Applied Water Science (2021) 11:186
https://doi.org/10.1007/s13201-021-01522-1

ORIGINAL ARTICLE

Delineation of groundwater potential zones for sustainable development and planning using analytical hierarchy process (AHP), and MIF techniques

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Received: 7 July 2021 / Accepted: 18 October 2021 / Published online: 6 November 2021

Abstract

Groundwater plays a vital role in the sustainable development of agriculture, society and economy, and it's demand is increasing due to low rainfall, especially in arid and semiarid regions. In this context, delineation of groundwater potential zones is essential for meeting the demand of different sectors. In this research, the integrated approach consisting of analytical hierarchy process (AHP), multiple influence factors (MIF) and receiver operating characteristics (ROC) was applied. The demarcation of groundwater potential zones is based on thematic maps, namely Land Use/Land Cover (LULC), Digital Elevation Model (DEM), hillshade, soil texture, slope, groundwater depth, geomorphology, Normalized Difference Vegetation Index (NDVI), and flow direction and accumulation. The pairwise comparison matrix has been created, and weights are assigned to each thematic layer. The comparative score to every factor was calculated from the overall weight of two major and minor influences. Groundwater potential zones were classified into five classes, namely very poor, poor, moderate, good and very good, which cover an area as follows: 3.33 km^2, 785.84 km^2, 1147.47 km^2, 595.82 km^2 and 302.65 km^2, respectively, based on AHP method. However, the MIF groundwater potential zones map was classified into five classes: very poor, poor, moderate, good and very good areas covered 3.049 km^2, 567.42 km^2, 1124.50 km^2 868.86 km^2 and 266.67 km^2, respectively. The results of MIF and AHP techniques were validated using receiver operating characteristics (ROC). The result of this research would be helpful to prepare the sustainable groundwater planning map and policy. The proposed framework has admitted to test and could be implemented in different in various regions around the world to maintain the sustainable practices.

Keywords Thematic maps · GIS · AHP · MIF · Remote sensing

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Introduction

Water is a significant natural resource to mankind and has been using and controlling from the moment of creation to sustain life. Groundwater for daily use in various purposes like drinking, cooking and grooming has provided about half the feasible freshwater. Irrigation and industrial production are depending on the groundwater supply (Ndatuwong et al. 2014; Takase et al. 2019; Luker et al. 2019). The regime of groundwater resources is difficult for researchers, planners and decision-makers in massive population and water shortage countries with surface and groundwater quality are affected by climate change (Al-Bakri et al. 2013; Zanini et al. 2019). In many regions, the groundwater level decreases, and the unavailability of freshwater to agriculture and irrigation uses. Therefore, this is also declining, which affects crops productivities (Agarwal et al. 2016). Urban water demands are continuously growing (Gauthier et al. 2019; Ghosh et al. 2019; Ray 2019). The remaining irrigated land has fast amplified from 28.7% in 1950 to 62.3% in 2013, respectively, in India. Climate change also affects water's demand and supply chain (Machiwal et al. 2011; Sahoo et al. 2015; Chinchmalatpure et al. 2019; Rudra 2019). In this context, groundwater development must be a top priority in any country (Suhag 2019; Thirumurugan et al. 2019).

The occurrence and groundwater distribution in geological rock formation depend primarily on the permeability of the formation. Rainwater quickly percolates and adds to groundwater by interconnecting cracks, joints, faults and shear zones or solution cavities (Ganapuram et al. 2009; Elmahdy et al. 2013; Khalid 2019). The hard rock area has been found in the central region of India. Surface runoff is very high in this area, and rainwater is not easily conserved in the fracture rock and aquifers. Most of the groundwater has been presented and conserved in the cracked and weathered rock areas (Saha et al. 2017; Díaz-Alcaide et al. 2019). Systematic aquifer mapping is required for sustainability growth but has not received much attention (Yu et al. 2019; Bierkens et al. 2019; Arabameri et al. 2019).

Remote sensing (RS) and geographical information system (GIS) have benefited from joining together primary and numeral data-set (Burrough 1986; Shailaja et al. 2019). Remote sensing has played a vital role to map and analysis at synoptic scales (Mahato et al. 2019; Chen et al. 2019; Gueretz et al. 2019). A combination of geospatial technologies datasets was processed in the RS and GIS software and used to delineate and interpret the suitable groundwater areas (Mahato et al. 2018; Qadir et al. 2019). Many scientists have used advanced techniques for the preparation of thematic factors, including slope, surface runoff, rainfall, soil types, drainage map, geomorphology, geological formation, land use, flow direction, groundwater level, NDVI and many others (Pradhan et al. 2019; Rani et al. 2019; Maity et al. 2019). It delivers correctness and decreases the probabilities of human mistakes by using a numeral of essential parameters like geology, lineament, lineament structure, stream density, slope, land use, and soils types. Previously, various approaches have been used for interpreting the groundwater suitable sites using weighted overlay analysis method, multi-influence factor (MIF) and AHP techniques (Kanagaraj et al. 2018; Thapa et al. 2018; Ghimire et al. 2019), RS, GIS and hydrological data were grouped (Singh et al. 2010; Selvarani et al. 2016), statistical approaches (Umar et al. 2014; Rajaveni et al. 2015; Sener et al. 2018) analytical hierarchy procedure and groundwater flow modeling (Murmu et al. 2019; Sashikkumar et al. 2017).

The Mula river basin is situated under the semi-arid condition of Maharashtra in India. In this area, more rainfall was observed only during monsoon seasons, and in particular in the last two months of monsoon, more rain was reported in the entire basin. In this context, an accurate groundwater potential zones map can play an essential role in maintaining the balance supply of water to human, industry and ecology development. Furthermore, changeable rainfall during the monsoon and freshwater shortage starting during December to June, upcoming year sustainable watershed development and planning should be required in these regions. This paper has provided more accurate techniques and information for groundwater potential maps that are useful for decreasing the groundwater issues and storing water in the aquifer.

Therefore, the purpose of this study delineated a correct groundwater potential map by using RS and GIS, the map is created using analytical hierarchy process (AHP) and multi-influence factor (MIF) techniques and is validated using ROC. The overall references of MIF and AHP approaches are listed and described in Table 1.

Materials and methods

Study area

The Mula river flows from northwest to southeast direction. The basin is situated between 19° 34′ 12" N latitude and 74° 59′ 24" E longitude (Fig. 1). The minimum and maximum elevation lies between 555 and 650 m above mean sea level (Source: DEM). The total basin area is 2275.86 km^2. The area has lowered from sources in a bottomless valley with a deep mountain, shortly in the northeast and for another 30 km enters the plains in the same direction. The entire longitude is around 2.5 m from the Mula river basis to convergence with the Pravara river. Many hills, the Mula basin, join Rahuri in a bottomless bed on steep rocky sides. In this area, sugarcane is the main crop, and secondary crops are onion, wheat and vegetables crops, etc., which indicates

Table 1 Literature analysis of detection of the groundwater potential zones through AHP and MIF methods

Thematic maps	Models/Methods	Description	Multicollinearity check	References
Soil texture, Stream link, Elevation, Weighted junction matrix score-based surface, Normalised Difference Water Index (NDWI), Land use category, Rainfall, NDVI, Geology, Slop, Lineament, Recharge, Groundwater Level	Multi-criteria decision-making models, AHP, PCA method, knowledge-based models	The natural resources and hydrological maps were used for the preparation of groundwater zones map with various methods and models applied on the processing of groundwater zones map	Not performed	Mahato et al. (2018); Pradhan et al. (2019); Gueretz et al. (2019)
Land use and land cover, geomorphology, geology, drainage density, soil texture, rainwater, topography, soil slope, slope, NDVI, groundwater depth of pre–post-monsoon	Remote sensing and GIS techniques and weighted method analysis	Remote sensing and geographical information system have carried in this subject taking great chance of different ways of parametric analysis	Not performed	Thapa et al. (2018); Mahato et al. (2019); Ghimire et al. (2019); Shailaja et al. (2019)
Elevation, slope, flow accumulation and agriculture, geomorphology, geology and lineament	Remote sensing and GIS techniques	These parameters have been also described as the leading characteristics along with the other influences cited above	Not performed	Qadir et al. (2019); Maity et al. (2019); Chen et al. (2019)
Geology, lineament, lineament structure, stream density, slope, land use classes and soils types	Geospatial technology and satellite data	Remote sensing and GIS information system also have the benefit of joining together basic and digital data sets	Not performed	Burrough, (1986); Rani et al. (2019)
LULC, soil, landforms, geology, groundwater recharge rate, stream density, NDVI, hydraulic data, water level of pre–post-monsoon	Multi-influence factor (MIF) and AHP	Traditional and advanced various methods have been used for the interpreted groundwater suitable sites and zones	Not performed	Rajaveni et al., (2015); Kanagaraj et al. (2018); Pande et al. (2019)
RS and GIS and hydrological data	Statistical approaches, AHP method and groundwater flow modeling	RS and GIS with hydrological data have been effectively used in the groundwater resources planning based on the AHP and other methods	Not performed	Selvarani et al. (2016) Umar et al. (2014) Sener et al. (2018) Elmahdy et al. (2013); SashikKumar et al. (2017)
Geology, soils types, lineaments, geomorphology, slope, density and drainage density	AHP and GIS	AHP and GIS methods are a very popular for the demarcation of groundwater potential zones mapping	Not performed	Ajay Kumar et al. (2020)
Geomorphology, Geology, aquifer depth, surface slope, geology formation, soil erosion, soil types, lineament density, stream density and rainfall	GIS, RS technology and AHP	Geological-related parameters are main role in the demarcation of the groundwater recharge planning and sustainable watershed management	Not performed	Shekhar and Pandey (2015); Pande et al. (2017); Arivazhagan et al. (2021)
Rainwater, groundwater depth of pre–post-seasons, landforms, geology, soil erosion, topography, surface elevation, land use, aquifer net recharge and surface water bodies	Weighted Overlay Method (WOA), GIS and RS	All thematic related to geology, hydrology is very key role in the groundwater development planning	Not performed	Machiwal et al. (2011); Pande et al. (2017)
Land cover, groundwater depth, slope, drainage, flow direction, flow accumulation and geomorphology	WOA, GIS and MIF	The MIF method has demarcated the groundwater potential zones mapping based on the satellite data and software	Not performed	Mehra et al., (2016)

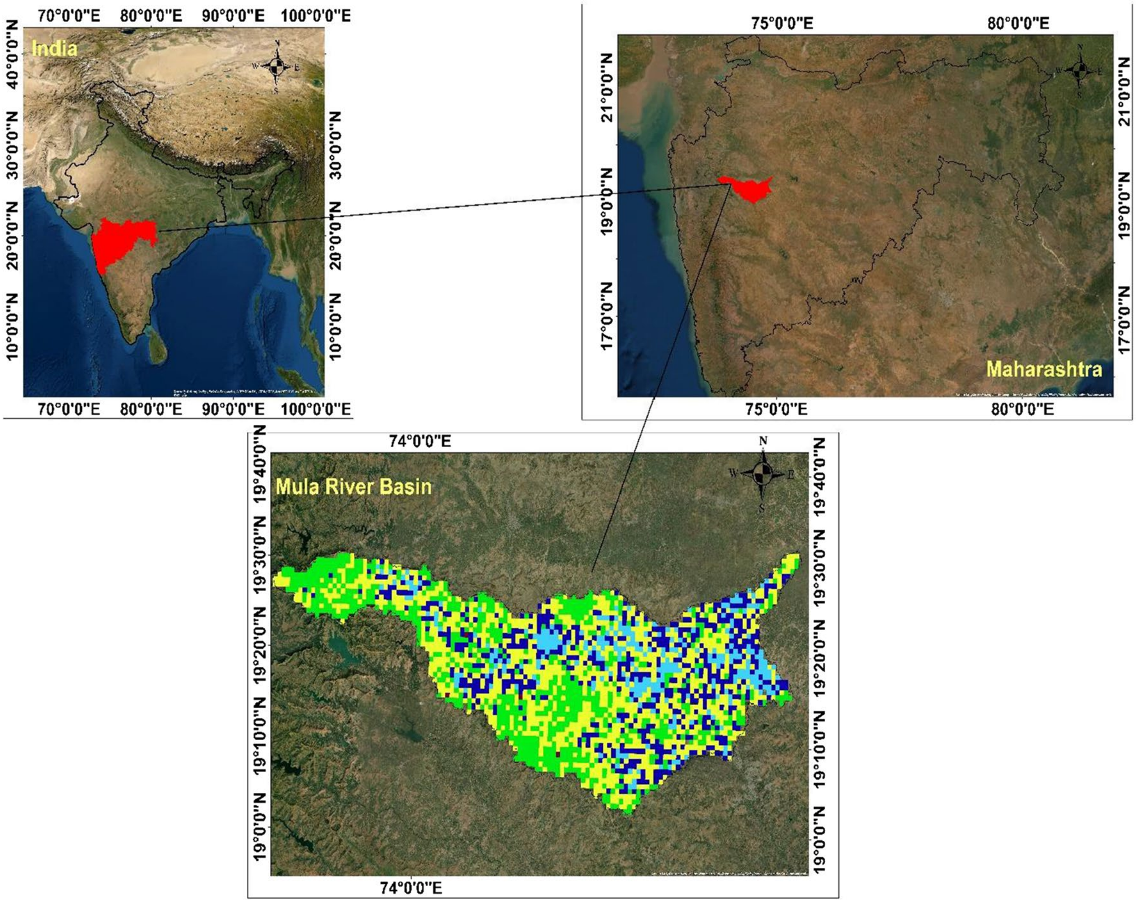

Fig. 1 Location map of Mula river basin area

crops based on the dam water and groundwater in the entire basin area. The Mula Dam is constructed and established on the Mula river in western region of Rahuri block. The maximum water storage volume is 26 TMC. Total annual rainfall is 345–850 mm (Source: Indian Metrological Department (IMD)) in the whole river basin area; it is very low rainfall compared to other regions of the state. The overall area is under the basaltic rock and Deccan Plateau. The river Mula is a tributary of the Bhima. Mula River has a dendritic drainage pattern type. In this view, the groundwater potential map can play a significant role in the groundwater level improvement and future challenges to face water demand and other related issues. The minimum and maximum temperatures recorded was 24 °C and 42 °C (Source: IMD) in Ahmednagar District.

Selection of the data layers

For this study, different factors, namely land use/land cover (LULC), soil types, geomorphology, digital elevation model (DEM), flow direction, hillshade, slope, normalized difference vegetation index (NDVI), aspect and groundwater depth of aquifer, were used. Basin level geological and hydrological information has been play an important role in the spatial groundwater circulation. The capacity for water holding for discharge/renew of rock groups and aquifer deposit was greatly affected by characteristics of aquifers (permeability, hydraulic conductivity, transmissivity and porosity), interconnectivity and forms of rock (Yeh et al. 2016; Mukherjee et al. 2020).

The NDVI shows the canopy density calculated by Sentinel-2 data, which is helpful as a factor considering the high canopy bulk increases the probability of groundwater harvesting in poor aquifer zone (Moharir et al. 2017; Archibald et al. 2019). The adopted methodology has been used for obtaining the potential groundwater maps for the basin area, and the adopted techniques are presented in Fig. 2.

Data collection and preparation of thematic layers

For the current analysis, ten thematic layers have been considered. The data sources and layers of information are

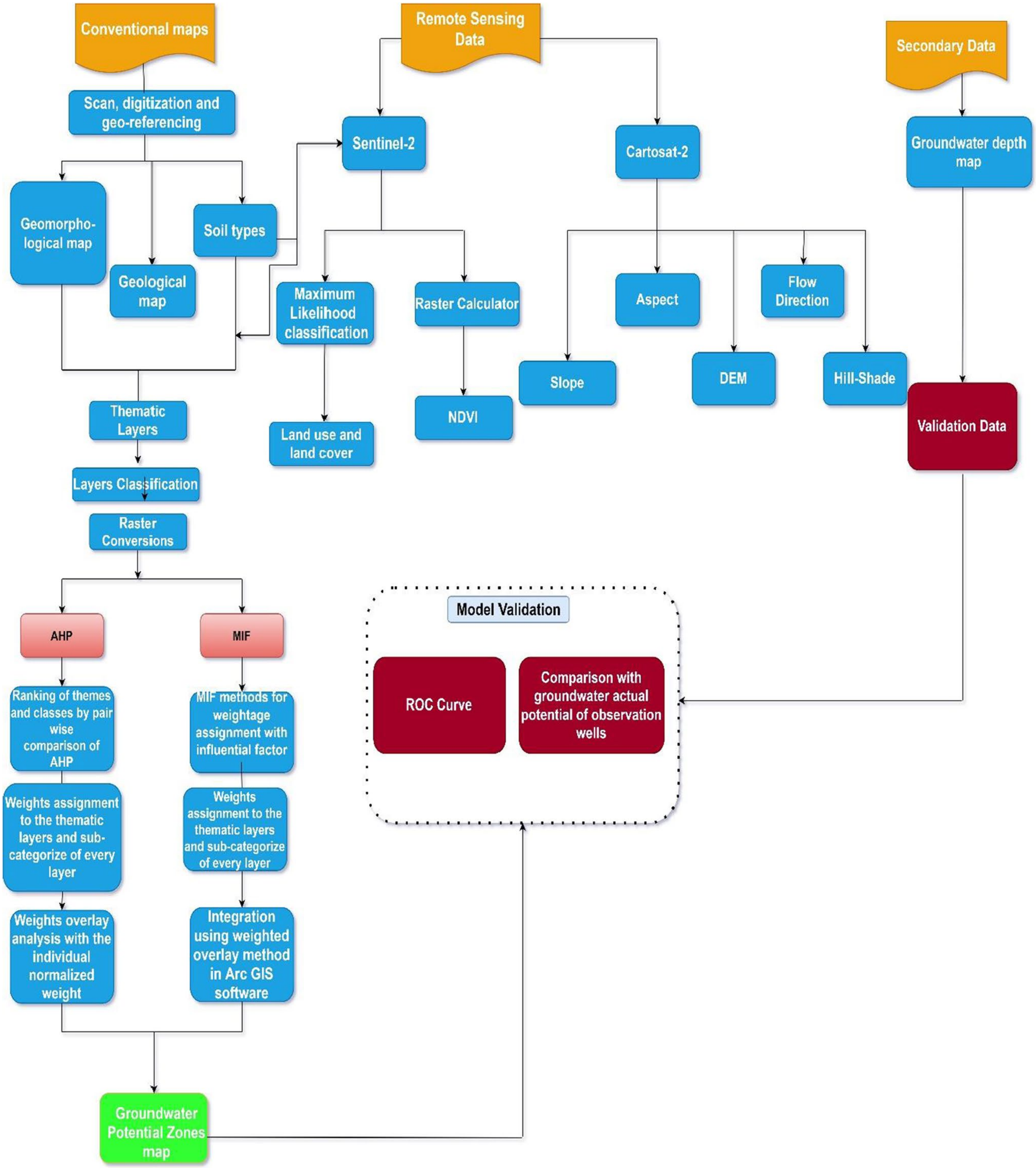

Fig. 2 Flowchart of methodology of the study area

Table 2 Selected parameters and related sources

Name of parameters	Sources
LULC	Linear Imaging Self-Scanning Sensor, (LISS-IV), November 2020
Soil texture	National Bureau of Soil Survey and Land Use planning, (NBSSLUP), Nagpur, India
Geomorphology	Geological Survey of India (GSI) (1: 50,000 scale)
Digital Elevation Model (DEM)	Cartosat-1data with Resolution 32 m, BHUVAN
Flow direction	Shuttle Radar Topography Mission (SRTM) data by spatial analyst tool in ArcGIS 10.5 software
Hillshade	SRTM data by spatial analyst tool in ArcGIS 10.5 software
Slope	Slope map
NDVI	NDVI maps developed by Sentinel-2 data
Aspect	SRTM data by spatial analyst tool in ArcGIS 10.5 software
Groundwater depth	Prepared from water level information by Interpolation method
Geospatial software	ArcGIS software 10.6, WOA, Overlay Analysis Tools

described in Table 2. Satellite imagery was collected from National Remote Sensing Center (NRSC) and U.S. Geological Survey earth explorer, accessible through http://bhuvan.nrsc.gov.in and pre-processed and https://earthexplorer.usgs.gov by image processing software. Geology was prepared from the Geological Survey of India (GSI, Nagpur) map available at a 1: 50,000 scale. A soil texture map has been prepared from National Bureau of Soil Survey and Land Use planning (NBSS & LUP), Nagpur. The groundwater level data were collected from observation wells of Central Groundwater Board (CGWB), India and used for validation. AHP and MIF results were validated with receiver operating characteristic curve (ROC). The basic approach for assessing the reliability of the analytical assessment is determined by the ROC (Egan 1975). False-positive values along with the x-axis, true positive along with the y-axis rate are plotted for ROC. The ROC curve is a balance of the two values (Negnevitsky 2002). The complete procedure used in this analysis is shown in Fig. 2.

Weighting and ranking of every layer (AHP)

Analytical hierarchy process (Saaty 1986, 2008) was used to calculate the weight of thematic layers. Every layer's effect was not equal; hence a relative weight, as per Saaty's scale from 1 to 12, was added to each thematic layer with its difficulties and capacity for water holding. The relative weights were allocated depending on past reports on other geographical areas with ground knowledge. The comprehensive stages have been identified of the procedure (Mu et al. 2017).

The pairwise comparison matrix has been created for thematic layers with strength judgments (Table 3). Based on their formation/categories, the slope, geomorphology, soil types and land use maps were categorized. AHP technique supports multi-parameter calculation (Saaty 1986; Bhatla et al. 2019). The slope map has divided into two sub-classes depending on the digital elevation model (Elewa et al. 2011). The NDVI thematic map was classified into four sub-classes using spatial analysis tools. However, a groundwater depth map has been prepared into four sub-classes based on the interpolation method in the ArcGIS platform. One sub-class was determined with a slope, hillshade and Digital Elevation Model (DEM) values of 0 and one class were found by the Jenks natural disruptions sorting technique as an extensively used technique for the creation of maps of the slope, hillshade and DEM sub-classes (Jothibasu et al. 2016; Arulbalaji et al. 2019). Additionally, some investigators have implemented the Jenks natural interruptions classification technique to categorize various maps (Mallick et al. 2019). A comparative rank on a 0–12 scale (Table 7) (Saaty's) was allocated to every sub-class of thematic layers depending on relative influences groundwater availability (Tables 4 and 5). The finding on the pairwise contrast and sub-classes of thematic maps was verified by estimating the consistency ratio (CR) by Eqs. (1 and 2) (Saaty 1990).

The following equation was used to measure the consistency ratio (CR) (Table 3).

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{(n - 1)} \tag{1}$$

Table 3 Pairwise comparison matrix of thematic maps and uniformity validation

Factors	Soil texture	LULC	Geomorphology	DEM	Flow direction	Hillshade	Slope	NDVI	Aspect	Ground-water depth	Weight	λ	λ_{max}	CI	CR
Soil texture	15/15	15/10	15/15	15/10	15/10	15/10	15/10	15/10	15/05	15/15	0.15	10	10	(10–10) /(10–1) = 0	0/1.48 = 0 < 0.10
LULC	10/15	10/10	10/15	10/10	10/10	10/10	10/10	10/10	10/05	10/15	0.10	10			
Geomorphology	15/15	15/10	10/15	15/10	15/10	15/10	15/10	15/10	15/05	15/15	0.10	10			
DEM	10/15	10/10	10/15	10/10	10/10	10/10	10/10	10/10	10/05	10/15	0.10	10			
Flow direction	10/15	10/10	10/15	10/10	10/10	10/10	10/10	10/10	10/05	10/15	0.10	10			
Hillshade	10/15	10/10	10/15	10/10	10/10	10/10	10/10	10/10	10/05	10/15	0.10	10			
Slope	10/15	10/10	10/15	10/10	10/10	10/10	10/10	10/10	10/05	10/15	0.10	10			
NDVI	10/15	10/10	10/15	10/10	10/10	10/10	10/10	10/10	10/05	10/15	0.10	10			
Aspect	05/15	05/10	05/15	05/10	05/10	05/10	05/10	05/10	05/05	05/15	0.05	10			
Groundwater depth	15/15	15/10	15/15	15/10	15/10	15/10	15/10	15/10	15/05	15/15	0.10	10			

Table 4 Assigned weight ranks and overall of the sub-classes of each thematic maps

Factors	Weight	Rank	Overall
Soil texture			
Loam	15	4	60
Sandy clay loam		5	75
Clay loam		3	45
Clay		3	45
LULC			
Wood or forest land—good	10	2	20
Wood or forest land—poor		2	20
Agriculture land		2	20
Water body		1	10
Bare soil		3	30
Geomorphology			
Pediplain	15	2	30
Pediment		3	45
Plateau		5	75
DEM			
0	10	3	30
1512		7	70
Flow direction			
1	10	1	10
255		9	90
Hillshade			
0	10	4	40
180		6	60
Slope			
0	10	6	60
3.61		4	40
NDVI			
− 0.21–0.16	10	3	30
0.17–0.36		3	30
0.37–0.54		3	30
0.55–1		1	10
Aspect			
− 1	05	1	05
359.77		4	20
Groundwater depth			
4.6–7.7	15	3	45
7.8–9		2	30
9.1–10		3	45
11–14		4	60

Table 5 Assigned score and individual score of every thematic layer for GPZ

Parameters	Score	Individual score	Groundwater potential zone
Soil texture			
Loam	20	7	Poor
Sandy clay loam		6	Very Poor
Clay loam		5	Moderate
Clay		2	Good
LULC			
Wood or forest land—good	10	2	Good/Very Good
Wood or forest land—poor		1	Good/Very Good
Agriculture land		2	Good/Very Good
Water body		1	Very Good
Bare soil		4	Poor
Geomorphology			
Pediplain	15	2	Very Good
Pediment		5	Moderate
Plateau		8	Very Poor/Poor
DEM			
0	05	2	Moderate
1512		3	Very Poor/Poor
Flow direction			
1	05	1	Very Good
255		4	Very Poor
Hillshade			
0	05	2	Very Good
180		3	Moderate
Slope			
0	10	4	Moderate
3.61		6	Very Poor/Poor
NDVI			
−0.21–0.16	10	4	Very Poor/Poor
0.17–0.36		2	Good
0.37–0.54		2	Moderate
0.55–1		2	Very Good
Aspect			
−1	05	1	Moderate
359.77		4	Very Good
Groundwater depth			
4.6–7.7	15	3	Moderate
7.8–9		2	Very Good
9.1–10		3	Moderate
11–14		4	Moderate

Table 6 Proposed score of each influencing parameter

Factors	Major effect (*A*)	Minor effect (*B*)	Relative weight (*A* + *B*)	Allocated weight
Soil texture	3	0.5	3.5	24
LULC	3	0	3	20
Geomorphology	3	0.5	3.5	15
DEM	2	0	2	4
Flow direction	2	0	2	3
Hillshade	2	0	2	5
Slope	3	0.5	3.5	9
NDVI	3	0.5	3.5	8
Aspect	2	0	2	2
Groundwater depth	4	0.5	4.5	11

where n is the number of parameters helpful in the study, where RI is the random index whose value by influencing parameter; and CI is consistency index which is estimated by the following Equations:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

$$\mathrm{CR} = \frac{0}{1.48} = 0.$$

If CR value ≤ 0.10, it is acceptable for analysis. If CR = 0, it is perfect level of consistency.

Overlay analysis method

Here the weights have been assigned to every thematic layer and ranks were allocated to every sub-class of various layers. The groundwater potential zones can be reported using multiple overlying maps using the weighted overlay technique (spatial analyst tool) in ArcGIS 10.5 using Eq. (3).

$$\mathrm{GPZ} = \sum_{i=1}^{n} \left(W_i X R_i\right). \tag{3}$$

Every factor and their particular classes have assigned the grades and weights depending on their proportional possible influence (Table 5).

The following equation was applied to calculate GWPZ.

$$\begin{aligned}\mathrm{GWPZ} = {} & \left(\mathrm{ST}_w \times \mathrm{ST}_{wi}\right) + \left(\mathrm{GM}_w \times \mathrm{GM}_{wi}\right) + \left(\mathrm{SL}_w \times \mathrm{SL}_{wi}\right) + \left(D_w \times D_{wi}\right) \\ & + \left(\mathrm{FD}_w \times \mathrm{FD}_{wi}\right) + \left(\mathrm{LULC}_w \times \mathrm{LULC}_{wi}\right) + \left(\mathrm{HS}_w \times \mathrm{HS}_{wi}\right) + \left(\mathrm{NDVI}_w \times \mathrm{NDVI}_{wi}\right) \\ & + \left(\mathrm{Aspect}_w \times \mathrm{Aspect}_{wi}\right) + \left(\mathrm{GD}_w \times \mathrm{GD}_{wi}\right)\end{aligned} \tag{4}$$

Table 7 Saaty's consistency indices of randomly generated reciprocal matrices

Order of the matrix (N)	1	2	3	4	5	6	7	8	9	10	11	12
RCI value	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Table 8 Classification of weighted parameters influencing the GWPZ

Parameters	Score	Individual score
Soil texture		
Loam	22	6
Sandy clay loam		8
Clay loam		4
Clay		4
LULC		
Wood or forest land—good	20	3
Wood or forest land—poor		5
Agriculture land		5
Water body		8
Bare soil		
Geomorphology		
Pediplain	15	3
Pediment		4
Plateau		8
DEM		
0	04	2
1512		22
Flow direction		
1	03	2
255		1
Hillshade		
0	05	2
180		3
Slope		
0	09	4
3.61		5
NDVI		
−0.21–0.16	08	3
0.17–0.36		2
0.37–0.54		2
0.55–1		1
Aspect		
−1	02	1
359.77		1
Groundwater depth		
4.6–7.7	11	1
7.8–9		3
9.1–10		4
11–14		4

where GWPZ illustrations the potential areas identified using Eq. 4. The various thematic maps such as soil texture (ST), LULC LULC (LULC), geomorphology (GM), DEM (D), flow direction (FD), hillshade (HS), slope (SL), NDVI, aspect, and groundwater depth (GD), have prepared. The weight of a particular class and layer has denoted by *w* and *wi*. The assigned weighted and individual scores were allocated as per the sub-classes of thematic layers. Those weighted values were used to demarcate possible zones viz. poor, very poor, good, moderate, and very good according to the potential groundwater areas (Arulbalaji et al. 2019).

Multi-influencing factors (MIF)

The important factors revealed interrelationship between factor and their effects are specified in Table 6. If an impact occurred, viewing a robust correlation between factors, after 1.0, a score is assigned. If a minimum effect occurred, revealing poor relations between elements, and those parameters score 0.5. The comparative score to each parameter was measured from the overall weight of two major and minor influences in the definition of groundwater potential zones. The relative score is extra functional for calculating the planned score of individually impacting parameters, as specified in Eq. 5. The arrangement of weighted influencing parameters is assigned into sub-classes to delineate potential groundwater areas (Tables 7 and 8).

$$D = \left(\frac{(A + B)}{\sum (A + B)}\right) \times 100 \tag{5}$$

where D represents the suggested mark of each inducing factor, A positions for the major relationship both factors, and B *is* view points for the minor interrelationship with both parameters.

Each group of single themes has been given a rank by weighted overlay investigation (Ghosh et al. 2015). By groundwater and hydrogeology information, the required scores have been assigned under the multi-influencing factor (MIF) of that specific factor (Manap et al. 2014). The methodology flowchart and the weighting particulars allocated to the different maps and their characteristics in the current study are shown in Tables 8 and 2. The single influence parameters' planned score was separated and assigned to each reclassified sub-parameter (Table 8).

Sensitivity analysis

The sensitivity analysis based on the map removal technique has been applied to identify to most sensitive layer in producing the GWPZ map. The study was performed using the 'raster calculator' of map algebra function available in the spatial analyst tool of ArcGIS.

Validation and accuracy of GWPZ

Total 35 dug and open wells data have overlapped to know the accuracy of the groundwater potential map. Receiver operating characteristic curve (ROC) method was applied to compare the accuracy of MIF- and AHP-based GWPZ. ROC helps to identify which method is the best for groundwater suitable zone mapping (Pourtaghi et al. 2014; Ozdemir et al. 2011). The ROC plot shows a range from 0.5 to 1.0. To test the accurateness of groundwater potential maps based on the ROC model (Nandi et al. 2009). The AUC is equal to 0.5 if models do not assess the amount of groundwater zone. ROC makes the graphical picture plotting the true positive (sensitivity) and untruthful positive (1-specificity) rates on the *Y* and *X* axes, respectively (Pourghasemi et al. 2012). The observation locations of wells were overlapped on the groundwater potential map and evaluated the correctness of the outcome using Eq. (6) in the numerous groundwater potential areas in the river areas (Murmu et al. 2019).

$$\text{Accuracy of high GWP (\%)} = \frac{\text{Well with low GWF in high GWPZ}}{\text{Total no. of wells in low GWP}} \times 100 \tag{6}$$

Results and discussion

The basin is under a hard basaltic rock and does not have more water in the fractured rock zones. The demarcated groundwater potential areas map exposed projecting dissimilarities in potential areas of the groundwater basing region. About 3.049 km^2, 567.42 km^2, and 3.33 km^2, 785.84 km^2 of the river basin area have very poor and poor possible areas of groundwater by MIF and AHP methods, respectively. At same time, basaltic rock is under the extremely low potential of groundwater in the river basin area. The MIF potential map has shown 20.43% very poor and poor area, but the AHP groundwater potentiality map has demarcated 25.34% very poor and poor area. The area is near about 20.43 and 25.34% semi-critical zones found as per MIF and AHP techniques. However, 1124.50 km^2, 868.86 km^2 and 266.67 km^2 of the basin areas have been observed as good, moderate and very good potential groundwater zones, respectively. Based on the MIF techniques, similarly, 1147.47 km^2, 567.82 km^2 and 302.65 km^2 of river basin area have identified classes, namely, good, moderate and very good groundwater possible areas, correspondingly using the AHP technique (Table 8).

Thematic layers

The data interrelated to different thematic layers created to potential zones maps are deliberated in below:

Aspect

Aspect replicates the moisture retention, vegetation, moisture air and attitude of rock bedding, which influenced soil structure's physical assets, sloped materials and potential groundwater zones. In the current investigation, the northern areas and northeast region of the river area have the positive weight for groundwater potential and south and southeast part of the study have higher steeper value of slope and gradient and shows negative weight for potential zones map of groundwater (Fig. 3).

Curvature

The most significant characteristic to be measured for observing the potential groundwater areas, water hydrology and instability assessment of terrain is based on the curvature of peak slopes, representing the morphology of the area topography. The dynamic of the subsurface of hydrology, formation and accumulation of soil is better precise by curvatures of a slope. The curvature value ranged between -4.35 and 2.90. The positive value of curvature indicates that the surface is curved. However, the negative value shows that it dipped, and the zero is assigned to the linear surface (Fig. 3). The entire river basin area comes under the category of concave. It represents that increase there is a in the pore water pressure during medium and heavy rainstorms.

Elevation

The factor elevation is a key feature used to detect groundwater potential areas. In general, plain surface area has low amount of irruption compared of moderate to high elevated points. The elevation map was created from CARTOSAT-30 m DEM data in GIS environment and it was reported that, the range of elevation varies from 0 to 1512 amsl in basin area (Fig. 3).

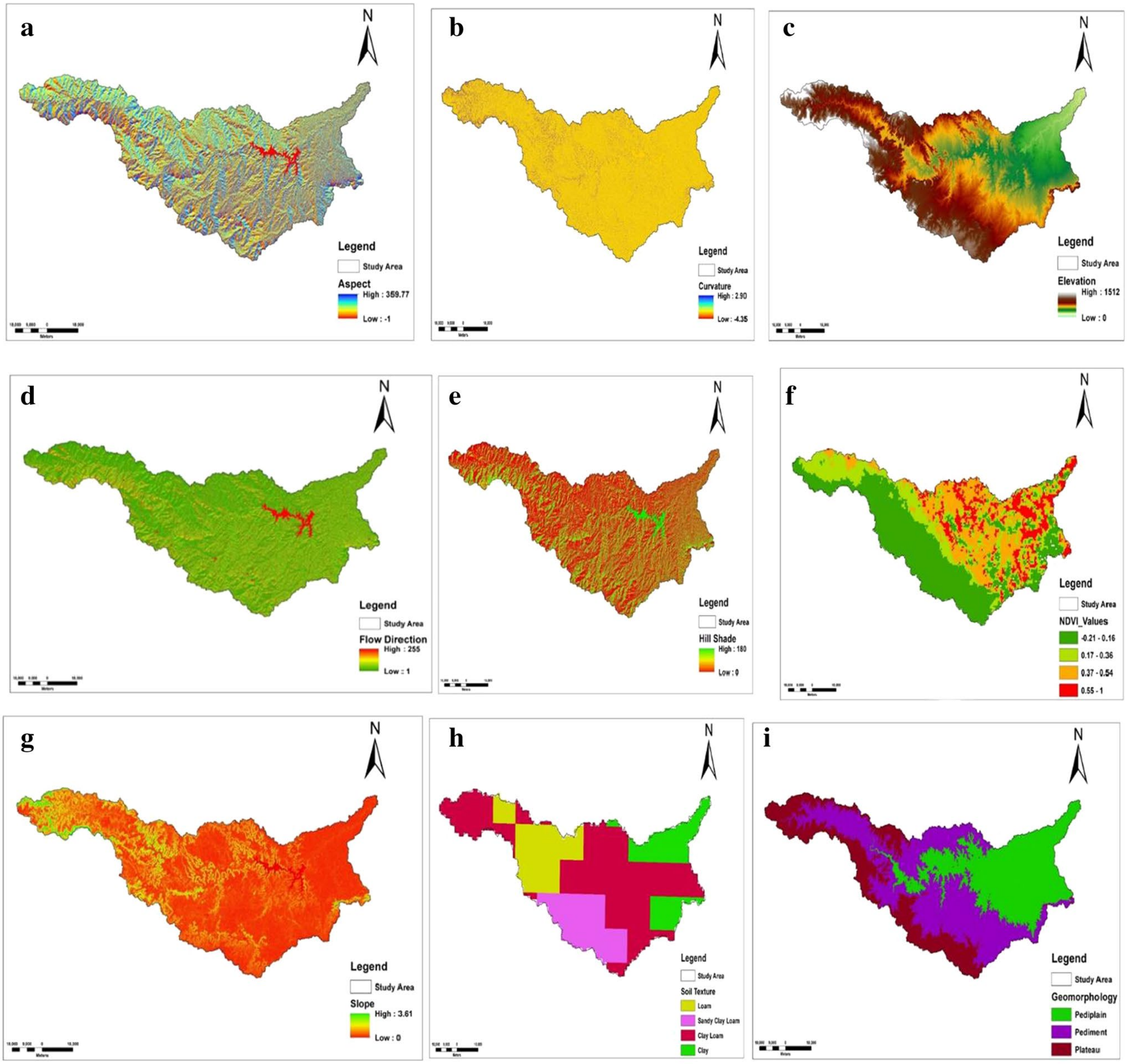

Fig. 3 **a** Aspect map, **b** curvature map, **c** elevation map, **d** flow direction map, **e** hillshade map, **f** NDVI map, **g** slope map, **h** soil texture map, and **i** geomorphology map

Flow direction

Flow direction is stated about the intimacy of the arrangement of channels. The stream or flow direction is the opposite of the permeability factor. The highest flow direction shows more runoff, which reduces the amount of water penetration to the subsurface and vice versa. In the study, the flow direction ranged between 1 and 255 (Fig. 3).

Hill shades

A hillshade is a 3D-grayscale depiction of the surface, considering the comparative site of the sun for the coloring of the related. To define the way of the sun, this feature uses the properties of altitude and azimuth. The hillshade map was created using a 3D-spatial analysis tool in the ArcGIS software 10.5. In the map, the hillshade value ranges from 0 to 180 (Fig. 3). This map is very important for the understanding of the surface topographic and hilly places entire basin area.

NDVI

The normalized difference vegetation index is another important parameter that plays a vital part in the constancy of grades by hydrological procedures in the eco-system. In the study, NDVI value is divided into four sub-classes: good, very good, very poor and moderate. The NDVI value varies from −0.21 to 1. The preparation of NDVI value of −0.21 to 0.16 was very poor, 0.17–0.36 was good, 0.37–0.54 was moderate, and 0.55–1 was very good (Fig. 3). For the potential groundwater areas, high weightage has been assigned for a higher value of NDVI, and low weightage has been given for a lower value.

Slope

The slope is the significant criterion to estimate the groundwater potentiality. It influences the penetration amount of surface water. The lower and higher value of slope angle indicates the flatter and steeper terrain, respectively. Many researchers handled the slope layer to evaluate the water flow and conserved in the specific region. In the present study, the flow of river water is entirely using the slope gradient of the basin. The figure shows that more extensive slopes are identified in the eastern, southeast part and lower slopes are determined in the northern and northeast parts of the study areas. The flat slope region causes more infiltration than to steep and moderate steep region. It is reported that the range of slope varied between 0 and 3.61 (Fig. 3). About a higher percentage is covered by moderate and more minor slope in river areas.

Soil texture

Soil texture is a crucial controller of infiltration of land water using voids and infiltrates into the subsurface to reach the aquifer. The preparation of soil type's maps is based on the mean size of the solid particle in soil, namely sand, silt and clay. The weights are allocated for every soil texture in rendering to its penetration rate. A higher weightage has provided clay loam, clay, sandy clam and clay (Fig. 3).

Geomorphology

Geomorphology is a scientific study of creating, changing, configuring and relating landforms to underlying structures. Visual interpretation of satellite image geomorphic units/landforms is categorized, which depend on visual image elements. The topographic information in SOI topo maps aids in interpreting satellite imagery (Moharir et al. 2020). Geomorphology is a clear way to define and examine the environments and their processes systemically. In the study area, geomorphology was divided into plateau, pediment and pediplain to calculate the potential groundwater zone (Fig. 3).

Land use and land cover

Land use changes are governed by anthropological intervention and general phenomena such as agronomic demand and skill, residential development, consumption patterns, urban expansion and economic development, science discipline and skill and added factors (Pande et al. 2018, 2021). As a

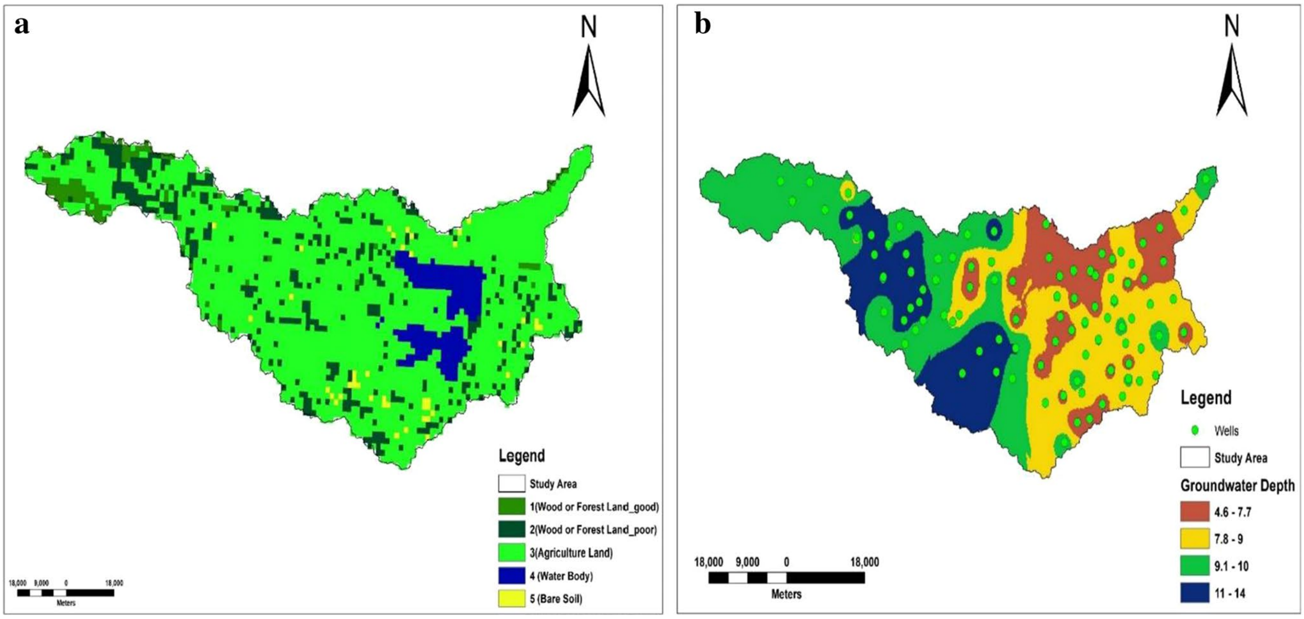

Fig. 4 **a** LULC map, and **b** groundwater depth map

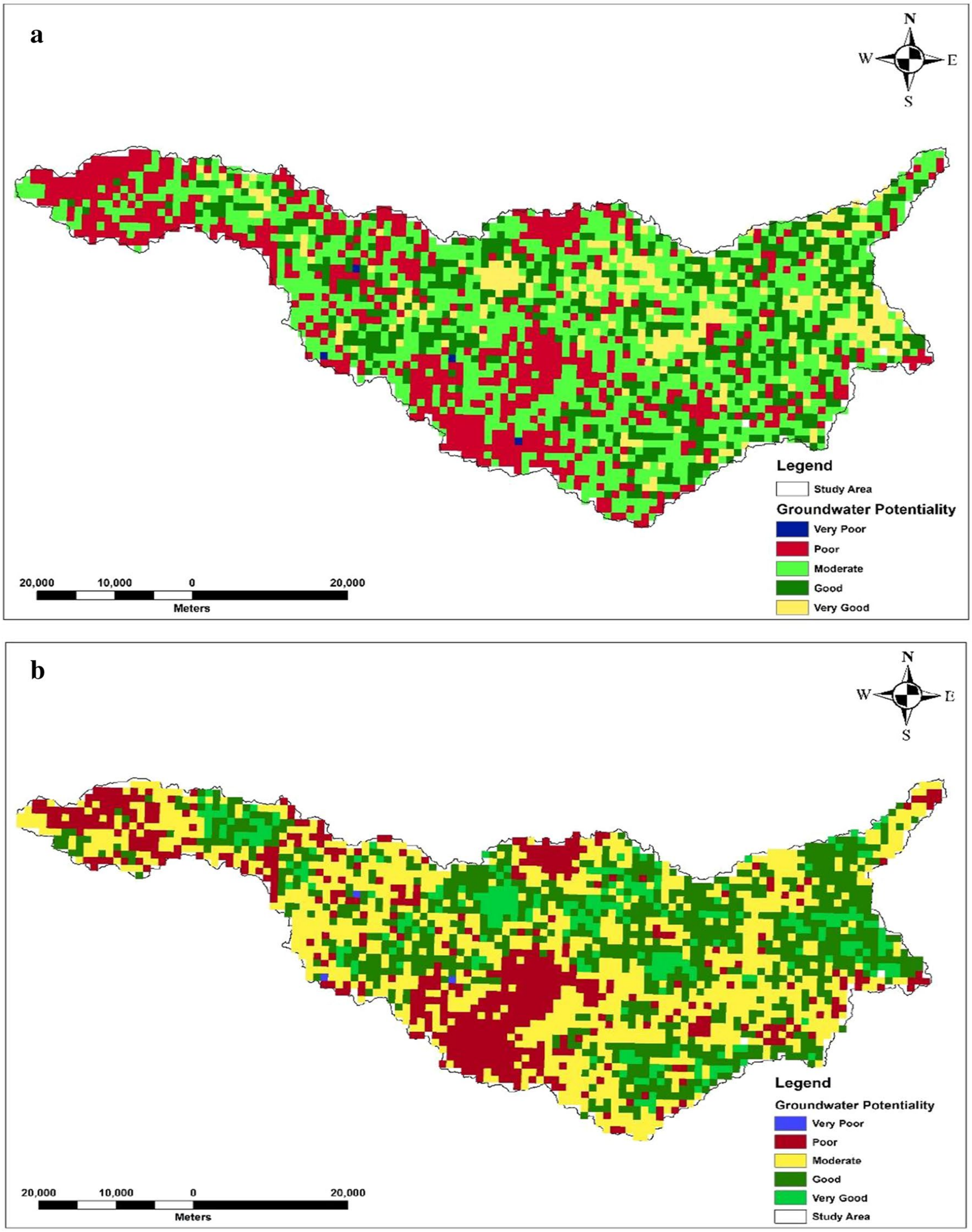

Fig. 5 **a** GPZ map based on AHP technique, and **b** GPZ map based on MIF technique

result, early and accurate information regarding LU/LC of earth's surface changes identification is essential for interpreting genetic and environmental phenomenon relationships and interactions to enhance decision-making. Supervised classification was done, and five classes have been found: forest land is good quality, forest land is poor quality, agriculture land and water body (Fig. 4).

Groundwater depth

The groundwater level is under the earth's surface. It is saturated water or the level to which groundwater would increase in the fine that is bored in a pressurized aquifer. Groundwater level analysis is the most significant feature to use in the preparation of potential areas of groundwater. The groundwater depth information is observed during the monsoon period; it is valuable data to check suitable zones for sustainable groundwater planning structures in the basin

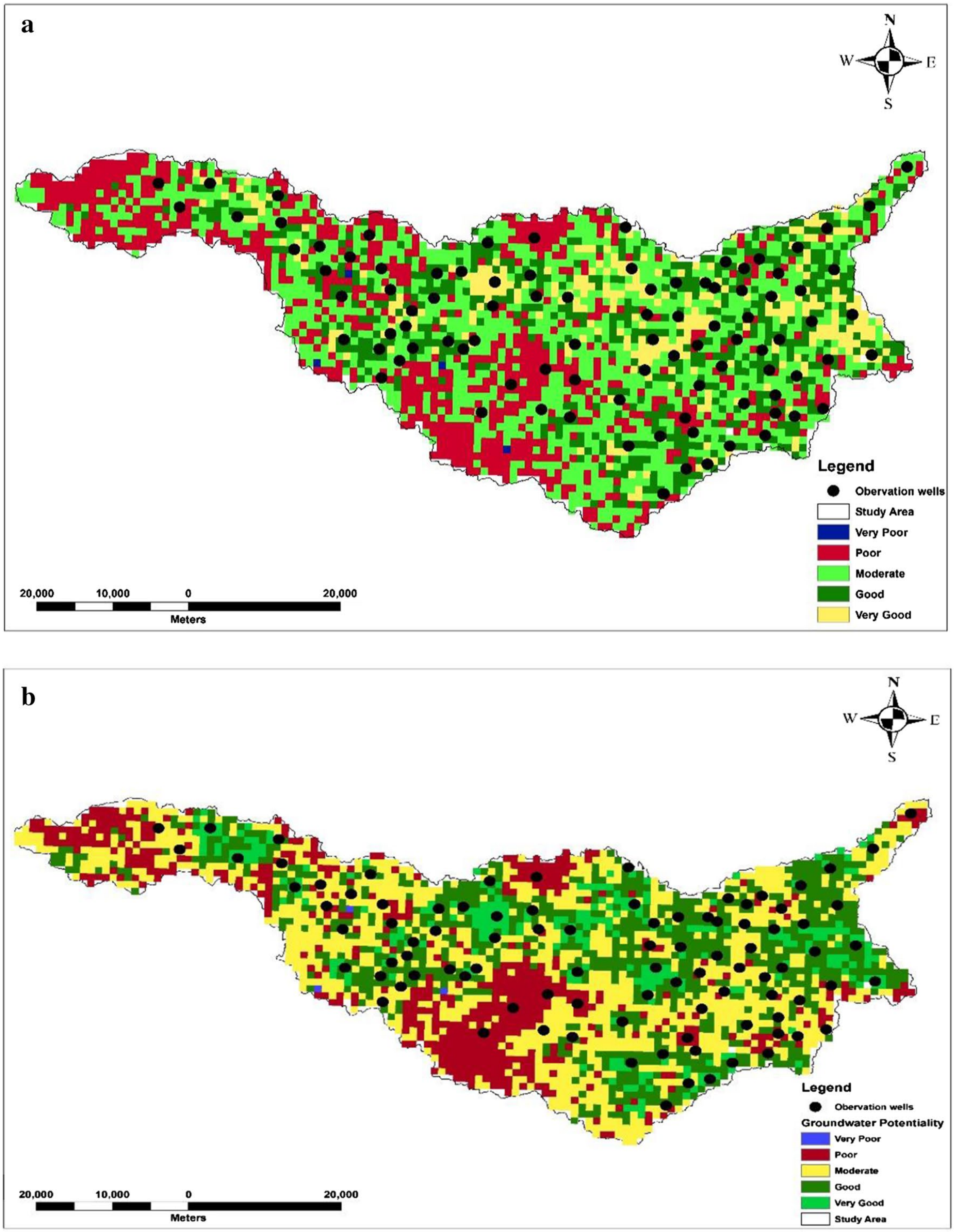

Fig. 6 Overlap wells data on groundwater potential maps of **a** MIF, and **b** AHP techniques

area. The inverse distance weighted method (IDW) created the groundwater level map in the ArcGIS software (v10.5). Groundwater depth map recorded minimum, and maximum values are 4.5–14 m (Fig. 4).

Calculation of groundwater potential zone maps

Contributing the thematic maps by weighted overlay method (WOA), and consistency ratios are computed for groundwater potential zone maps. The value shows that the finding matrices were authentic (<0.10) with rational reliabilities. Therefore, reclassified maps were combined based on their found weightiness (Table 5) by overlay analysis technique with groundwater potential map made by AHP technique (Fig. 5). The AHP maps of potential groundwater areas were delineated into five types (such as very poor, moderate, good, poor and very good possible zones of groundwater) founded on the pixel values; these map classes were divided by normal breaks technique in the Arc GIS system (Fig. 5). To minimum the grid marking, the map was developed by the common filter of the GIS system. The existing study emphasizes that preparing a potential map of groundwater depends on significant teen parameters, LULC, soil texture, DEM, flow direction, geomorphology, hillshade, slope, NDVI, aspect and groundwater depth. The weightage was assigned to the whole ten thematic layers, and their features depend on the multi-influencing factor (MIF) (Magesh et al. 2012). The groundwater potential areas map was classified as very poor, moderate, good, poor and very good using the MIF technique (Fig. 5).

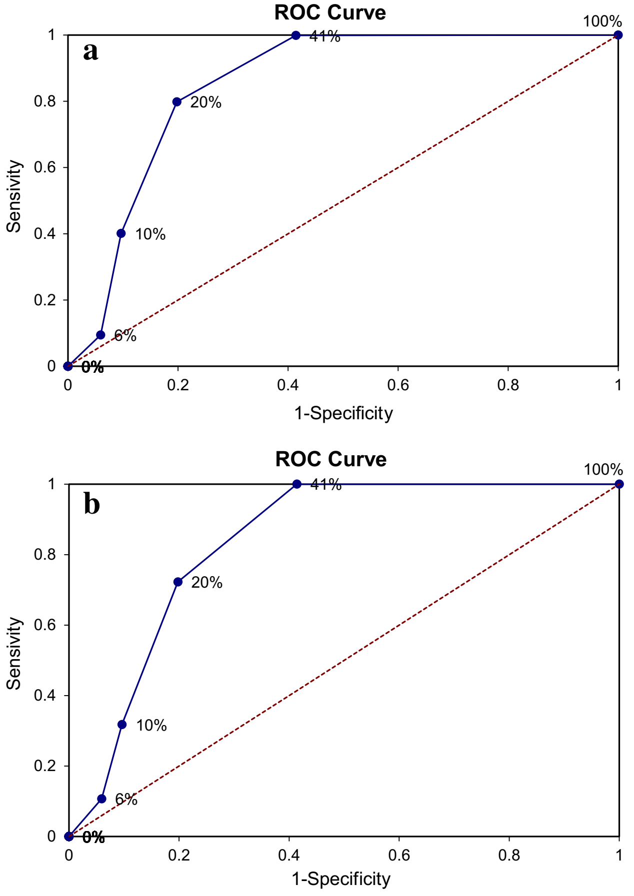

Fig. 7 Validation of groundwater potential map of **a** MIF and **b** AHP techniques by ROC curve

Discussion

Validation of groundwater potential zone maps

Through cross-validation, the accuracy of the produced possible zones map of groundwater has been compared to groundwater level data of wells collected from the CGWB (2016–2017). The difference might be due to the long-years over-withdrawal of groundwater for farming works that have co-operated the groundwater harvest volume at the current environmental situation in the river basin. Access to groundwater for agricultural use is also flattering progressively week to the dangers of groundwater reduction, which has been informed by numerous studies (Chindarkar et al. 2019). To avoid groundwater depletion, modifying the conventional cropping types and implementing drips, sprinklers and micro-irrigation practices may be helpful for specific areas (Wang et al. 2018; Kaarakka et al. 2019).

Total 36 observation water level data are covered on the described potential areas map of groundwater was used to validate (Fig. 6). Thirty-six observation wells locations, nearly 25 wells were found to contest the demarcated potential zones maps (Table 9). The full correctness of groundwater potential zones mapping by implemented AHP, MIF and GIS approach has been identified to be 86% and 80% correct, signifying the dependability of the techniques (Shekhar and Pandey 2014; Mohamed and Elmahdy 2017; Saranya and Saravanan 2020). The investigation added measurable

Table 9 Area under different groundwater potential zones estimated by MIF and AHP techniques (value within the additions shows % of area)

Methods	Area under different groundwater potential zones (km^2)					ROC and AUC models
	Very poor	Poor	Moderate	Good	Very good	
MIF	3.049	567.42	1124.50	868.86	266.67	0.80 (Good)
AHP	3.33	785.84	1147.47	595.82	302.65	0.86 (Good)

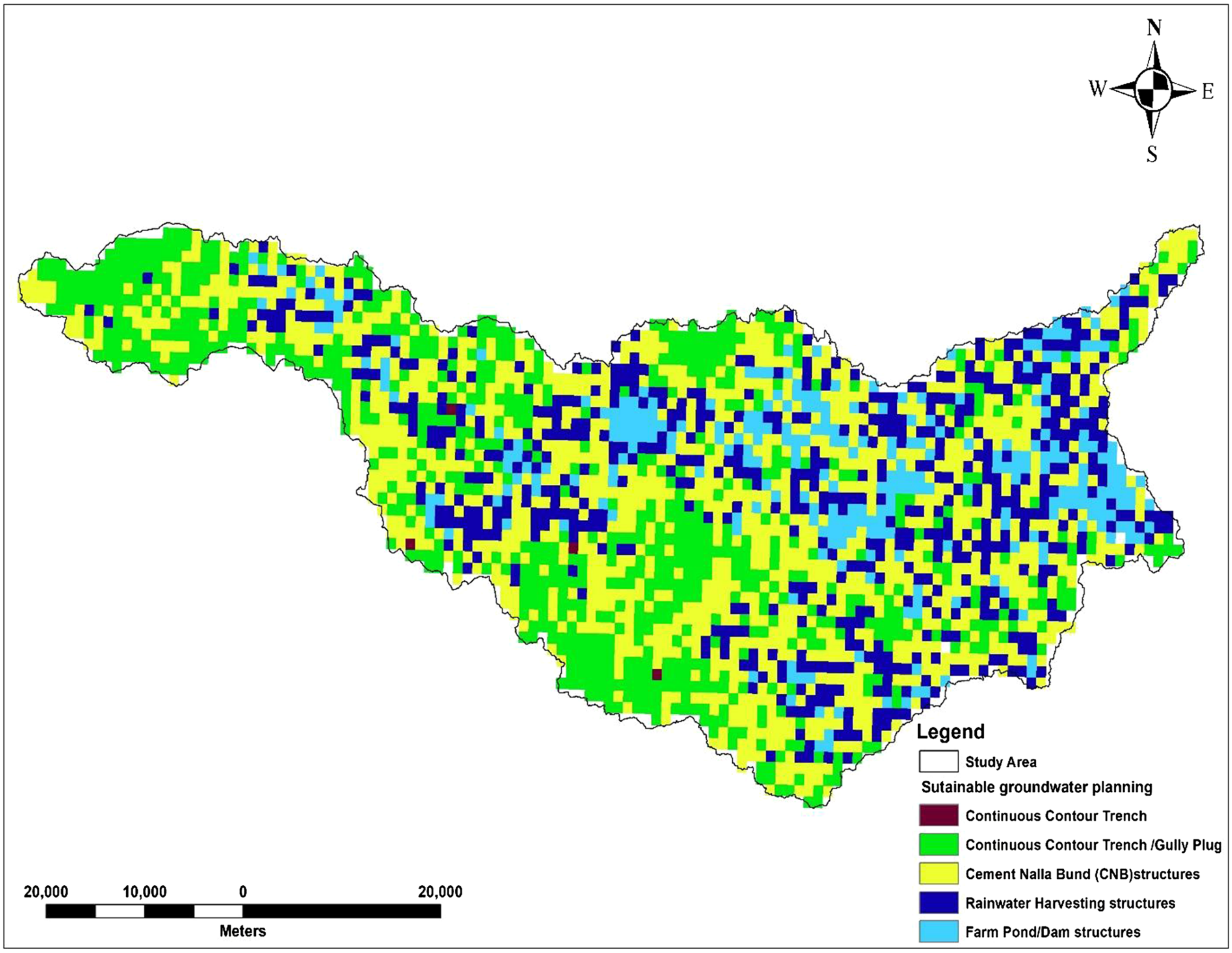

Fig. 8 Sustainable groundwater planning and development of Mula river basin area

cross-validation maps of groundwater prospect areas by receiver operating characteristic (ROC) graphs (Fig. 7). For various cut-off themes of variable, the ROC charts a true positive rate against an untruthful positive rate and every idea on the arc denotes the sensitivity couple referring to a threshold. On the other side, the field in the Curve (AUC) calculates how well a factor can differentiate both analytical sets from each other. AUC value inside the 0.5–0.6 range recommends low accurateness of forecast. At the same time, the 0.6–0.7, 0.7–0.8, 0.8–0.9 and 0.9–1 levels recommend that very good, average, excellent and good accurateness of forecast, correspondingly (Andualem et al. 2019; Kumar et al. 2020). The validation of outcomes exposed for good prediction by the AHP method as the AUC of the map of the potential areas was 0.86 (Fig. 7). In this context, validation of results correlated reasonable prediction using MIF technique as the AUC was 0.80 of potential groundwater zones. Therefore, the current work has accomplished a suggestively higher correctness level with the highest quantity of appropriate thematic maps by using AHP and MIF procedures (Ahmed and Mansor (2018), Bayala and Prieto (2019), Bhanja et al. (2019), Kumar and Krishna (2018a, 2018b), Pande and Moharir (2017), Vijith and Dodge-Wan (2019), Wakode et al. (2018), Yang et al. (2019), Central Groundwater Board Annual Report (2016–2017).

The observed potential zones can give primary strategies in choosing new wells locations for the removal of energetic water resources management in the basin areas. This outcome could be valuable for the implementation of a groundwater harvesting strategy. It is exciting to note the limitations and room of the work and the originality of the work. Ten thematic layers have been selected in this research, but the addition of some data such as hydro-geological and geomorphology maps (geomorphology and water level) could have provided more accurate results. Sustainable planning primarily emphasizes the use of groundwater, water management, restricted abstraction, advanced water structure, water awareness, alternative cropping methods, domestic with industrial water conserved. The non-polluted groundwater preparation would be valuable for water improvement in the long term.

Likely plans are suggested to entire basin area with poor aquifer zone (Fig. 8). There are theoretical limitations to the analysis due to being of the adopted approach. MIF and AHP is a used that can also suppress persuaded errors. Factors of impact are the rate of water flow for agriculture, and the use of drinking water often plays an important part in regulatory possible in groundwater zones which have not been considered in this investigation. However, given these variables in the examination technique and estimation, the results are accurate and scientific. The AHP results can help enhance the managing of groundwater in the river basin.

Recommendation

Reworking of managed aquifer recharge (MAR) techniques with sustainable groundwater harvesting activities is suggested to rise the potentiality areas of groundwater for the drought patches in the basin. As application of new groundwater recharge structures are cost-intensive, planning and progress of new cement nala bund, CCT and farm pond, development and tunneling of the drainage line with presenting pools might be supportive to suitable sites of groundwater recharge and storing capacity in the study area. The current investigation can be helpful in the soil and water management operations to make community publicity. In order to obtain more specific guidance on the rate of groundwater which is obtained from various groundwater potential areas, this study is necessary for the technically prediction of groundwater in various potential regions in the Mula river basin.

Limitations

While this investigation follows a cost-efficient scientific way of analysis of various natural resources parameters, some limitations cannot be unheeded. The main limitations are defined below:

(i) The various satellite and field data of this study are deepened on satellites, supplied by various agencies and departments. However, maximum of this map is an extremely widespread in countryside. A maximum difference in whole these parameters may be identified at the local stage or small scale. Therefore, by reason of this issue, the produced groundwater potential maps could not be very precise at a same local scale.
(ii) AHP is an experiential technique where the ranking of criteria is completed based on proficiency. Although this research displays very good correctness, an additional detailed map may be forecasted by using the one way by rearranging the ranks.
(iii) MIF and AHP results are validated with water level data, but the groundwater level is changed in region to region, although ROC plot has been given more precise results at local, international and national scales.
(iv) The sustainable groundwater planning and development have been prepared by AHP results but the soil and water conservation structures planning can apply on field, it is a big problem.
(v) This investigation is totally intensive on AHP, MIF and RS that give a general estimate of groundwater potential zones and planning maps. However, for risky detailed valuation, ground survey-based geophysical approaches are very beneficial. However, groundwater potential zonations using ground-based geophysical survey and field survey are not only expensive but also tremendously time-consuming.

Conclusion

The present study investigated the identification of potential zone in the basin using MIF and AHP. In this paper, two types of methods have been applied for the delineation of potential groundwater areas. AHP and MIF have found 595.82–302.65 and 868.86–302.65 km^2 areas as extremely possible for finding groundwater. MIF technique has made more remarkable outcomes than the AHP method than set theory based on the equation. This study also recommends the enclosure of other geological, groundwater and metrological factors to develop the result. This paper discussed and correlated the two techniques with each other which techniques best for the potential zones of groundwater. Two groundwater potential area maps were cross-validated with the groundwater depth data in the ROC and AUC models. The cross-validation outcomes recognized AHP as a more effective technique (accuracy = 0.86) to demarcate potential groundwater zones for the basin area. The cross-validation results found MIF is a moderately effective method (accuracy = 0.80) to extract the groundwater potential mapping in the area.

This result of the study can be useful to apply sustainable groundwater plans for rainwater harvesting, soil erosion and cropping types. In the area, four to three big dams and water bodies are found to be better conditioning parameters for potentiality areas of groundwater, so speedily recovery of water frame is required to be stopped directly. Therefore, adequate management of groundwater is significant for the long sustainable social, financial and environmental development for the Mula river area of Maharashtra in India. It developed sustainable groundwater.

Acknowledgements The authors would like to thank the USGS, NRSC (ISRO) and CGWB, New Delhi, for providing the satellite and ground data.

Funding The authors received no specific funding for this work.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval The authors declare no any ethical conduct.

References

Agarwal R, Garg PK (2016) Remote sensing and GIS based groundwater potential & recharge zones mapping using multi-criteria decision making technique. Water Resour Manage 30(1):243–260

Ahmed JB, Mansor S (2018) Overview of the application of geospatial technology to groundwater potential mapping in Nigeria. Arab J Geosci. https://doi.org/10.1007/s12517-018-3852-4

Ajay Kumar V, Mondal NC, Ahmed S (2020) Identification of groundwater potential zones using RS, GIS and AHP techniques: a case study in a part of Deccan volcanic province (DVP), Maharashtra India. J Indian Soc Remote Sens 48:497–511. https://doi.org/10.1007/s12524-019-01086-3

Al-Bakri JT, Al-Jahmany YY (2013) Application of GIS and remote sensing to groundwater exploration in Al-Wala Basin in Jordan. J Water Resour Prot 5:962–997

Andualem TG, Demeke GG (2019) Groundwater potential assessment using GIS and remote sensing: a case study of Guna tana landscape, upper blue Nile Basin Ethiopia. J Hydrol Reg Stud 24:100610. https://doi.org/10.1016/j.ejrh.2019.100610

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

Archibald S, Bond WJ, Hoffmann W, Lehmann C, Staver C, & Stevens N (2019) Distribution and determinants of savannas. Savanna Woody Plants and Large Herbivores, pp. 1–24

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. https://doi.org/10.1007/978-3-030-68124-1_21

Arulbalaji P, Padmalal D, Sreelash K (2019) GIS and AHP techniques based delineation of groundwater potential zones: a case study from Southern Western Ghats India. Sci Rep. https://doi.org/10.1038/s41598-019-38567-x

Bayala J, Prieto I (2019) Water acquisition, sharing and redistribution by roots: applications to agroforestry systems. Plant Soil. https://doi.org/10.1007/s11104-019-04173-z

Bhanja SN, Mukherjee A, Rangarajan R, Scanlon BR, Malakar P, Verma S (2019) Long-term groundwater recharge rates across India by in situ measurements. Hydrol Earth Syst Sci 23(2):711–722

Bhatla R, Verma S, Pandey R, Tripathi A (2019) Evolution of extreme rainfall events over Indo-Gangetic plain in changing climate during 1901–2010. J Earth Syst Sci 128:120. https://doi.org/10.1007/s12040-019-1162-1

Bierkens MF, Wada Y (2019) Non-renewable groundwater use and groundwater depletion: a review. Environ Res Lett 14(6):063002

Burrough PA (1986) Principles of geographical information systems for land resources assessment. Oxford University Press, Oxford, p 193

Central Groundwater Board Annual Report (2016–2017) Ground water year book 2016–17 Jammu & Kashmir

Chen W, Hong H, Li S, Shahabi H, Wang Y, Wang X, Ahmad BB (2019) Flood susceptibility modelling using novel hybrid approach of reduced-error pruning trees with bagging and random subspace ensembles. J Hydrol 575:864–873

Chinchmalatpure AR, Gorain B, Kumar S, Camus DD, &Vibhute SD (2019) Groundwater pollution through different contaminants: Indian scenario. In Research developments in saline agriculture. Springer, Singapore. pp. 423–459

Chindarkar N, Grafton RQ (2019) India's depleting groundwater: when science meets policy. Asia Pacific Policy Stud 6:108–124. https://doi.org/10.1002/app5.269

Díaz-Alcaide S, Martínez-Santos P (2019) Advances in groundwater potential mapping. Hydrogeol J 27(7):2307–2324

Egan JP (1975) Signal detection theory and ROC analysis. Series in cognition and perception. Academic. Press, New York

Elewa HH, Qaddah AA (2011) Groundwater potentiality mapping in the Sinai Peninsula, Egypt, using remote sensing and GIS-watershed-based modeling. Hydrogeol J 19:613–628. https://doi.org/10.1007/s10040-011-0703-8

Elmahdy SI, Mohamed MM (2013) Groundwater potential modelling using remote sensing and GIS: a case study of the Al Dhaid area, United Arab Emirates. Geocarto Int. https://doi.org/10.1080/10106049.2013.784366

Ganapuram S, Vijaya KGT, Murali KIV, Ercan K, Cüneyd DM (2009) Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. Adv EngSoftw 40(7):506–518

Gauthier C, Lin Z, Peter BG, Moran EF (2019) Hydroelectric infrastructure and potential groundwater contamination in the Brazilian amazon: altamira and the belo monte dam. Prof Geogr 71(2):292–300

Ghimire M, Chapagain PS, Shrestha S (2019) Mapping of groundwater spring potential zone using geospatial techniques in the central Nepal Himalayas: a case example of Melamchi-Larke area. J Earth Syst Sci 128(2):26

Ghosh KP, Bandyopadhyay S, Jana NC (2015) Mapping of groundwater potential zones in hard rock terrain using geoinformatics: a case of Kumari watershed in western part of West Bengal. Model Earth Syst Environ 2:1

Ghosh R, Kansal A, Venkatesh G (2019) Urban water security assessment using an integrated metabolism approach: case study of the national capital territory of Delhi in India. Resources 8(2):62

Gueretz JS, Da Silva FA, Simionatto EL, Férard JF, Radetski CM, & Somensi CA (2019) A multi-parametric study of the interaction between the Parati river and Babitonga Bay in terms of water quality. J Environ Sci Health, Part B

Jothibasu A, Anbazhagan S (2016) Modeling groundwater probability index in Ponnaiyar River basin of South India using analytic hierarchy process. Model Earth Syst Environ 2:109. https://doi.org/10.1007/s40808-016-0174-y

Kaarakka L, Smolander A, Lindroos A-J, Nöjd P, Korpela L, Nieminen TM, Helmisaari H-S (2019) Sprinkling infiltration as an artificial groundwater recharge method: long-term effects on boreal forest soil, tree growth and understory vegetation. For Ecol Manage 448:240–248. https://doi.org/10.1016/j.foreco.2019.06.015

Kanagaraj G, Suganthi S, Elango L, Magesh NS (2018) Assessment of groundwater potential zones in Vellore district, Tamil Nadu, India using geospatial techniques. Earth Sci Inf. https://doi.org/10.1007/s12145-018-0363-5

Khalid S (2019) An assessment of groundwater quality for irrigation and drinking purposes around brick kilns in three districts of Balochistan province, Pakistan, through water quality index and multivariate statistical approaches. J Geochem Explor 197:14–26

Kumar A, Krishna AP (2018a) Assessment of groundwater potential zones in coal mining impacted hard-rock terrain of India by integrating geospatial and analytic hierarchy process (AHP) approach. Geocarto Int 33(2):105–129

Kumar A, Krishna AP (2018b) Assessment of groundwater potential zones in coal mining impacted hard-rock terrain of India by integrating geospatial and analytic hierarchy process (AHP) approach. Geocarto Int 33:105–129. https://doi.org/10.1080/10106049.2016.1232314

Kumar VA et al (2020) Ahmed Identification of groundwater potential zones using RS, GIS and AHP techniques: a case study in a part of Deccan Volcanic Province (DVP), Maharashtra India. J Indian Soc Remote Sens 48(2020):497–511

Lazarus G, Ndatuwongand G, Yadav S (2014) Integration of hydrogeological factors for identification of groundwater potential zones using remote sensing and GIS techniques. J Geosci Geomat 2(1):11–16

Luker E, Harris LM (2019) Developing new urban water supplies: investigating motivations and barriers to groundwater use in Cape Town. Int J Water Resour Dev 35(6):917–937

Machiwal D, Jha MK, Mal BC (2011) Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manage 25(5):1359–1386

Magesh NS, Chandrasekar N, Soundranayagam JP (2012) Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing. GIS MIF Tech Geosci Front 3(2):189–196

Mahato S, Pal S (2018) Changing land surface temperature of a rural Rarh tract river basin of India. Remote Sens Appl: Soc Environ 10:209–223

Mahato S, Pal S (2019) Groundwater potential mapping in a rural river basin by union (OR) and intersection (AND) of four multi-criteria decision-making models. Nat Resour Res 28(2):523–545

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(2):1013–1034

Mallick J, Khan RA, Ahmed M, Alqadhi SD, Alsubih M, Falqi I, Hasan MA (2019) Modeling groundwater potential zone in a semi-arid region of Aseer using fuzzy-AHP and geoinformation techniques. Water 11:2656. https://doi.org/10.3390/w11122656

Manap MA, Nampak H, Pradhan B, Lee S, Sulaiman WNA, Ramli MF (2014) Application of probabilistic-based frequency ratio model in groundwater potential mapping using remote sensing data and GIS. Arab J Geosci 7(2):711–724

Mehra M et al (2016) Integrated assessment of groundwater for agricultural use in Mewat District of Haryana India using geographical information system (GIS). J Indian Soc Remote Sens. https://doi.org/10.1007/s12524-015-0541-6

Mohamed MM, Elmahdy SL (2017) Fuzzy logic and multi-criteria methods for groundwater potentiality mapping at Al Fo'ah area, the United Arab Emirates (UAE): an integrated approach. Geocarto Int 32(10):1120–1138. https://doi.org/10.1080/10106049.2016.1195884

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 8(6):1385–1395

Moharir Kanak N, Pande Chaitanya B, Singh Sudhir Kumar, Rio Rodrigo Abarca Del (2020) Evaluation of analytical methods to study aquifer properties with pumping test in Deccan basalt region of the Morna River Basin in Akola District of Maharashtra in India, groundwater hydrology. Intec open Publication, UK. https://doi.org/10.5772/intechopen.84632

Mu E, Pereyra-Rojas M (2017). Understanding the analytic hierarchy process. In: Practical decision making. An introduction to the analytic hierarchy process (AHP) using super decisions V2. Springer briefs in operations research, Springer, Cham, pp. 7–22. https://doi.org/10.1007/978-3-319-33861-3_2

Mukherjee I, Singh UK (2020) Fluoride abundance and their release mechanisms in groundwater along with associated human health risks in a geologically heterogeneous semi-arid region of east India. Microchem J 152:104304. https://doi.org/10.1016/j.microc.2019.104304

Murmu P, Kumar M, Lal D, Sonker I, Singh SK (2019) Delineation of groundwater potential zones using geospatial techniques and analytical hierarchy process in Dumka district, Jharkhand India. Groundw Sustain Dev 9:100239. https://doi.org/10.1016/j.gsd.2019.100239

Nandi A, Shakoor A (2009) A GIS-based landslide susceptibility evaluation using bivariate and multivariate statistical analyses. Eng Geol 110(2009):11–20

Negnevitsky M (2002) Artificial intelligence: a guide to intelligent systems. Addison–Wesley/Pearson, Harlow, p 394

Ozdemir A (2011) GIS-based groundwater spring potential mapping in the Sultan Mountains (Konya, Turkey) using frequency ratio, weights of evidence and logistic regression methods and their comparison. J Hydrol 411(3–4):290–308

Pande CB, Moharir K (2017) GIS-based quantitative morphometric analysis and its consequences: a case study from Shanur River basin Maharashtra India. Appl Water Sci 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 Resour Manage 4:965–979

Pande CB, Moharir KN, Khadri SFR et al (2018) Study of land use classification in an arid region using multispectral satellite images. Appl Water Sci 8:123

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 Dev Sustain 22:4867

Pande CB, Moharir KN, Khadri SFR (2021) Assessment of land-use and land-cover changes in Pangari watershed area (MS), India, based on the remote sensing and GIS techniques. Appl Water Sci 11:96. https://doi.org/10.1007/s13201-021-01425-1

Pourghasemi HR, Pradhan B, Gokceoglu C (2012) Application of fuzzy logic and analytical hierarchy process (ahp) to landslide susceptibility mapping at Haraz watershed, Iran. Nat Hazards 63(2):965–996. https://doi.org/10.1007/s11069-012-0217-2

Pourtaghi ZS, Pourghasemi HR (2014) GIS-based groundwater spring potential assessment and mapping in the Birjand Township, southern Khorasan Province. Iran Hydrogeol J 22:643–662. https://doi.org/10.1007/s10040-013-1089-6

Pradhan S, Kumar S, Kumar Y, Sharma HC (2019) Assessment of groundwater utilization status and prediction of water table depth using different heuristic models in an Indian interbasin. Soft Comput 23(20):10261–10285

Qadir J, Bhat MS, Alam A, Rashid I (2019) Mapping groundwater potential zones using remote sensing and GIS approach in Jammu Himalaya Jammu and Kashmir. Geo-Journal 85(2):487–504

Rajaveni SP, Brindha K, Elango L (2015) Geological and geomorphological controls on groundwater occurrence in a hard rock region. Appl Water Sci 7(3):1377–1389. https://doi.org/10.1007/s13201-015-0327-6

Rani M, Joshi H, Kumar K, Pande A, Rawat DS (2019) Development of recharge and conservation site suitability model for groundwater retrieval and evaluation of artificial recharge potential in a complex hydro-geological spring-fed river basin. Arab J Geosci 12(18):589

Ray SS (Ed.) (2019) Ground water development-issues and sustainable solutions. Springer

Rudra K (2019). Interrelationship between surface and groundwater: the case of West Bengal. In ground water development-issues and sustainable solutions. Springer, Singapore. pp. 175–181

Saaty TL (1986) Axiomatic foundation of the analytic hierarchy process. Manage Sci 32:841–855

Saaty TL (1990) How to make a decision: the analytic hierarchy process. Eur J Oper Res 48:9–26

Saaty TL (2008) Decision making with the analytic hierarchy process. Int J Serv Sci 1(1):83–98

Saha S (2017) Groundwater potential mapping using analytical hierarchical process: a study on Md. Bazar Block of Birbhum District West Bengal. Spat Inf Res 25:615–626. https://doi.org/10.1007/s41324-017-0127-1

Sahoo S, Jha MK, Kumar N, Chowdary VM (2015) Evaluation of GIS-based multicriteria decision analysis and probabilistic modeling for exploring groundwater prospect. Environ Earth Sci 74(3):2223–2246

Saranya T, Saravanan S (2020) Groundwater potential zone mapping using analytical hierarchy process (AHP) and GIS for Kancheepuram district, Tamilnadu India. Model Earth Syst Environ 6(2020):1105–1122

Sashikkumar MC, Selvam S, Kalyanasundaram VL, Johnny JC (2017) GIS based groundwater modeling study to assess the effect of artificial recharge: a case study from Kodaganar river basin, Dindigul district Tamil Nadu. J Geol Soc India 89(1):57–64. https://doi.org/10.1007/s12594-017-0558-2

Selvarani AG, Elangovan K, Kumar CS (2016) Evaluation of groundwater potential zones using electrical resistivity and GIS in Noyyal River basin Tamil Nadu. J Geol Soc India 87(5):573–582. https://doi.org/10.1007/s12594-016-0431-8

Sener E, Sener S, Davraz A (2018) Groundwater potential mapping by combining fuzzy analytic hierarchy process and GIS in Beysehir Lake Basin Turkey. Arab J Geosci 11:187. https://doi.org/10.1007/s12517-018-3510-x

Shailaja G, Kadam AK, Gupta G, Umrikar BN, Pawar NJ (2019) Integrated geophysical, geospatial and multiple-criteria decision analysis techniques for delineation of groundwater potential zones in a semi-arid hard-rock aquifer in Maharashtra India. Hydrogeol J 27(2):639–654

Shekhar S, Pandey AC (2014) Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques. Geocarto Int 30(4):402–421

Shekhar S, Pandey AC (2015) Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques. Geocarto Int 30:402–421. https://doi.org/10.1080/10106049.2014.894584

Singh S, Singh C, Mukherjee S (2010) Impact of land-use and land-cover change on groundwater quality in the Lower Shiwalik hills: a remote sensing and GIS based approach. Open Geosci 2(2):124–131

Suhag R (2019) Overview of ground water in India. PRS. Geocarto Int 30(4):402–421. https://doi.org/10.1080/10106049.2014.894584

Takase K, Fujihara Y (2019) Evaluation of the effects of irrigation water on groundwater budget by a hydrologic model. Paddy Water Environ 17(3):439–446

Thapa R, Gupta S, Gupta A, Reddy DV, Kaur H (2018) Use of geospatial technology for delineating groundwater potential zones with an emphasis on water-table analysis in Dwarka River basin, Birbhum India. Hydrogeol J 26(3):899–922

Thirumurugan M, Elango L, Senthilkumar M, Sathish S, & Kalpana L (2019). Groundwater management in alluvial, coastal and hilly areas. In Ground water development-issues and sustainable solutions. Springer, Singapore. pp. 109–119

Umar Z, Pradhan B, Ahmad A, Jebur MN, Tehrany MS (2014) Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province Indonesia. Catena 118:124–135. https://doi.org/10.1016/j.catena.2014.02.005

Vijith H, Dodge-Wan D (2019) Modelling terrain erosion susceptibility of logged and regenerated forested region in northern Borneo through the analytical hierarchy process (AHP) and GIS techniques. Geoenviron Disasters 6:8. https://doi.org/10.1186/s40677-019-0124-x

Wakode HB, Baier K, Jha R, Azzam R (2018) Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad India. Int Soil Water Conserv Res 6:51–62. https://doi.org/10.1016/j.iswcr.2017.10.003

Wang X, Huo Z, Guan H, Guo P, Qu Z (2018) Drip irrigation enhances shallow groundwater contribution to crop water consumption in an arid area. Hydrol Process 32:747–758. https://doi.org/10.1002/hyp.11451

Yang J, Zhang H, Ren C, Nan Z, Wei X, Li C (2019) A cross-reconstruction method for step-changed runoff series to implement frequency analysis under changing environment. Int J Environ Res Public Health 16:4345. https://doi.org/10.3390/ijerph16224345

Yeh HF, Cheng YS, Lin HI, Lee CH (2016) Mapping groundwater recharge potential zone using a GIS approach in Hualian River Taiwan. Sustain Environ Res 26(1):33–43

Yu W, Wardrop NA, Bain RE, Alegana V, Graham LJ, Wright JA (2019) Mapping access to domestic water supplies from incomplete data in developing countries: an illustrative assessment for Kenya. PloS one 14(5):e0216923

Zanini A, Petrella E, Sanangelantoni AM, Angelo L, Ventosi B, Viani L, Chelli A (2019) Groundwater characterization from an ecological and human perspective: an interdisciplinary approach in the functional urban area of Parma Italy. Rendicontilincei Scienzefisiche e Naturali 30(1):93–108