	3	
		Water Body	Good	1	
		Forest	Moderate	2	
2	Geomorphology	Structural Origin	Moderate	2	25

		Denudational Origin	Good	1	
3	Slope	0 to 5	Good	1	10
		5 to 15	Moderate	2	
		15 to 25	Moderate	2	
		Above 25	Very poor	4	
4	Rainfall in mm	500 to 600	Moderate	2	25
		Above 600	Good	1	
5	Drainage Density	1 to 2	Very Poor	4	15
		2 to 3	Poor	3	
		3 to 4	Moderate	2	
		Above 4	Good	1	
6	Soil	Clayey	Moderate	2	10
		Gravelly Sandy Loam	Good	1	

Using above ranks and weightages for various groundwater controlling factors and their classes a groundwater prospect zones map was obtained with the help of ArcGIS software by Multi-Criteria Analysis (i.e. weighted overlay analysis) in GIS environment, which is shown in (Fig. 9).

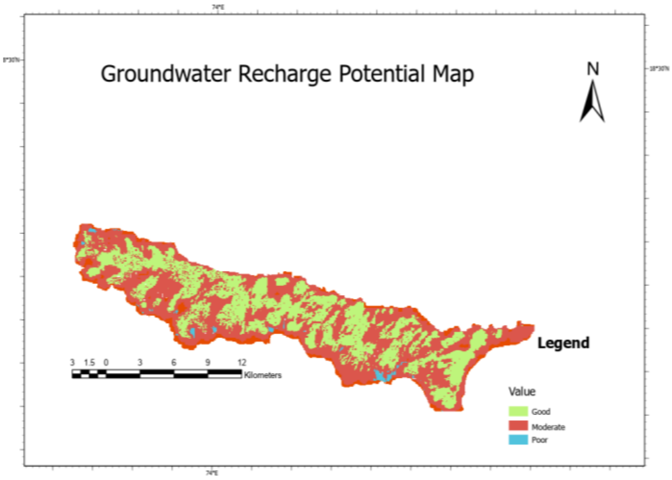

Figure 9. Groundwater Recharge Potential Zones map

3. CONCLUSIONS

From the results obtained from the GIS analysis conducted it is revealed that the occurrence of groundwater in the study area is controlled by geomorphology, land use land cover and slope. Geo-spatial techniques have been used to integrate various thematic maps which are very important to delineate the groundwater occurrence and movement for mapping and management plan on a scientific basis.

Overall result demonstrates that the use of geospatial techniques provides powerful tool to study groundwater resources and design a suitable exploration plan. The integrated groundwater prospect map for the study area has been categorized into 'good', 'moderate' and 'poor' prospecting zones, on the basis of the cumulative ranking and weightage assigned to different features of the thematic maps. The geomorphology map of the study area indicates it comprises mostly denudational origin and a small part of structural origin. The denudational origin of the study area indicates good and moderate groundwater recharge potential.

From this study it is observed that geo-spatial technique can be used effectively to delineate groundwater recharge potential zones map, which can be used for various purposes like identification of location of wells for drinking purpose, tube wells for irrigation and efficient management of groundwater for the betterment of the society, economic development, etc. Further scope of study will focus on identifying the locations for artificial recharge structures to improve the water resources in the study region.

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BIOGRAPHIES

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