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Identification of Groundwater Potential Zones in Wakawali Watershed Using Remote Sensing and Geographic Information System (GIS)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundwater is a crucial source of fresh water that is stored below the Earth's surface in the saturated zone, filling gaps and spaces in soil and geological formations. Groundwater is a hidden natural resource that cannot be directly detected, therefore mapping of this resource can be

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challenging task. In the present study, remote sensing and geographic information systems techniques were collectively used to categorize groundwater potential zones in the Wakawali watershed of Ratnagiri District. In this study, SRTM DEM of 30 m resolution and conventional data was used to generate thematic layers such as slope, drainage density, lithology, geomorphology, soil and rainfall. Weightage percentages to each thematic layer were assigned according to their relative importance to groundwater potentiality using AHP technique. Further, integrated using "weighted sum" tool in Arc-GIS software. The outcomes of the groundwater potential map of the study area were classified into five zones *viz*., very poor, poor, moderately poor, good, very good contributing to 3.18%, 17.68%, 30.86%, 31.18% and 17.11% respectively. The study conclude that the remote sensing and Geographic Information System is a significant tool for land and water resource studies as well as preparation of water resources development plans, so as to prepare economically viable plans.

Keywords: DEM; groundwater potential zone; GIS; remote sensing.

1. INTRODUCTION

Water is the crucial natural resources essential for agricultural production and human survival. Different types of precipitation lead to various sources of water, with the most plentiful reservoir of freshwater being situated underground which known as groundwater. "Groundwater is a form of water held under the ground in the saturated zone that fills all the pore space of soils and geologic formations. It is formed by rainwater or snowmelt water that seeps down through the soil and into the underlying rocks" [1]. The regions of the Earth's crust that contain water and act as channels for water movement and storage are known as groundwater potential zones. Approximately 80% of the water needed for drinking comes from groundwater. The increased need for agricultural products for both food and non-food uses, along with population growth and economic development, have led to increased competition for freshwater resources in recent decades. So, we can't imagine a world without water!! [2,3,4]. In places where water levels vary yearly, rainfall is essential for replenishing groundwater levels.

The total annual groundwater withdrawal of the country in the year 2023 is estimated to be 241.34 billion cubic meter (bcm), in which agricultural sector is the largest consumer of underground water resources, accounting for 87% of the annual groundwater volume of 209.74 bcm. Household use accounts for 11% (27.57 bcm) and industry 2% (4.03 bcm) [5]. The increased need for agricultural products for both food and non-food use, along with population growth and economic development, have led to increased competition for freshwater resources in recent decades. Hence, the delineation of groundwater potential zones has acquired great importance.

Maharashtra is underpinned by various rock types of various geological ages from the precambrian to the recent. Deccan Traps cover most of the state. The remaining geological formations, which are both younger and older than the Deccan Traps, are found in the northeast and as solitary areas in the districts of Sindhudurg and Ratnagiri [6]. The state's projected annual groundwater recharge is 32.76 billion cubic meters, whereas its annual extractable groundwater resources are 30.95 billion cubic meters. The total yearly extraction of ground water is 16.66 bcm, of which 15.28 bcm is extracted for irrigation, 0.03 bcm for industrial use and 1.36 bcm for domestic use, and the extraction stage is 53.83% [5].

"As groundwater is a hidden natural resource that is difficult to locate and mapping it can be a difficult task. It is directly or indirectly controlled by terrain characteristics i.e. geomorphology, streams density, topography, water bodies, etc all these surface hydrology characteristics engage in recreation of groundwater replenishment" [7]. Meanwhile, Geographic Information Systems (GIS) and Remote Sensing (RS) are helpful in locating its prospect zones. Since groundwater cannot be directly detected by remote sensors, its existence is inferred from a variety of surface characteristics obtained from satellite photography, including surface water bodies, geology, landforms, soils, land use land cover, and so on [8,9]. "The application of the AHP model, along with RS and GIS techniques, is more popular all over the world due to its acceptance. A large number of research works with the best results have already been done on groundwater assessment by this model" [10,11]. Present study was carried out to identified the groundwater potential zones by preparation and analysis of various thematic layers.

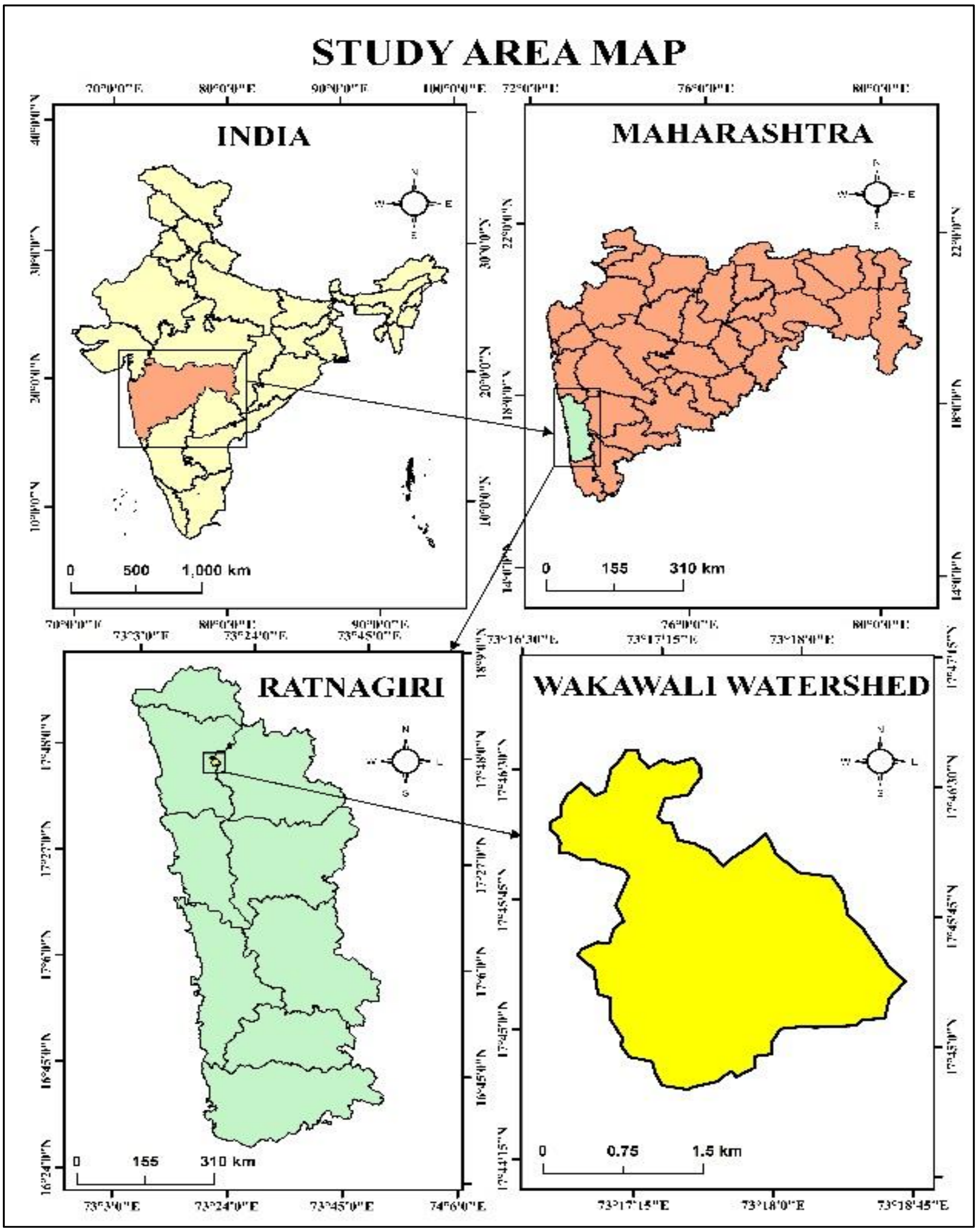

Fig. 1. Location map of Wakawali watershed

1.1 Study Area Details

Wakawali watershed is situated in Ratnagiri district of Maharashtra and covers a geographical area of 620 ha. which shown in Fig. 1. The watershed is located between the 17^o 44' to 17^o 47' N and 73^o 16' to 73^o 18' E.

Software Used: The Arc GIS 10.3 Software was use for the study, which is available at Department of Soil and Water Conservation Engineering, CAET, DBSKKV, Dapoli (M.S).

2. MATERIALS AND METHODS

In the present study digital elevation model (DEM) of shuttle radar topographic mission (SRTM) with 30 m resolution was downloaded from (http://earthexplorer.usgs.gov/) to delineate the Wakawali watershed boundary which shown in Fig. 1. The Arc GIS software has been used for generation of different thematic layers (drainage density, slope, land use land cover, geomorphology, lithology, rainfall and soil) as well as processing the remotely sensed data for delineating watershed, extraction of drainage network and slope of the watershed. Geomorphology and lithology data were downloaded from Bhukosh portal (https://bhukosh.gsi.gov.in/).

The MSL Level-1C Sentinel 2-B satellite imagery (10m resolution) was used to generate the land use land cover map of the Wakawali watershed, with acquisition date 24.01.2024 and downloaded from Copernicus Data Space Ecosystem portal (https://dataspace. copernicus.eu/). The land use land cover map of the Wakawali watershed generated through the supervised classification method in ERDAS IMAGINE Software. After the generation of the land use land cover map, an accuracy assessment was conducted using Arc-GIS and Google Earth Pro software. The overall accuracy and Kappa coefficient were found to be 88 % and 0.84, respectively.

Rainfall is key source for surface water and then it goes for recharging the groundwater. For this research, precipitation records spanning from 1991 to 2023 of five locations in close proximity to the Wakawali watershed were obtained from the Department of Agronomy, DBSKKV, Dapoli. The rainfall distribution map was generated using inverse distance weighted (IDW) tool of Arc GIS, and soil map of the study area was generated using Arc GIS Software.

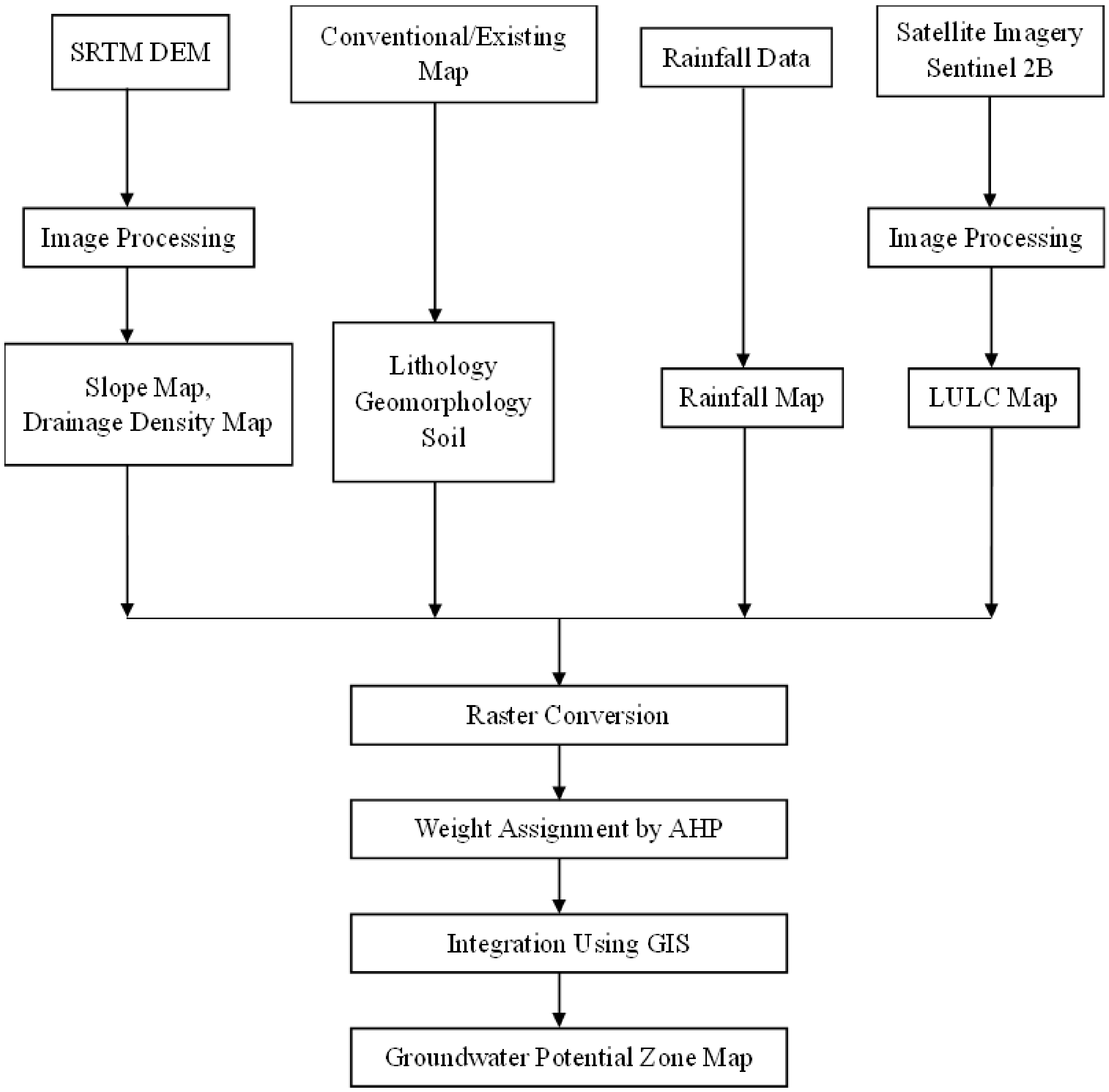

Fig. 2. Flow chart for groundwater potential zone map

Table 1. Weightage and ranking for different thematic maps are assigned using Saaty's Analytical Hierarchy Process (Saaty, 1980)

Sr. No.	Theme	Sub-Class	Rank	Weight (%)
1	Land use land cover	Water Body	5	26
		Agriculture	4	
		Barren Land	2	
		Forest	3	
		Built Up	1	
		Orchard	3	
2	Slope %	0 to 5	5	16
		5 to 10	4	
		10 to 15	3	
		15 to 20	2	
		>20	1	
3	Drainage Density (km/km^2)	<1	5	13
		1 to 3	4	
		3 to 5	3	
		5 to 8	2	
		>8	1	
4	Rainfall (mm)	3830 - 3850	3	7
		3850 - 3870	3	
		3870 - 3890	4	
		3890 - 3910	4	
5	Soil	Sandy Loam	3	15
6	Lithology	Basalt	4	10
		Laterite	2	
7	Geomorphology	Moderately Dissected Plateau	2	13
		Pediment Pediplain Complex	4	
	Total=			**100**

2.1 Identification of Groundwater Potential Zones

Multi-criteria decision analysis utilizing the Analytical Hierarchical Process (AHP) is the most widely used and well-known GIS-based technique for locating groundwater potential zones. The AHP is the measurement of weightage through pairwise comparison which was made on a scale of numbers 1 to 9 which indicates particular layer is how much important than other factors [12]. AHP method is the extremely adopted by researchers around the world for identification groundwater potential mapping studies [13,14]. "A specific weight was assigned to each theme. Rank was allotted to each characteristic. Every factor had divergent influence in different area. Therefore, every factor was assigned a weight depending upon their involvement towards ground water potentiality" [7].

In this study the ranks were then finalized considering the weights suggested by various experts and the weights used in earlier studies [7,15] as well as from local experience. A matrix table was developed for pair-wise comparison of all parameters that used in this research. After that the obtained matrix was checked for consistency and if consistency ratio < 0.1, and then the criteria weights therefore derived were employed for analysis [12]. To check the consistency of assigned weights, the Consistency Ratio (CR) as suggested by Saaty (1980) was computed using Equation 1 and 2. The procedure for calculation of consistency ratio is given below.

$$CR = \frac{\mathrm{CI}}{RCI} \tag{1}$$

Where,

CI = Consistency Index
RCI = Random Consistency Index

The Consistency Index (CI) is given by the Equation 2.

$$CI = \frac{\lambda \max - n}{n-1} \tag{2}$$

Where,

λmax = average ratio of weighted sum (WS) / criteria weight (CW)
n = Matrix size

Further, ratio of weighted sum (WS) and criteria weight (CW) calculated for each of the thematic factor which is important to estimate the λmax. The value of λmax was found 7.77 by calculating the average (mean) value of the ratio of weighted sum (WS) and criteria weight (CW). Afterword, the consistency index (CI) was calculated and found to be 0.128. In the final step, consistency ratio (CR) was estimated and found to be 0.09. The obtained consistency ratio (CR) is less than 0.1 which is in fairly acceptable condition. The weightages assigned to the different thematic layers by AHP are given in Table 1. Similar weightage and ranks were assigned by Bhange et al. [7], Landage et al. [16] and Keskar et al. [15].

After the assigning the weights, all thematic layers were reclassified with their ranking values. Further, reclassified thematic layers with ranking values were integrated with the help of “weighted sum” tool in Arc GIS to obtain the groundwater potential zone (GWPZ) map of the study area. The generated map indicating the very poor, poor, moderately poor, good, very good groundwater potential zones.

3. RESULTS AND DISCUSSION

3.1 Slope

The topographic slope of the area has its own importance in affecting the runoff, recharge and movement of surface water [13]. In general slope is the maximum rate of change in height across a surface. In this study, a slope map was generated from SRTM DEM using Arc-GIS software. The slope of Wakawali watershed varies from 0 to >20 % and divided into five classes namely gentle, moderately gentle, steep, moderately steep and very steep, similar results were also observed by Bhange et al. [7]. About 79 percent area of the watershed found in the range of gentle to moderately gentle slope. The areal extent of slope ranges over the study area is represented in Table 2 and spatial distribution of different classes of slope percent over the study area is depicted in Fig. 3.

3.2 Drainage Density (DD)

Drainage density is the ratio of the total length of all streams of all orders within a watershed to the total area of the watershed. Drainage density map of the Wakawali watershed was developed using stream order map through Arc-GIS software. If drainage density is higher, less will be infiltration and more will be runoff [17]. The area with low drainage density, probability of groundwater potential zone is high. Drainage density of Wakawali watershed is divided into five classes viz, 0-1 km/km^2, 1-3 km/km^2, 3-5 km/km^2, 5-8 km/km^2 and >8 km/km^2, Similar results were also observed by Bhange et al. [7], Landage et al. [16] and Keskar et al. [15]. Their areal distribution is given in Table 3 and spatial distribution map of slope depicted in Fig. 4.

3.3 Lithology

It is a very significant characteristic in predicting groundwater potential zones. Lithology includes the study of general physical properties of rocks as well as chemical, mineral composition of rock as well as it plays an important role in groundwater potential because properties of rocks such as porosity and permeability affect infiltration and groundwater flow [15]. The Wakawali watershed fall under two group of geological formation, which is (i) Laterite (ii) Basalt. In this study laterite rock formation was found 51% (314.90 ha). of total area and around 49% (305.10 ha) of total area is covered by basalt rock formation, similar results were found by Keskar et al. [15]. The spatial distribution of lithology is depicted in Fig. 5.

Table 2. Areal extent of slope

Sr. No.	Slope Range	Class	Area (ha)	Area (%)
1	0 to 5	Gentle	284.53	45.89
2	5 to 10	Moderately Gentle	205.42	33.13
3	10 to 15	Steep	72.40	11.68
4	15 to 20	Moderately Steep	23.37	3.77
5	>20	Very Steep	34.28	5.53
	Total=		**620.00**	**100**

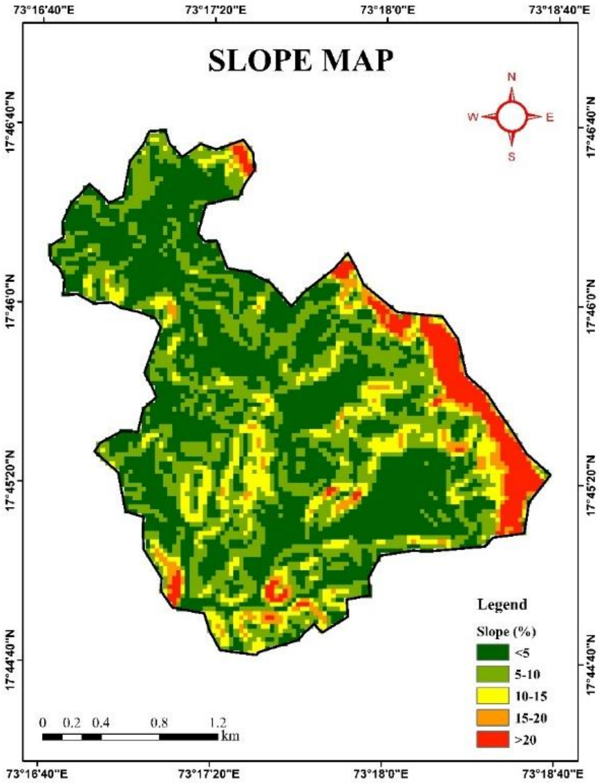

Fig. 3. Spatial distribution map of slope

Table 3. Areal distribution of drainage density

Sr. No.	Drainage Density (km/km^2)	Category	Area (ha)	Area (%)
1	0 to 1	Very Good	435.92	70.31
2	1 to 3	Good	27.19	4.38
3	3 to 5	Moderate	31.31	5.05
4	5 to 8	Poor	38.69	6.24
5	>8	Very Poor	86.89	14.02
	Total=		**620.00**	**100**

3.4 Geomorphology

Geomorphology is the study of earth structures and landforms. It is mainly depended on structural evolution of geological formation [18,19]. In this study area, only two geomorphic units were identified namely moderately dissected plateau which covering area of 97.90 ha. (15.79%) and pediment pediplain complex which covering area of 522.10 ha. (84.21%), similar results were found by Keskar et al. [15]. The spatial distribution of lithologic group over the stud area is depicted in Fig. 6.

3.5 Soil

“The water-holding capacity of an area depends upon the soil types and their permeability” [20,21]. “The initial infiltration and transmission of surface water into an aquifer system is a function of soil type and its texture” [22]. Some researchers conducted field experiment on soil characteristics in Wakawali watershed their findings revealed that the soil in the study area classified as 'Sandy loam' in terms of texture [23,24,25]. On the basis of their study, it was considered that the soil texture of the Wakawali watershed is also sandy loam. The spatial distribution of soil texture over the study area is depicted in Fig. 7.

3.6 Rainfall

Rainfall is the main source of surface water which plays a significant role in the groundwater recharge of an area. The monsoon rainfall map of the study area ranged from 3830 mm to 3910 mm. The rainfall map was classified into four classes which are mentioned in Table 4. The Wakawali watershed contains a major of 30.67% area covered by rainfall ranging 3870 mm to 3890 mm followed by 3850 mm to 3870 mm (about 28.66%). The decrease tendency of rainfall scenario reflects from southern to northern part in study area which is depicted in Fig. 8.

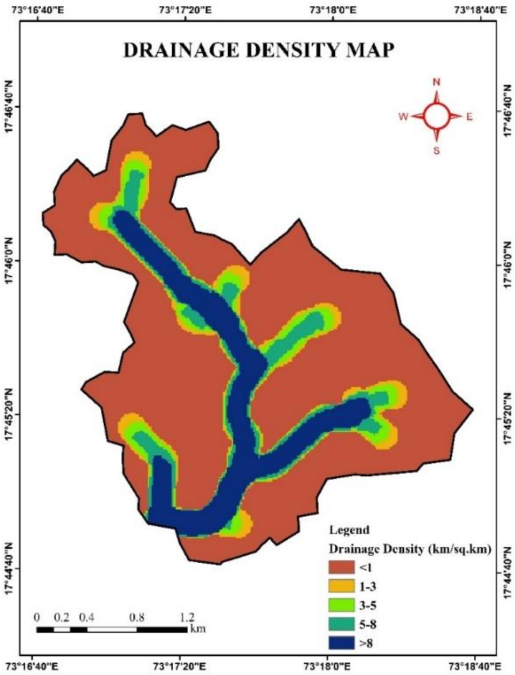

Fig. 4. Spatial distribution map of drainage density

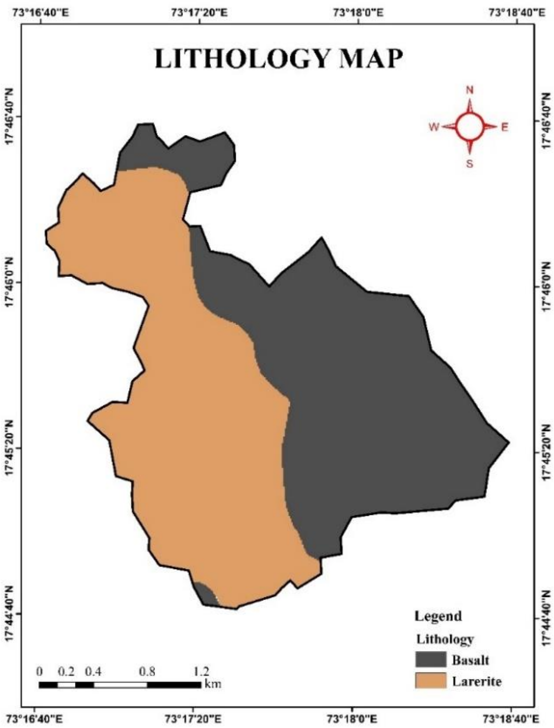

Fig. 5. Spatial distribution map of lithology

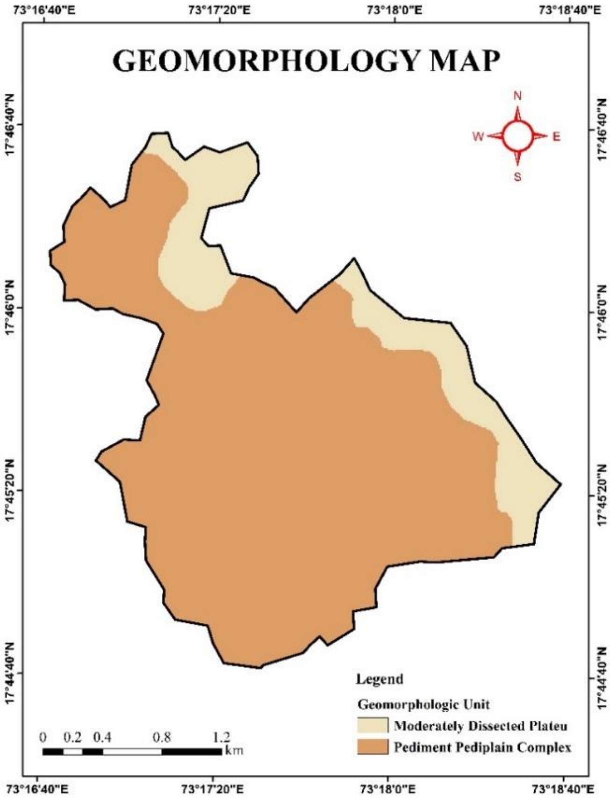

Fig. 6. Spatial distribution map of geomorphology

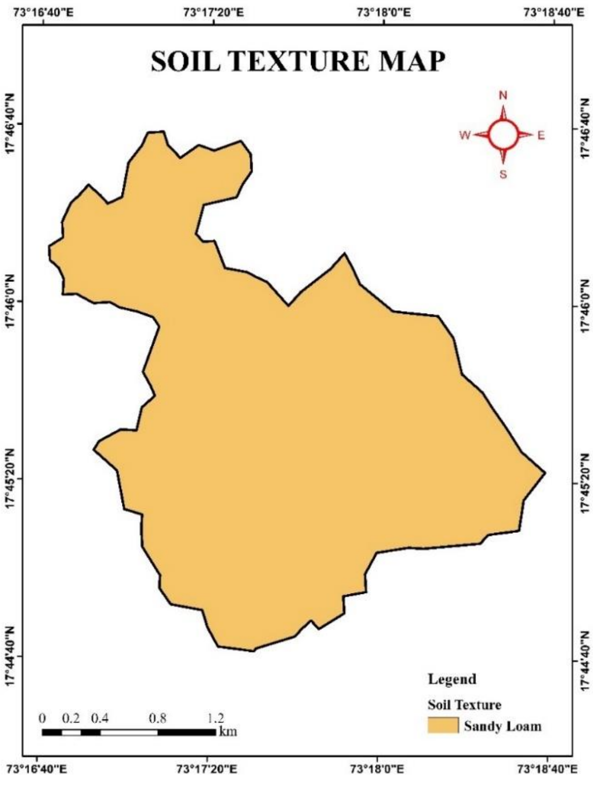

Fig. 7. Spatial distribution map of soil texture

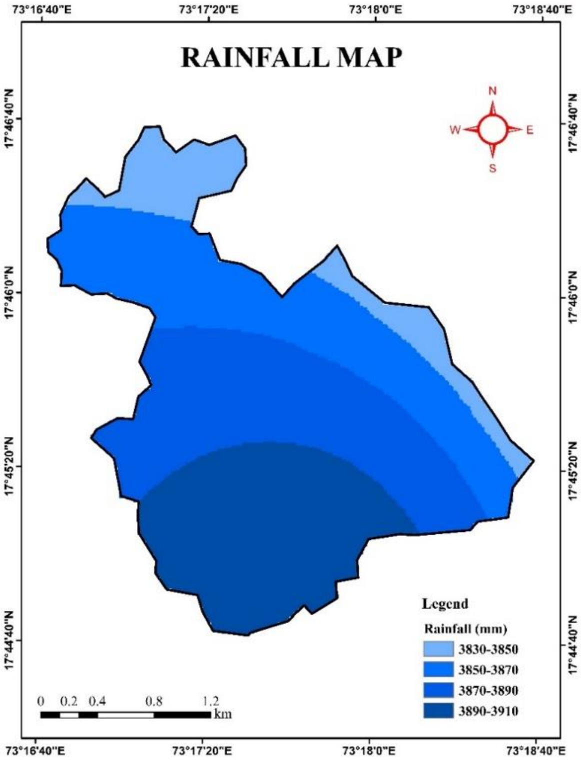

Fig. 8. Spatial distribution map of rainfall

Table 4. Areal distribution of land use land cover

Sr. No.	Land use land cover classes	Area (ha)	Area (%)
1	Water Body	2.90	0.47
2	Agriculture	126.72	20.44
3	Barren Land	173.52	27.99
4	Forest	202.06	32.59
5	Built Up	30.80	4.97
6	Orchard	84.00	13.55
	Total=	**620.00**	**100**

3.7 Land Use Land Cover (LULC)

"Land use land cover is an important factor related to ground water potential zoning. Land use land cover provides information about the kind of surface cover in the land, because infiltration of the water is much depending on the kind of surface cover" [19]. In the present study, classes of the land use land cover map classified into six major classes namely water bodies, agriculture land, barren land, forest, built up area and orchard, similar classes of land use land cover were generated by Nandgude et al. [26] which is depicted in Fig. 9. The areal distribution of land use land cover classes of the Wakawali watershed is illustrated in Table 4. It was observed that the forest land cover major part of the watershed (32.59%) followed by land (27.99%). The least portion of the Wakawali watershed was associated with water bodies which consist of 0.47%.

3.8 Groundwater Potential Zone

The groundwater potential zones map through AHP technique and weighted overlay method divided the study area into five classes, viz., very poor, poor, moderately poor, good and very good zones contributing to 19.67 ha. (3.18%), 109.60 ha. (17.68%), 191.34 ha. (30.86%), 193.31 ha. (31.18%) and 106.05 ha. (17.11%) respectively. Similar results were also observed by Bhange et al. [7], Landage et al. [16] and Keskar et al. [15]. Fig. 10 shows the spatial distribution of groundwater potential zones over the study area.

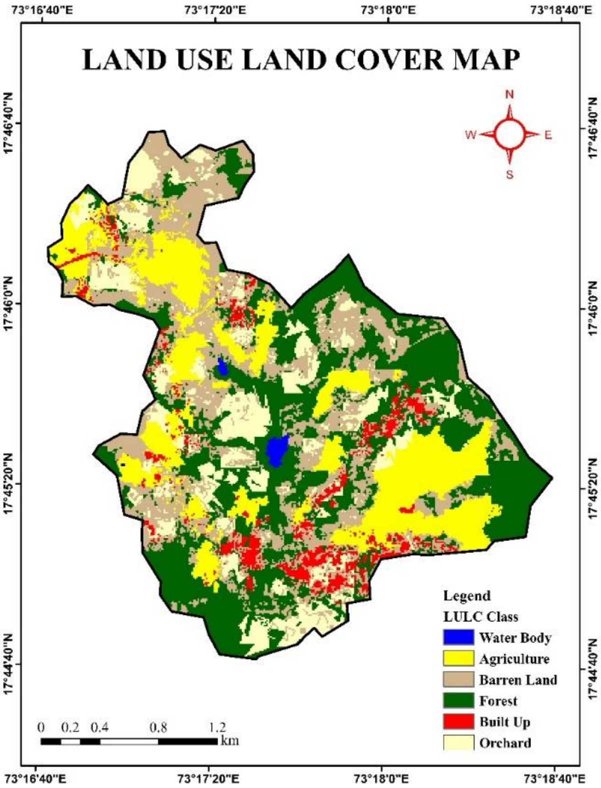

Fig. 9. Spatial distribution map of land use land cover

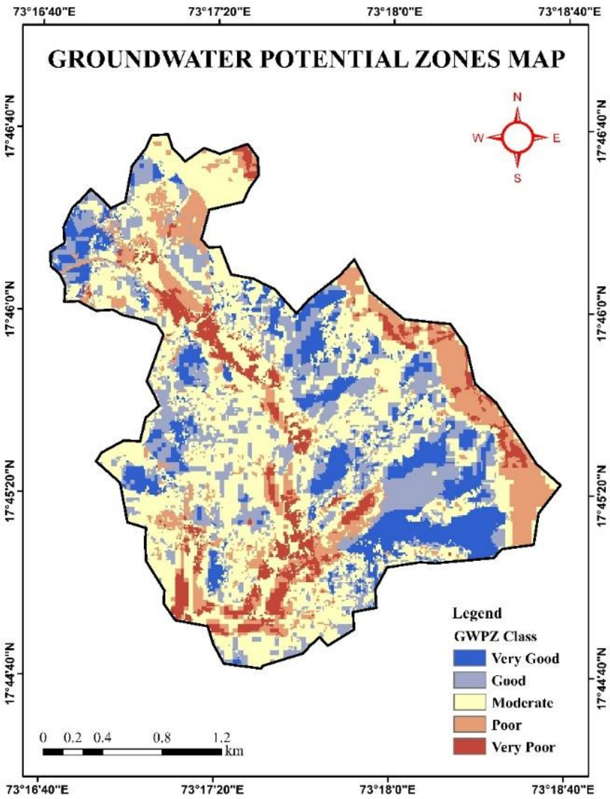

Fig. 10. Groundwater potential zone map of Wakawali watershed

4. CONCLUSION

In the present study, the combined use of Remote Sensing and GIS with Analytical Hierarchy Process (AHP) technique is proved to be a powerful tool for the identification of groundwater potential zones in the study area. The study area divided into five groundwater potential zones. The greater part of the study area shows moderately poor to good range of groundwater potential. The integration of slope, drainage density, geomorphology, lithology, soil, rainfall and land use land cover gives prior information to planner and decision makers involved in the preparation of water resources development plans, so as to prepare economically viable plans.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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