



# Exploration of groundwater potential zones using analytical hierarchical process (AHP) approach in the Godavari river basin of Maharashtra in India

J. Rajesh<sup>1</sup> · Chaitanya B. Pande<sup>1</sup> · Sunil A. Kadam<sup>1</sup> · Sunil D. Gorantiwar<sup>1</sup> · Mukund G. Shinde<sup>1</sup>

Received: 27 May 2020 / Accepted: 18 October 2021 / Published online: 6 November 2021  
© The Author(s) 2021

## Abstract

Total natural and groundwater resources play the most crucial role in developing ecological, biological and socioeconomic doings. Various parameters like land use, geology, elevation, slope, lineament, lineament density, drainage density and geomorphology affect the groundwater development of recharge and its accessibility. In this research, geographical information system (GIS), remote sensing, weighted overlay analysis and analytical hierarchy process (AHP) methods have been used for groundwater prospects mapping, and identifying suitable solutions site for soil and water conservation structures. To calculate the weights were assigned to every layers component in the determination of affecting factors. The weighted overlay analysis (WOA) tool is applied to give the sub-parameter ratings based on the scientific literature. The final map of potential groundwater zone map has prepared using Arc GIS 10.1 software and AHP methods. About 49.71% of the areas fall under the 'good potential zone, 41.05% falls under the 'moderate potential zone', and 9.22% falls under the 'poor zone by using AHP technique. Groundwater potential zone map is depend on the weighted overlay analysis and analytical hierarchy process (AHP) methods. The highest GWP is located in the lower part of the basin due to the best surface runoff gathering, infiltration situations and subsurface storage volume. The present study procedure, methods and outcomes can be valuable to estimate the suitable groundwater zones parallel to improve the dry land area in the semi-arid and arid regions of India.

**Keywords** Analytical hierarchical process · Weighted overlay analysis · Groundwater potential zone · RS · GIS

## Introduction

Groundwater is the second greatest important source of fresh water on the earth surface and the finest for human and commercial developments and planning associated with surface water (Arabameri et al. 2019).

Over-exploitation of groundwater has led to declining groundwater levels and ever-increasing stress on available groundwater resources in several parts of the world as a result of the accelerated pace of development and intensive agriculture across the globe to meet increasing global food and energy demands (Fathi et al. 2021; Priyan 2021).

In the semi-arid region with various climatic factors affect the management of water resources (Kandekar et al. 2021). Agriculture activates and makes an important contribution to the Indian economy. India is the second-largest populated country globally, and most of the population live in rural areas and are involved in agriculture practices (Priyan 2021). In this view, groundwater is play a very important role in developing the Indian economy and other countries. The natural resources such as land, water and air etc. can be maintained for India's ecological balance in upcoming years. The groundwater resources are important for agriculture development absence of surface water in India (Arivazhagan et al. 2021; Maity et al., 2019).

The southern part of India rivers affects the wasteland, and fallow and barren lands have increased due to shortage of water during kharif and rabi seasons. Groundwater accessibility significantly changes in various seasons, and river runoff substantially affects the groundwater recharge mechanism (Kuriqi et al., 2020). Rainfed agriculture has contributed to 58% of the world's food supply, which comes from

✉ J. Rajesh  
drjrajesh89@gmail.com

<sup>1</sup> Centre for Advanced Agricultural Science and Technology,  
For Climate Smart Agriculture and Water Management,  
Rahuri, Ahmednagar 413722, Maharashtra, India

80% of the agriculture sector (Moharir et al., 2017). The world's population has been increasing, automatically the demand of fresh water has increasing, and only one groundwater source is the most crucial source of fresh water if there are drought conditions that time directly impacts food security, agricultural production, climate imbalance, surface and groundwater shortages in the semi-arid region (Maity et al. 2019; Moharir et al. 2019). Watershed management development programme is considered an effective instrument for inclining to a massive number of water-related issues and is perceived as a suitable mechanism for groundwater development and improvement in delicate and marginal rainfed areas (Khadri et al. 2014a).

The groundwater potential zones mapping is essential for developing groundwater and rainwater conservation planning in the semi-arid region based on remote sensing techniques (Asadi et al. 2007; Biswas et al. 2012; Anu Varughese 2012; Etishree et al. 2013). So many researchers have completed research on the groundwater development topics such as chemical and physical groundwater quality analysis, aquifer mapping, groundwater flow modelling, groundwater potential zones map and advanced remote sensing and GIS technologies applied on the natural resource's assessment (Ranjana et al. 2009; Pande et al. 2017). The novel emerging technologies like MIF, AHP, remote sensing and geographical information system (GIS) have found accurately suitable groundwater zones for the development and planning of watershed at small and large scale (Javed and Wani 2009; Pande et al. 2019; Khadri et al. 2016).

GIS software can be an effective tool for monitoring groundwater development. GIS and remote sensing technologies have been used to assess the feasibility of groundwater recharge sites and dam locations in the semi-arid region (Pande et al. 2018a). Remote sensing and geographic information systems (GIS), with their advantages of spatial, spectral and temporal availability and manipulation of data covering vast and inaccessible zones in a short period, have become valuable tools for observing and monitoring groundwater resources within watershed areas. These methods and technology have been applied to identify suitable zones and sites for groundwater exploration and development to poor aquifer zones in basaltic rock (Pande et al. 2018b; Rane et al. 2021). Remote sensing and GIS softwares used for natural resources mapping, this maps are helpful to the development of groundwater and watershed based on the satellite images (Pande et al. 2021). The main aim of this research investigation has been to prepare various thematic layers, i.e. lithology, geomorphology, drainage density, lineament, rainfall, slope, land-use cover, etc. To estimate potential groundwater area within this study area for weight assignment by AHP (Analytical Hierarchical Process)-based approach for each thematic layer and incorporate the same to classify potential groundwater zones. To estimate groundwater potential

zones within this study area for weight assignment by AHP (Analytical Hierarchical Process)-based approach for each thematic layer and incorporate the same to classify potential groundwater zones. All of these layers were integrated using the AHP technique and GIS software. These layers have been integrated for the accurate identification of potential groundwater zones, soil and water conversation sites. This study shows groundwater suitable zones mapping was divided into three classes: poor, moderate and good according to assigned weights, remote sensing, GIS and AHP techniques. The results of the study area can be helpful for the assessment of the natural resources, watershed planning and groundwater development to the agriculture production with maintaining the ecological balance in the semi-arid region.

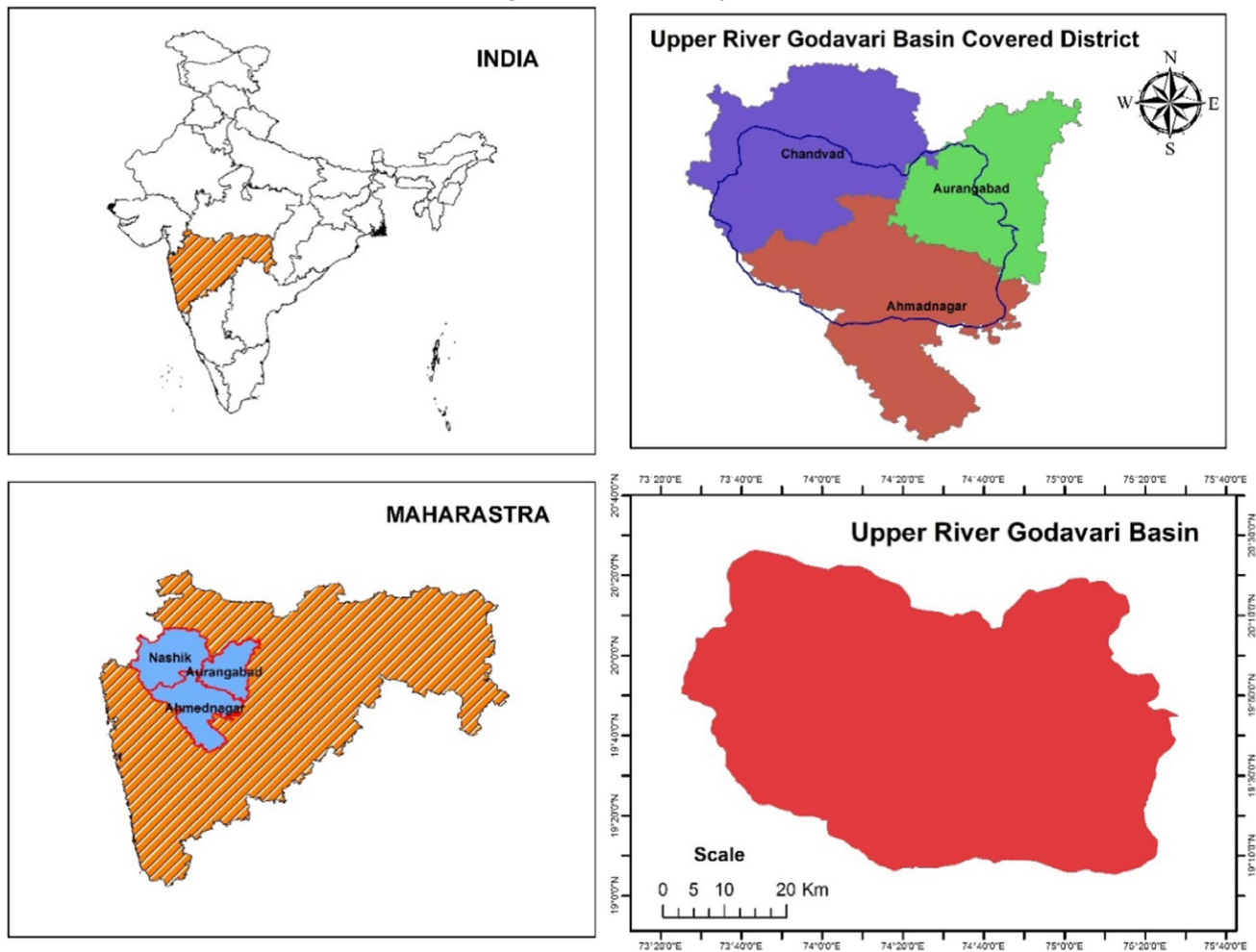
## Study area

The Godavari river basin is located between latitude 16° 00' 00" North and 22° 36' 00" North and longitude 73° 26' 00" East and 83° 07' 00" East (Fig. 1). The Godavari river basin is an important river in the Marathwada region and other parts of Maharashtra state. This river has the largest basin and is critical for the development of crops in Maharashtra. According to the digital elevation model, the highest elevation of mean sea level is 1,067 m. It is approximately 38 kms from the source of the river basin. In this study area, many major crops are available such as sugarcane, cotton, horticulture and soybean etc. This area is highly cultivated land as compared to other basin areas, while so many crops only depend on the groundwater and rainwater in the semi-arid region.

## Materials and methodology

A drainage network map produces based on the digital elevation model data for the Godavari river basin. Stream orders map is created based on the stream map and Arc GIS software. The land use and land cover map are prepared from the satellite data by using supervised classification tools in the Arc GIS software. Geomorphology landforms classes were identified based on the Indian Remote Sensing-P6-LISS-IV imagery with the references of field data and Arc GIS software. Then, the LULC map was created and used for potential groundwater zones mapping. The Arc GIS system has made the various thematic layers to know baseline data of multiple factors associated with groundwater and poor aquifer. In most scientific studies, the criteria for delineation of groundwater zones have often been used for geomorphology, geology, drainage density, soils, lineament, land use, etc. (Prasad et al., 2008; Das and Pal, 2019). All thematic layers like geomorphology,

## Study Area Location Map

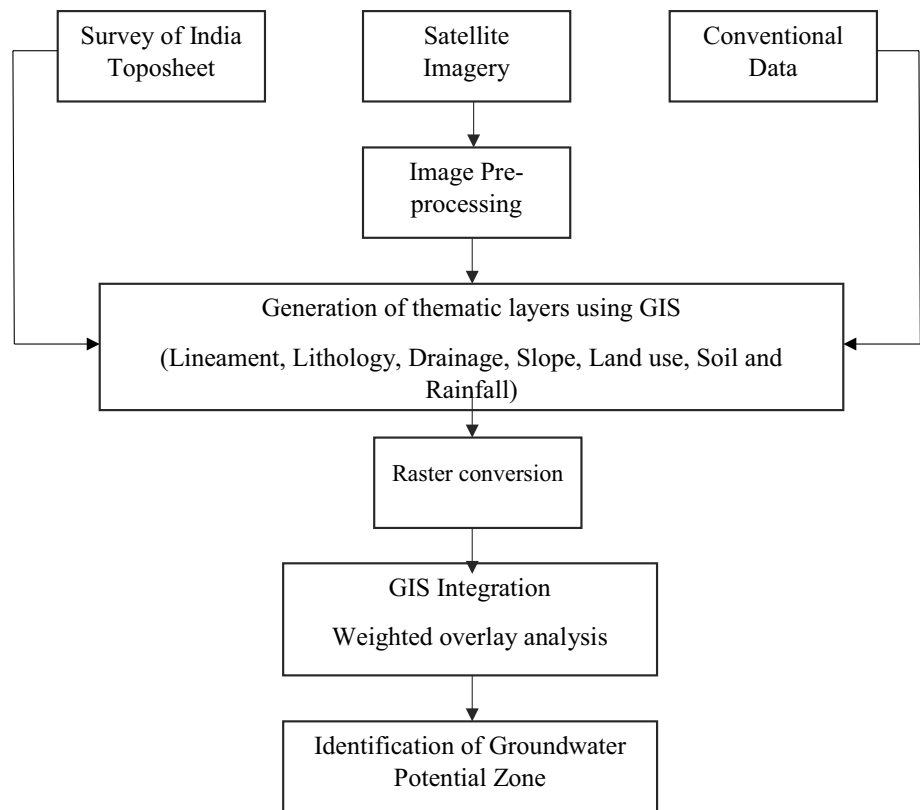


**Fig. 1** Location map of the study area

geology, lineament density, and drainage density maps were generated by remote sensing and GIS techniques. The geology and soil classes have been verified with a ground database (Pande et al. 2018b; and Pande et al. 2019). All integrated data have effectively delineated the potential groundwater zones using AHP technique (Fig. 2). Every thematic layer classes were assigned weightages using AHP and WOA (weighted overlay analysis) methods. A change in groundwater level has been found due to various environmental factors. Thematic layers have been determined to map potential groundwater zones based on the weighted overlay analysis (WOA). AHP is an MCDM method technique developed by Saaty (1997). In order to detect a potential groundwater area, and multi-parameters were considered. In the decision-making process for finding groundwater zones, the weights of each parameters were calculated based on their relative importance. AHP's hierarchical formulation, economical and few time intense and accurate outcomes, etc. (Das, 2019).

A 1 to 10 scale has been used to allocate result of sub-criteria depend on the favourable situations and their value in groundwater detection. The most appropriate sub-criterion has given the maximum score (10), the minimum score (1) has shown the most inappropriate under-parameter, and an intermediate score is allocated to moderately appropriate GPZ identification criteria sub-parameters. Therefore, the selected parameters were given, e.g. geology, geomorphology, land use, drainage density, slope and soil, etc. The groundwater potential zones map was prepared using the analytical hierarchy process. The groundwater zones map of the study area was verified using the available water level and well yield information. The water level points were superimposed on the final groundwater potential zones map to verify the correctness of the current work in the different groundwater suitable zones. The AHP method has been given beneficial accurate results about the potential groundwater zones. The adopted methodology flow chart is enclosed in Fig. 2.

**Fig. 2** The interrelationship between the multi-influencing factors concerning the groundwater potential zone



## Results and discussion

The groundwater potential zones mapping is vital for groundwater recharge development. The results have been applied for the planning and development of watersheds with poor aquifer zones area. These results have developed using remote sensing and AHP methods. In this study, assessing natural resources mapping play a vital role in identification of suitable groundwater zones (Khadri et al. 2013 and 2014b). All extraction classes of layers have been demarcated based on the digital and visual interpretation techniques with verified field data (Pande et al., 2015). In this study selected seven necessary thematic layers are used for groundwater suitable zones mapping, and these thematic layers assigned the ranks as per the hierarchical analytical process with the scale of Satty.

### Geology

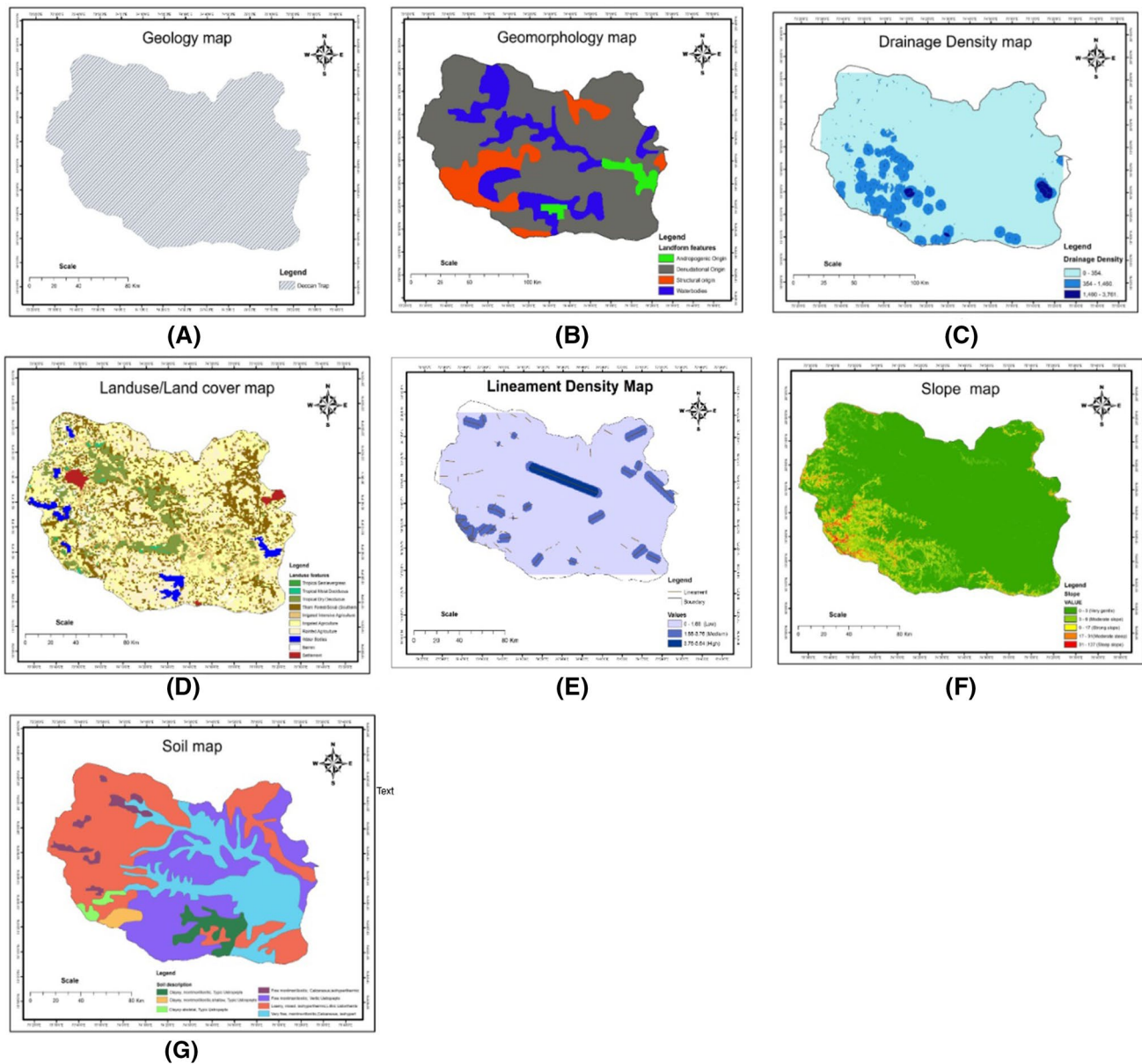
Geology is playing an important role in identification of groundwater potential zones analysis and occurrence. The study area is suffering so many problems from groundwater and drought, particularly in the semi-arid region. The groundwater classes were assigned weightage as per the AHP method. The final geology map was used to understand aquifer flow and rocks (Fig. 3A and Table 3).

### Geomorphology

Geomorphology factors are the main essential parameters in the hydrological system process on the earth surface. It is most important role in the poor aquifer zones mapping under the hard rock terrain. In this view, geomorphology mapping should be needed for the preparation of the groundwater suitable zones mapping. Satellite data are used for the identification of different landforms in the geomorphology mapping. A geomorphology map was created using Arc GIS software (Khadri et al., 2015). In the Deccan trap, different structural characteristics are essential for sustainable water resource development. The geomorphology characteristics are depended on the geological rock formation's structural evaluation. Hence, the geomorphology mapping is play a significant role in the delineation of groundwater zones as well as planning of soil and water conservation (Fig. 3B).

### Drainage density

Drainage density play is an essential role in the groundwater potential zones on the drainage line and agriculture field. Water runoff would be high if the drainage level is high and water penetration to the ground is lower, but the surface water runoff region with low drainage density would be lower, so surface water is highly infiltrated into the ground. The drainage density map was prepared from the SRTM



**Fig. 3** Thematic maps: **A** geology, **B** geomorphology, **C** drainage density, **D** LULC, **E** lineament density, **F** slope, **G** soil maps

data in the Arc GIS software (Fig. 3C). The streamline can define the area's drainage capacity in the river basin (Pande et al., 2015).

**Land use and land cover (LU/LC)**

The land use and land cover maps were generated from LISS-IV satellite data in the Arc GIS software. The land use classes are essential for the planning and development the groundwater, drought and agriculture sectors in the semi-arid region. The remote sensing software is accurate elementary information about land use classes for making a land-use map compared to other software. The land use

classes were classified through supervised classification methods and ground data. This basin is divided into ten LU/LC, viz. tropical semievergreen, tropical moist deciduous, tropical dry deciduous, thorn forest/shrub, irrigated intensive agriculture, irrigated agriculture, rainfed agriculture, water bodies, barren land and settlements (Patode et al. 2017). Due to climate change factors and the unavailability of water sources in the semi-arid region, the land use classes quickly change. The large section of the land cover was under irrigated intensive agriculture, irrigated agriculture, rainfed agriculture, followed by tropical dry deciduous is 64.67 and 14.17%, respectively (Fig. 3D and Table 3).

## Lineaments density

Lineaments and faults are the unequal earth structures identified. These features disclose the characteristics of the surface and the hidden layer. Suppose high lineament density is helpful in the development of the aquifer zone in the hard basaltic rock with very high terrain (Kartic Bera et al., 2012). The lineament directly shows poor aquifer zones entire in the basin area. This information can target groundwater development and watershed management to agriculture crops under climate changes. Thus, lineaments density played a significant role in the planning and developing groundwater resources in the study area. Geomatica software delineates and provides appropriate relative weighted depending on the groundwater infiltration rate (Table 3). The lineament map was prepared from a satellite image with the reference of field data in the Arc GIS software (Fig. 3E).

## Slope

The slope is defining as a rate of infiltration and surface runoff on the planned earth areas. It can retain and stream to water within the ground, which can raise the retention to groundwater, while the deep slopes extend the runoff with a decrease in the penetration of surface runoff entire in the earth. The surface slope was prepared using a spatial analysis tool in the Arc GIS environment based on the digital elevation model. Therefore, the surface slope was divided into five classes in the slope map. Slope classes weights were allocated weight using the WOA and AHP methods (Fig. 3F and Table 3). The slope map is a more important parameter in groundwater planning and soil and water conservation sites, particularly in undulating topography and challenging rock terrain (Khadri et al. 2016b).

## Soil

Soil is the main factor for the delineation of groundwater potential zones mapping. Currently, so many software and techniques like remote sensing, field, GIS and AHP modeling are applied to groundwater-related research work and watershed development planning. The soil maps were developed in the Arc GIS software with ground truth and laboratory data (Fig. 3G). The groundwater and surface water flow penetration into the ground depends on the porosity and permeability of the soil. Therefore, estimating and determining the amount of groundwater with suitable sites in the river basin area for groundwater recharge.

The soil classification database was obtained from the National Soil Survey and Land Use Planning Bureau, Nagpur. In the study area, we have observed the seven soil classes such as Loamy, mixed hyperthermic, Lithic Ustorthents, Very fine, montmorillonite, Calcareous, is

hyper, Fine montmorillonitic, Calcareous, isohyperthermic, Clayey-skeletal, Typic Ustropepts, Clayey, montmorillonitic, shallow, Typic Ustropepts, Clayey, montmorillonitic, Typic Ustropepts and Fine montmorillonitic, Vertic Ustropepts. The movement of the infiltration of water in these seven types of soil is not the same, so based on its property, the weights have been assigned (Table 3).

## Saaty's analytical hierarchical process

Analytical hierarchical process (AHP) is a modern technique for demarcation of groundwater potential zones mapping based on the remote sensing and GIS database. It is included to design the multiple decision criteria based on the hierarchy method. To evaluating the comparative is needed rules for every paradigm and determining the full ranking of the replacements. The establishment of the analytic hierarchy process (AHP) is fixed of critical problem solving for groundwater-related issues as wells as natural resources problems (Saaty 1980). AHP method is a prevalent and accurate result of the groundwater potential zones mapping. It depends on the well-characterized scientific design of reliable environments, and there is connected right eigenvector's able to create approximately weights. The AHP technique is a standard, or options concerning a model, in a natural, pairwise model (Sajikumar et al., 2013). AHP utilizes the fundamentals of total numbers proven in practice and validated by physical and decision problems. The principal scale has been demonstrated to be a scale that captures different preferences concerning quantitative and qualitative attributes well compared to other scales and methods. It is shifted over individual choice into ratio scale weights combined into a linear added weight for every different scale. The outcomes of AHP methods can be utilized to study potential groundwater zones and subsequently help the decision-maker create a selection. AHP is a mathematical technique for likening an outline of the aim and objectives of the study area. The comparison matrix created by expertise utilizing Saaty's scale is shown below. Finally, the analytical hierarchical process combined the criteria weight and the option scores, deciding a worldwide mark for every alternative and subsequent ranking. The world rank for provide choice is the weighted aggregate of the rank. It is acquired concerning every one of the norms. The nine numbers display more considerable significance, while 1/9 displays minor importance, while 1 illustrates a parameter's equivalent weight or class. Because of these weightage criteria, every parameter was classified (Table 1). Table 2 displays the weightage allocated to the choice seven factors for the groundwater potential zones mapping.

**Table 1** Saaty’s Scale of relative importance

SCALE	1	3	4	5	6	7	8	9
Relative importance	Equal importance	Weak	Moderate importance	Strong importance	Strong plus	Very strong	Highly strong	Extreme importance

**Table 2** Percentage of influencing factor based on Satty’s analytical hierarchical process

S.No	Influencing factor	Value	Sattys scale (in Fract.)	Sattys scale (in Deci.)	% Influence = (Sattys Scale/Sum)*100	Relative Influence Value
1	Lithology (Geology)	High	1	1	38.75	39
2	Geomorphology	↓	1/2	0.5	19.37	19
3	Lineaments density		1/3	0.33	12.79	13
4	Drainage density		1/4	0.25	9.68	10
5	Soil		1/5	0.2	7.75	8
6	Slope		1/6	0.16	6.2	6
7	Land use/ Land cover	Low	1/7	0.14	5.42	5
					<b>2.58</b>	<b>100</b>

### Weighted overlay

The marked weights of thematic layers for every important factor were assigned per the weighted overlay analysis technique (Table 2). Thematic layers classes parameters weights are shown in Table 3. The weighted overlay analysis method was done using Spatial Analyst Tools in the Arc GIS software. The WOA tool is worked on the various layers in the form of a raster surface, and this raster is easily defined general scale and weight for every layer important for the groundwater suitable zones mapping. The groundwater potential zones maps were divided into very low, low, moderate, high and extremely high (Fig. 4). In this study area, observed groundwater zones area is 126.83 km<sup>2</sup> areas fall under very high, 193.20 km<sup>2</sup> areas are under high, 248.09 km<sup>2</sup> having moderate, 192.49 km<sup>2</sup> having low and 37.19 km<sup>2</sup> areas.

### Delineating the groundwater potential zone

The potential groundwater zone was developed based on the AHP, remote sensing and GIS techniques. All layers were integrated, viz. geology, geomorphology, lineament density, slope, soil, land use, etc. The demarcation of potential groundwater zones was done based on thematic layers, weighted overlay analysis and analytical hierarchical process approaches (Magesh et al. 2011, Pandian et al. 2014 and Nagarajan et al. 2009). Finally, assigning the different groundwater potential zones as per thematic layers

for groundwater planning and development. Groundwater potential zones are divided into three classes such as good, moderate and poor (Fig. 4). This map shows that the magnificent groundwater potential zone is an excellent zone concentrated in most of the study area because of the appropriation of fine montmorillonitic, Vertic Ustropepts, Loamy, blended isohyperthermic, Lithic Ustorthents and intensive agriculture land, irrigated agriculture land and rainfed area with high infiltration ability. The directly indicates that soil types and slope values play a vital role in the groundwater development of the semi-arid region. Also, the convergence of drainage density and lineament density likewise helps the groundwater system's infiltration ability. About 49.71% of the areas fall under the excellent zone, 41.05% fall under the 'moderate' zone, and 9.22% fall under the 'poor' groundwater potential zone Agarwal et al. (2013); Agrawal et al. (2009); Arkoprovo et al. (2012); Khadri et al. (2016a); Magesh et al. (2012); Varughese (2012).

### Conclusions

Satellite images are given significant topography data to classify different geology classes, lineaments and hydro-geomorphological elements. Large of these geographies helped as secondary pointers of groundwater amount in the river basin area. The most important results have been obtaining for developing the Godavari river basin based on the AHP, GIS and remote sensing techniques. The remote sensing and GIS technology is demarcated and assessment of natural resources for the entire basin. The groundwater

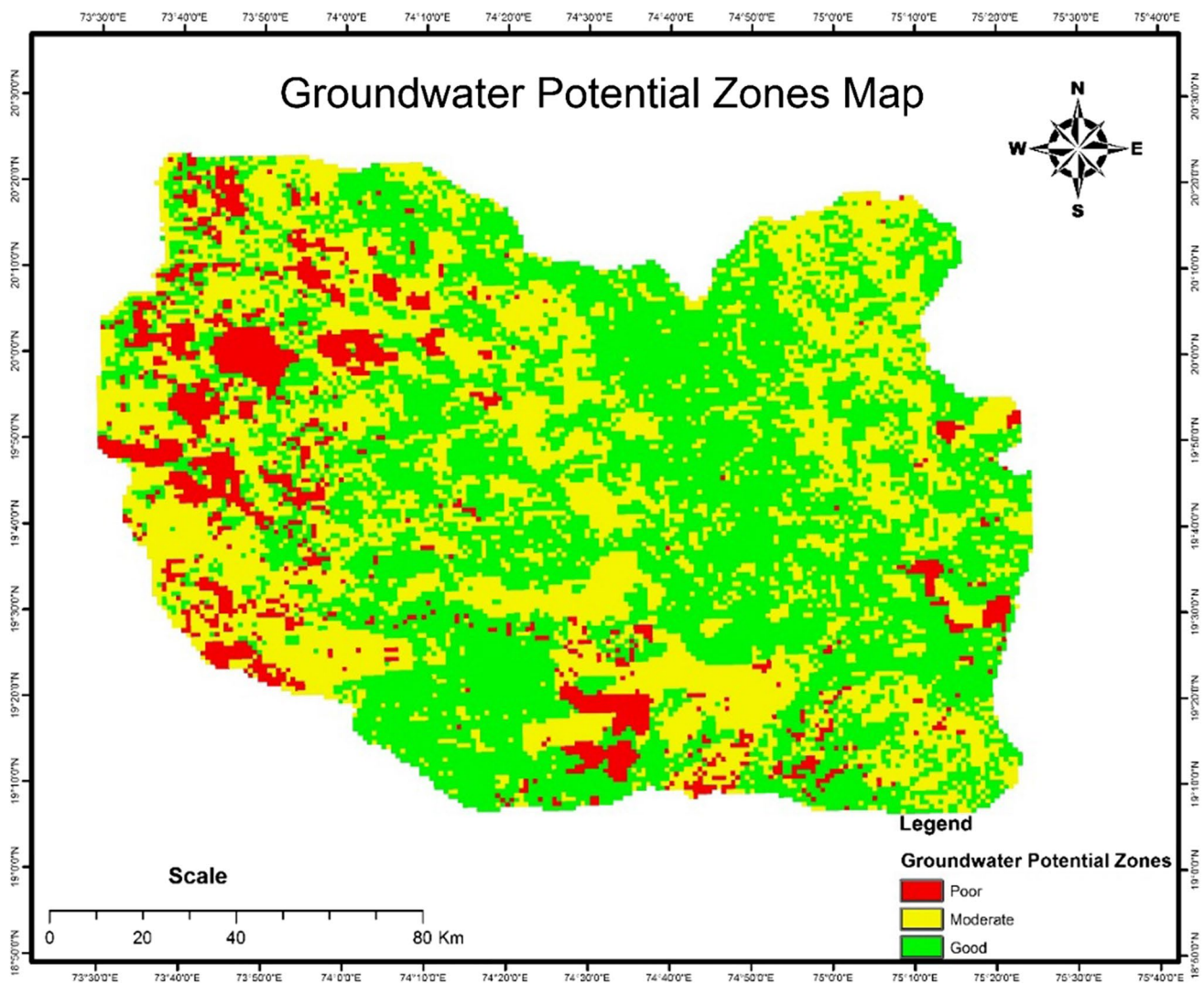
**Table 3** Assigned weight according to Satty's analytical hierarchical process

S.No	Influencing factors	Class interval	Groundwater Availability	Sattys Scale (in Frac.)	Sattys Scale (in deci.)	% Influence = (Sattys Scale/Sum)*100	Relative Weight
1	Drainage density	0–350	High	1	1	65.35	65
		350–1500	Moderate	1/3	0.33	21.56	22
		1600–3800	Low	1/5	0.2	13.07	13
				<b>1.53</b>			
2	Geology	Deccan Trap	Moderate	1/3	0.33	0.33	100
				<b>0.33</b>			
3	Geomorphology	Waterbodies	Moderate	1/3	0.33	28.44	28
		Structural origin	Moderate	1/3	0.33	28.44	28
		Denudational Origin	Low	1/4	0.25	21.55	22
		Andropogenic Origin	Low	1/4	0.25	21.55	22
				<b>1.16</b>			
4	Land use Land cover	Irrigated Intensive Agriculture	High	1/2	0.5	15.29	15
		Irrigated Agriculture	High	1/2	0.5	15.29	15
		Rainfed Agriculture	High	1/2	0.5	15.29	15
		Tropical Semievergreen	Moderate	1/3	0.33	10.09	10
		Tropical Moist Deciduous	Moderate	1/3	0.33	10.09	10
		Thorn Forest/Scrub (Southern)	Moderate	1/3	0.33	10.09	10
		Water Bodies	Moderate	1/3	0.33	10.09	10
		Settlement	Low	1/4	0.25	7.64	8
		Barren	very low	1/5	0.2	5.4	5
				<b>3.27</b>			
5	Soil	Very fine, montmorillonitic, Calcareous, isohyperthermic	High	1/2	0.5	20.08	20
		Fine montmorillonitic, Vertic Ustropepts	High	1/2	0.5	20.08	20
		Loamy, mixed. isohyperthermic, Lithic Ustorthents	Moderate	1/3	0.33	13.25	13
		Fine montmorillonitic, Calcareous, isohyperthermic	Moderate	1/3	0.33	13.25	13
		Clayey, montmorillonitic, shallow, Typic Ustropepts	Moderate	1/3	0.33	13.25	13
		Clayey-skeletal, Typic Ustropepts	Low	1/4	0.25	10.04	10
		Clayey, montmorillonitic, Typic Ustropepts	Low	1/4	0.25	10.04	10
				<b>2.49</b>			
6	Slope	0–3	Very High	1	1	54.64	54
		3–9	High	1/3	0.33	18.03	18
		9–18	Moderate	1/5	0.2	10.92	11
		18–31	Low	1/6	0.16	8.74	9
		> 31	Very Low	1/7	0.14	7.65	8
				<b>1.83</b>			
7	Lineament density	0–0.26	High	1	1	65.35	65
		0.27–0.54	Moderate	1/3	0.33	21.56	22
		0.55–1.3	Low	1/5	0.2	13.07	13
				<b>1.53</b>			

potential zones map was divided into three classes: excellent potential, poor, moderate and good. The study area is under the good potential zone (49.71%), moderate potential

zone (41.05%) and the low potential zone has been covered very least by 9.22%. The complete help of AHP through GIS resulted in the development of an effective procedure





**Fig. 4** Groundwater potential zone map

for spatial data management and weighted overlay analysis methods. The combination and analyses of different thematic layers show support in the demarcation of suitable groundwater zones. The results accuracy proves the Satty's analytical hierarchical process is one of the appropriate techniques to assign the weightage for potential groundwater studies.

Therefore, the study results can be utilized in the planning for exploring groundwater development and aquifer properties. The investigation additionally suggests the utilization of GIS innovation with RS data for the further study of groundwater, which can minimize the cost, time, human power with higher accuracy. The results can be helpful for groundwater, agriculture and irrigation purposes in the semi-arid region. The remote sensing and GIS techniques can be an adequate assessment of natural

resources under climate change factors. Watershed development programme executives and organizers can utilize the conclusion of this study area for appropriate managing of watersheds activities. The water harvesting structures have been improved to deep groundwater poor, and good aquifers zones and water should also be selected in the moderate and to good GWP zones to decrease the pressure on the close surface aquifers.

**Acknowledgements** We are grateful towards Principal Investigator, Centre for Advance Agriculture Science and Technology on Climate-Smart Agriculture and Water Management, MPKV, Rahuri (Agricultural University) and ICAR, NAHEP and World Bank for providing the necessary facilities and financial support for conducting this research.

## Declarations

**Conflict of interest** The authors do not have any conflict of interest to publish this research work.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

## References

- Agarwal E et al (2013) Delineation of groundwater potential zone: An AHP/ANP approach. *J Earth Syst Sci* 122(3):887–898
- Agrawal R, Argal R, Pokharna S (2009) An assessment of groundwater quality of Chaksu town in Rajasthan India. *Curr World Environ* 4(1):161–164
- Arabameri A, Rezaei K, Cerda A, Lombardo L, Rodrigo-Comino J (2019) GIS-based groundwater potential mapping in Shahroud plain, Iran. A comparison among statistical (bivariate and multivariate), data mining and MCDM approaches. *Sci Total Environ* 658:160–177. <https://doi.org/10.1016/j.scitotenv.2018.12.115>
- Arivazhagan S, Karthi A, Kirubakaran M, Mubasheer VT (2021) Change Detection Analysis and Delineation of Artificial Groundwater Recharge Suitability Zone for Dindigul Block Using Geoinformatics Techniques. In: Pande CB, Moharir KN (eds) *Groundwater Resources Development and Planning in the Semi-Arid Region*. Springer, Cham
- Arkoprovo B et al (2012) Delineation of Groundwater Potential Zones using Satellite Remote Sensing and Geographic Information System Techniques: A Case study from Ganjam district Orissa, India. *Res J Recent Sci* 1(9):59–66
- Asadi et al (2007) Remote Sensing and GIS Techniques for Evaluation of Groundwater Quality in Municipal Corporation of Hyderabad (Zone-V). India, *Int J Environ Res Public Health* 4(1):45–52
- Das B, Pal SC (2019) Assessment of groundwater recharge and its potential zone identification in groundwater-stressed Goghat-I block of Hugli District. West Bengal, India. <https://doi.org/10.1007/s10668-019-00457-7>
- Fathi S, Hagen JS, Matanó A, Nogueira GEH (2021) Review of GIS Multi-Criteria Decision Analysis for Managed Aquifer Recharge in Semi-Arid Regions. In: Pande CB, Moharir KN (eds) *Groundwater Resources Development and Planning in the Semi-Arid Region*. Springer, Cham
- Javed A, Wani MH (2009) Delineation of groundwater potential zones in Kakund watershed, Eastern Rajasthan, using remote sensing and GIS techniques. *J Geol Soc India* 73:229–236
- Kandekar VU, Pande CB, Rajesh J et al (2021) Surface water dynamics analysis based on sentinel imagery and Google Earth Engine Platform: a case study of Jayakwadi dam. *Sustain Water Resour Manag* 7:44. <https://doi.org/10.1007/s40899-021-00527-7>
- Kartic Bera and Jatisankar Bandyopadhyay (2012) Ground Water Potential Mapping in Dulung Watershed using Remote Sensing & GIS techniques West Bengal, India. *Int J Scientific Res Publ* 2(12):1–7
- Khadri SFR, Moharir K (2016a) Characterization of aquifer parameter in basaltic hard rock region through pumping test methods: a case study of Man River basin in Akola and Buldhana Districts Maharashtra India. *Model Earth Syst Environ*. <https://doi.org/10.1007/s40808-015-0047-9>
- Khadri, S. F. R and Chaitanya B. Pande (2014a), Morphometric Analysis of Mahesh River Basin Exposed in Akola and Buldhana Districts, Maharashtra, India Using Remote Sensing & GIS Techniques, *International Journal of Golden Research Thoughts*, 3 (11).
- Khadri S.F.R. and Chaitanya Pande (2014b), Hypsometric Analysis of The Mahesh River Basin in Akola and Buldhana Districts Using Remote Sensing & GIS Technology, *International Journal of Golden Research Thoughts*, Feb-2014I, 3 (9).
- Khadri SFR, Pande C (2015) Remote Sensing Based Hydro-geomorphological Mapping of Mahesh River Basin Akola, and Buldhana Districts, Maharashtra, India-Effects for Water Resource Evaluation and Management, *International. Jgeol Earth Environ Sci* 5(2):178–187
- Khadri SFR, Pande C (2016) Ground water flow modeling for calibrating steady state using MODFLOW software: a case study of Mahesh River basin India. *Model Earth Syst Environ* 2:39. <https://doi.org/10.1007/s40808-015-0049-7>
- Khadri S.F.R. Chaitanya Pande and Kanak Moharir (2013), Geomorphological investigation of WRV-1 Watershed management in Wardha district of Maharashtra India; using Remote sensing and Geographic Information System techniques, *International Journal of Pure and Applied Research in Engineering and Technology*, 1 (10).
- Kuriqi, A., Pinheiro, A.N., Sordo-Ward, A., Garrote, L., (2020b). *Energy Convers. Manage.* 223, 113267.
- Magesh NS, Chandrasekar N, Soundranayagam JP (2011) Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing GIS and MIF techniques. *Geosci Front* 3(2):189–196
- Magesh NS, Chandrasekar N, Soundranayagam JP (2012) Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. *Geosci Front* 3(2):189–196
- Maity DK, Mandal S (2019) Identification of groundwater potential zones of the Kumari river basin, India: an RS & GIS based semi-quantitative approach. *Environ Dev Sustain* 21:1013–1034. <https://doi.org/10.1007/s10668-017-0072-0>
- Moharir K, Pande C, Patil S (2017) Inverse modeling of Aquifer parameters in basaltic rock with the help of pumping test method using MODFLOW software. *Geosci Front Elsevier J* 8(6):1385–1395
- Moharir K, Pande C, Singh S, Choudhari P, Rawat K, Jeyakumar L (2019) Spatial Interpolation Approach-Based Appraisal of Groundwater Quality of Arid Regions in Aqua Journal 68(6):431–447
- Nagarajan M, Singh S (2009) Assessment of Groundwater Potential Zones using GIS Technique. *J Indian Soc Remote Sens* 37:69–77
- Pande CB, Moharir K (2015) GIS-based quantitative morphometric analysis and its consequences: a case study from Shanur River Basin Maharashtra India. *Appl Water Sci Springer J* 7(2):861–871
- Pande CB, Khadri SFR, Moharir KN, Patode RS (2017) Assessment of groundwater potential zonation of Mahesh River basin Akola and Buldhana districts Maharashtra, India Using Remote Sensing and GIS Techniques. *Sustain Water Res Manag Springer J*. <https://doi.org/10.1007/s40899-017-0193-5>
- Pande CB, Kanak N, Moharir and Rajeshwari Pande (2018a) Assessment of Morphometric and Hypsometric study for watershed development using spatial technology - A Case Study of Wardha river basin in the Maharashtra India in *International. J River Basin*

- Manag Taylors & Francis J. <https://doi.org/10.1080/15715124.2018.1505737>
- Pande CB, Kanak N, Moharir KSFR, Patil S (2018b) Study of Land Use Classification in the Arid Region using Multispectral Satellite Images. *Appl Water Sci Springer J* 8(5):1–11
- Pande CB, Moharir KN, Singh SK, Varade AM (2019) An integrated approach to delineate the groundwater potential zones in Devdari watershed area of Akola district Maharashtra, Central India. *Environ Develop Sustain Springer J*. <https://doi.org/10.1007/s10668-019-00409-1>
- Pande CB, Moharir KN, Khadri S (2021) Watershed Planning and Development Based on Morphometric Analysis and Remote Sensing and GIS Techniques: A Case Study of Semi-Arid Watershed in Maharashtra, India. In: Pande CB, Moharir KN (eds) *Groundwater Resources Development and Planning in the Semi-Arid Region*. Springer, Cham
- Pandian.M Rajasimman.U Saravanel.J, (2014) Identification of Groundwater Potential Recharge Zones using WETSPASS Model in parts of Coimbatore & Tiruppur Districts in Tamil Nadu India. *Int J Water Res* 2(1):27–32
- Patode RS, Pande CB, Nagdeve MB, Moharir KN, Wankhade RM (2017) Planning of Conservation Measures for Watershed Management and Development by using Geospatial Technology – A Case study of Patur Watershed in Akola District of Maharashtra. *Curr World Environ* 12(3):706–714
- Prasad RK, Mondal NC, Banerjee P, Nandakumar MV, Singh VS (2008) Deciphering potential groundwaterzone in hardrock through the application of GIS. *Environ Geol* 55:467–475. <https://doi.org/10.1007/s00254-007-0992-3>
- Priyan K (2021) Issues and Challenges of Groundwater and Surface Water Management in Semi-Arid Regions. In: Pande CB, Moharir KN (eds) *Groundwater Resources Development and Planning in the Semi-Arid Region*. Springer, Cham
- Rane N, Jayaraj GK (2021) Evaluation of Multiwell Pumping Aquifer Tests in Unconfined Aquifer System by Neuman (1975) Method with Numerical Modeling. In: Pande CB, Moharir KN (eds) *Groundwater Resources Development and Planning in the Semi-Arid Region*. Springer, Cham
- Saaty TL (1980) *The analytical hierarchy process*. McGraw Hill, New York
- Saaty TL (1997) Ascending method for priorities in hierarchical structures. *J Math Psychol* 15:234–281. [https://doi.org/10.1016/0022-2496\(77\)90033-5](https://doi.org/10.1016/0022-2496(77)90033-5)
- Sajikumar N, Pulikkottil G (2013) Integrated Remote Sensing and GIS Approach for Groundwater Exploration using Analytic Hierarchy Process (AHP) Technique. *IJIRSET* 2(1):66–74
- Varughese A (2012) Identification of shallow groundwater potential zones using GIS – A case study. *Int J Adv Eng Appl* 5(4):65–70

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.