



Delineation of groundwater potential zones in Karha river basin, Maharashtra, India, using AHP and geospatial techniques

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Received: 23 October 2019 / Accepted: 9 July 2020 / Published online: 18 July 2020
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Abstract

Groundwater is a life-sustaining resource catering the daily water requirements of mankind, aids in industrial development, influences agricultural activity, and maintains the ecological balance. The present study was carried out in the Karha river basin, Maharashtra State, having an area of 1314.98 km². In hydro-geological research, for the exploration of groundwater resources, the integration of remote sensing data and GIS plays a remarkable role in monitoring, assessing, and conserving groundwater resources for water resource management and development. A total ten thematic layers such as geomorphology, geology, land use/land cover, drainage density, slope angle, lineament density, rainfall distribution map, curvature, topographical wetness index, and soil map were integrated into a GIS platform, using the spatial analyst tool in Arc GIS 10.0 to delineate the Ground Water Potential Zones in Karha river basin area. The analytical hierarchy process (AHP) technique is used to determine the weighted value for each parameter and their sub-parameters, based on their relative importance of influencing factors for groundwater recharge. The final groundwater potential zonation map of the study area was categorized into four classes namely, poor, moderate, good, and excellent potential zones. The western part of the basin, particularly in Ghorawadi, Garade, and Saswad regions, have been identified as excellent potential zones for groundwater exploration. The result has shown about 21.96% (285.43 km²) and 28.82% (374.49 km²) of the study area falls under “excellent” and “good” groundwater potential zone, respectively, whereas about 10.81% (140.46 km²) area falls under the poor potential zone.

Keywords Thematic layers · AHP · Geospatial technique · Groundwater potential · Karha river

Introduction

Groundwater is a precious natural resource; exploration and proper management of this resource play an essential role in determining suitable locations of groundwater recharge, monitoring wells, water supply, and groundwater quality (Jha et al. 2010). Several physio-climatic and hydrogeological factors such as lithological structures, primary and secondary porosity, slope angle, geomorphological landforms, land use/land

cover, drainage pattern, distribution and intensity of rainfall, and other physio-climatic conditions affect the occurrence of groundwater and help in locating groundwater potential zones (Greenbaum 1992; Singh et al. 2011). Many countries of the world have groundwater potential maps that guide planners and decision-makers in the development, allocation, and management of the groundwater resources (Elbeih 2014; Ahmed II and Mansor 2018). The lack of practical water resources management leads to adverse effects including water pollution, saline water intrusion, land degradation, decline of water levels, and other hydrogeological and geo-environmental problems (Wada et al. 2010; Kumar et al. 2014; Rehman et al. 2019). India is going to suffer an acute water crisis in many of its states and on the brink of a severe water crisis in the future if all necessary measures are not taken in time (Jasrotia et al. 2019). Significantly more than 50% of urban domestic water and 85% of rural needs are now being met from groundwater resources, while irrigation records approximately 92% of groundwater extraction in India (Kolanuvada et al. 2019). The problem of groundwater is getting worsen

Responsible Editor: Broder J. Merkel

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due to imbalance between groundwater recharge and exploitation as a large amount of rain water is lost through surface runoff (CGWB 2014; Rani et al. 2019). Groundwater is generally considered less polluted due to the lack of direct contact, but increasing demand in recent decades is decreasing its quality (Das and Pal 2019). Corresponding to the worldwide increased demand of freshwater in various sectors, domestic and agriculture, calls for identification of the groundwater potential zones (GPZ). Till now, several field-based conventional methods were employed to delineate GPZ (Edet and Okereke 1997; Taylor and Howard 2000; Srivastava and Bhattacharya 2006; Shishaye and Abdi 2016; Messerschmid et al. 2018; Lee et al. 2019a, b). However, in recent decades, geospatial techniques are playing a sensational role in the field of hydrogeology, surface-hydrology, and water resources management and development. The application of GIS in groundwater monitoring and management such as delineation of GPZ has been reported by several researchers (Nagarajan and Singh 2009; Magesh et al. 2012; Shukla 2014; Oikonomidis et al. 2015; Kumar et al. 2016; Das et al. 2017; Thapa et al. 2017; Das and Pardeshi 2018; Pande et al. 2019; Bhattacharya et al. 2020; Ghosh et al. 2020; Memon et al. 2020; Rajasekhar et al. 2020). Remote-sensing study has become a very handy tool with its advantages of temporal, spectral, and spatial availability of data covering vast and remote areas within a very short time and also monitoring, assessing, and managing groundwater resources (Jackson 2002). Various researchers in recent days undertake several advanced methodological approaches for groundwater exploration among which frequency ratio (Elmahdy and Mohamed 2015; Das 2019), logistic regression (Zandi et al. 2016; Lee et al. 2019a, b), fuzzy logic (Cameron and Peloso 2001; Das and Pal 2020), Dempster-Shafer model (Mogaji et al. 2015; Roy and Datta 2019), weights of evidence model (Masetti et al. 2007; Tahmassebpour et al. 2016), artificial neural network (Mohanty et al. 2010; Chitsazan et al. 2015), maximum entropy model (Rahmati et al. 2016), and decision tree model (Saghebian et al. 2014; Stumpp et al. 2016) have been successfully implemented. GPZ map using AHP model is delineated worldwide by many researchers (Srdjevic and Medeiros 2008; Machiwal et al. 2011; Rahman et al. 2013; Jhariya et al. 2016; Akinlalu et al. 2017; Chakraborty et al. 2018; Banerjee et al. 2018; Aggarwal et al. 2019; Arulbalaji et al. 2019; Mageshkumar et al. 2019; Al-Djazouli et al. 2020; Hamdani and Baali 2020; Roy et al. 2020; Saranya and Saravanan 2020).

Karha river basin is located in rain shadow zone of the Western Ghats region. The source area of the river is marked by a precipitous landscape with high relief, which gradually becomes flat in the downstream of the basin (Kale 2011). The river is seasonal and flows in the monsoons only. Being located in semi-arid region, it is one of the driest drought-prone watersheds of the Maharashtra state (Kamuju 2016).

Extensive basalt rock of the Cretaceous–Tertiary period is the primary rock type of the Karha basin. Groundwater movement in hard rock aquifers is mainly controlled by secondary porosity caused by lineament intersection, fracturing, and faulting of the underlying rocks; hence, groundwater occurrences are mainly concentrated to shallow overburden of weathered materials and fracture bedrocks (Das 2017). Due to the scanty rainfall in this region, the area suffers scarcity of drinking and irrigational water, which adversely affect the human society. Delineation of groundwater potential zones through proper modeling approach is essential to handle the water scarcity problem in semi-arid drought-prone region (Das et al. 2019). Very few studies have been done over Pune district regarding water issues. The present work focuses on the identification of GPZ in the Karha river basin, Maharashtra, using GIS and AHP techniques for the management and planning of groundwater resources.

Location of the study area

The study was conducted at the Karha river basin in Maharashtra (Fig. 1). The geospatial extent of the Karha basin is between 18° 03' 30" N and 18° 25' 58" N and 73° 52' 45" E to 74° 40' 05" E, respectively. The catchment area of the Karha basin is 1314.98 km². The basin area falls in the severe drought-prone area of Pune district, Maharashtra. Relief variation of the basin ranges from 402 to 1297 m. The Karha river is a left-bank tributary of the Nira river basin. It originates near the Garade village in Purandhar taluka of Pune district and drains into the Nira river near the village Songaon in Baramati taluka of Pune district. Purandhar is situated in the upper part of the Karha basin and Baramati is at its lower part. The climate of the Karha river basin is under the influence of the southwest monsoon. The average annual rainfall amount is 678 mm and maximum humidity has been observed in the month of June. The basin covers a large area of agricultural land. Here, irrigation for farming is practiced widely. Therefore, relying on groundwater is absolutely necessary for this region. In the study area, more than 89% of the rainfall is confined to monsoon, mainly from June to October. The semi-arid condition makes the water easily consumable only during the monsoons. During summer, however, a serious water scarcity problem occurs in the study area. Karha river channel remains mostly dry in the non-monsoon season due to minimal rainfall.

Materials and methods

Preparation of thematic layers

In the present study, a digital elevation model of the Karha river basin was built based on ASTER elevation data having a

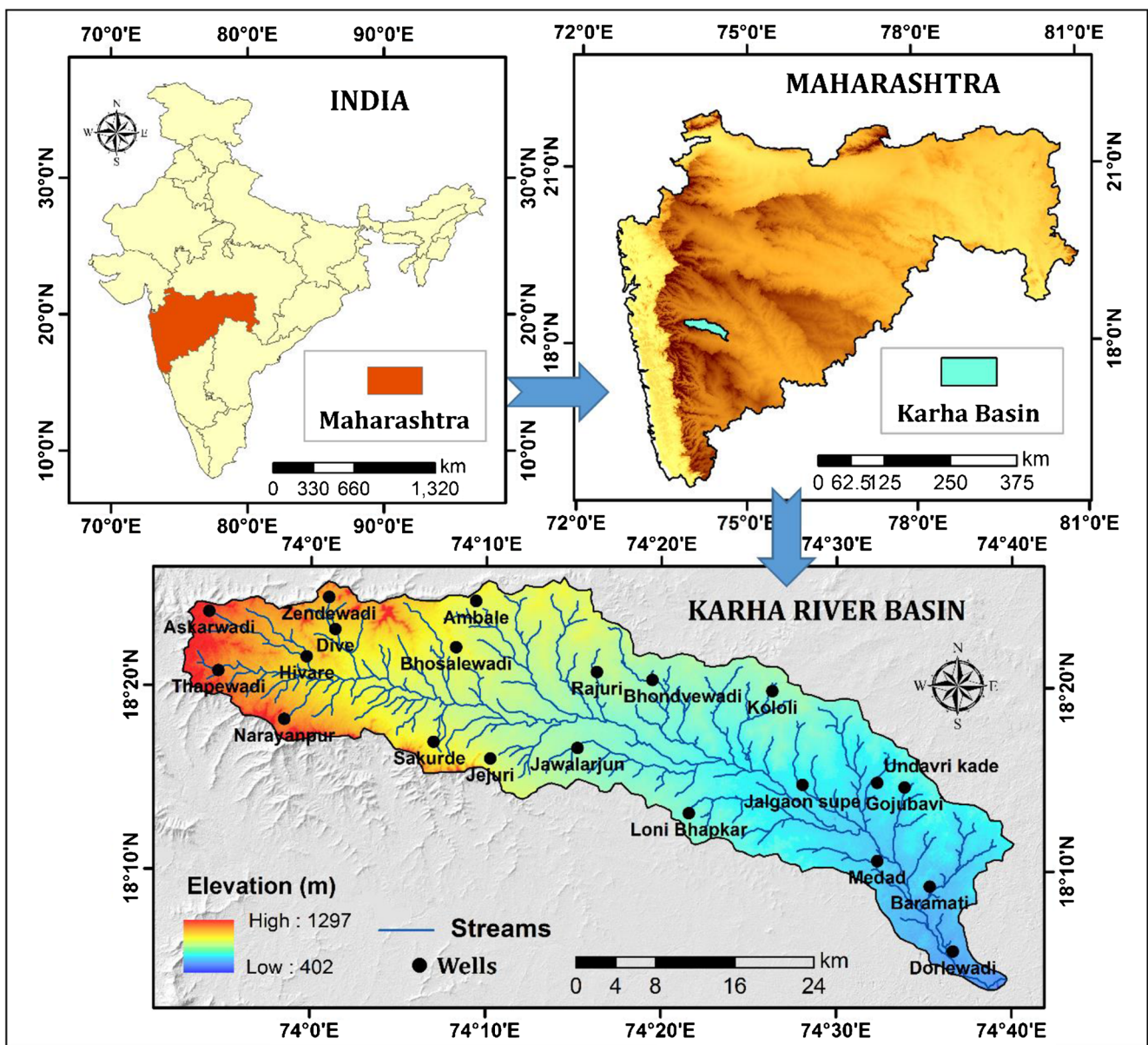


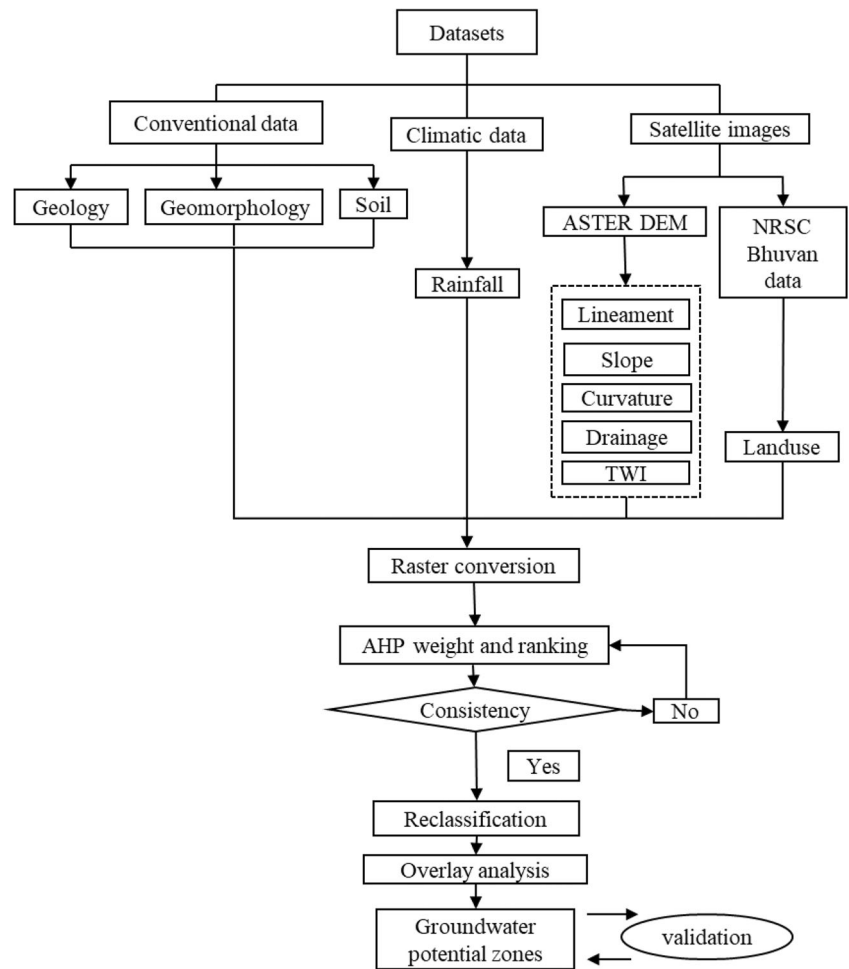
Fig. 1 Location map of the study area

30-m resolution. The base map of the Karha river basin was prepared based on SOI topographical sheets (47 F/15, 47 F/16, 47 J/3, 47 J/4, 47 J/7, 47 J/8, 47 J/11, and 47 J/12) on a 1:50,000 scale. These SOI topographical maps were georeferenced using WGS 84 datum, UTM zone 43 N projection in ArcGIS 10.0. The influencing factors considered for groundwater recharge in this study were geology, land use/land cover, drainage density, slope, curvature, lineament, topographical wetness index, rainfall, and soil type. The methodological flowchart in this study has been presented in Fig. 2.

To delineate suitable zones of various groundwater potentiality, several conventional data, geospatial data, and meteorological data have been collected from different organizations and websites to prepare thematic layers (Table 1). To

generate a stream network in the Karha basin, ASTER DEM has been selected. Under spatial analyst tools in ArcGIS, flow direction and flow accumulation raster calculation sub-tools were used to generate streams. Vectorization of the raster streams map is done by using conversion tools (Raster to polyline). Finally, the drainage density map of the Karha basin has been prepared by utilizing the line density tool in the ArcGIS environment. The geological map of the Karha river basin was collected from the Geological Survey of India. Soil data of the basin area was collected from NBSS and LUP, Govt. of India. Geomorphology map has been obtained from the published report of Central Ground Water Board (CGWB) on aquifer mapping, Purandhar, and Baramati Talukas, Maharashtra. The ArcGIS 10.0 software has been employed

Fig. 2 Methodological flow chart for GPZ mapping



to digitize the map intended for further analysis. Topographic wetness index (TWI) was calculated using the basic terrain analysis tool of SAGA GIS 7.3.0 software. The curvature

and slope map have been created directly from the DEM in the ArcGIS environment by using surface tools after sinking the data gaps of the elevation model. ASTER DEM was

Table 1 Details of data sources used for thematic layers preparation

Thematic layers	Data type	Scale/resolution	Data sources
Base map (topographical map)	Polygon	1:50,000	Survey of India (SOI)
Slope	Raster (ASTER DEM)	30 m (spatial resolution)	USGS website (https://earthexplorer.usgs.gov/)
Lineament			
Curvature			
Drainage density			
TWI			
Geology	Polygon	1:2,000,000	Geological Survey of India
Geomorphology	Polygon	1:50,000	CGWB report on aquifer mapping, Purandhar, and Baramati Talukas, Maharashtra
Soil	Polygon	1:50,000	NBSS & LUP
Rainfall	Raster	1 km ² (spatial resolution)	WorldClim-Global Climate Data version-2 of the years 1970–2000
Land use/land cover	Raster	1:50,000	NRSC-Bhuvan Thematic Services.
Depth to water level	Point	–	Central Ground Water Board

processed in ArcGIS to prepare shaded relief map using hillshade tools. Light illumination azimuth angles of the shaded relief maps are 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°, respectively (Das et al. 2018). By using a shaded relief map, all the linear features such as dykes, cliff, straight valley, and straight streams have been digitized manually to generate a lineament map. After that, line density tool has been used to prepare a lineament density map of the Karha basin. Land-use/land cover map was prepared from NRSC-Bhuvan Thematic Services. Karha basin has a very limited number of rain gauge stations; due to this problem, grid-based rainfall data were selected to prepare the rainfall distribution map. Rainfall data was collected from the WorldClim-Global Climate Data (www.worldclim.org) of the years 1970–2000 with a spatial resolution of 1 km². Rainfall distribution map has been prepared in the ArcGIS environment using inverse distance weighting (IDW) method of interpolation. Water-level depth data (pre-monsoon and post-monsoon) and fluctuation data of 21 wells were collected from Central Ground Water Board report on “Aquifer maps and ground water management plan Purandhar and Baramati Talukas, Pune District, Maharashtra.”

Analytic hierarchy process weightage analysis and normalization

The present study helps in analyzing the weightage of criteria and sub-criteria of the thematic layers included with the help of the analytic hierarchy process (AHP) process. The AHP method (Saaty 1980; Saaty and Vargas 1991) is a well-known means of multi-criteria technique which has been incorporated into the GIS-based suitability procedures (Jankowski and Richard 1994; Marinoni 2004). Each thematic map was converted to a raster image with 30 m × 30 m pixel size. AHP helps in the analysis of multiple criteria into a pairwise comparison matrix for making decisions. It calculates the needed weighting factors with the help of a preference matrix where all identified relevant criteria are compared against each other with reproducible preference factors, and then aggregates the weights of criterion map layers in a way similar to the weighted linear combination (WLC) methods (Chen et al. 2010). Quantitative (objective) and qualitative (subjective) information about decision-making analysis can be organized using the AHP method. Each criterion was assigned a rank from 1 to 9 based on their relative importance (Table 2). The relative scale of all these parameters is given based on different criteria and preferences (1, equally important; 3, slightly important; 5, quite important; 7, extremely important; 9, absolutely important; 2, 4, 6, and 8 are intermediate values). The criteria are analyzed accordingly using the AHP matrix (Table 3, Table 4). This matrix comprises an equal number of columns and rows, with value 1 arranged in a diagonal manner. Each row determines the relative

importance of 2 criteria. The first row of the matrix represents the significance of a criterion with respect to 10 other criteria positioned in the column of a matrix. The rows have an inverse value of each criterion and its respective significance with other criteria (geomorphology is a bit more essential than slope; hence, geomorphology has its value 1 and slope has the value 2; thus, in the next row, the slope has a value of 1/2). The consistency ratio (CR) was calculated in order to determine whether the pairwise comparisons were consistent or not. One of the strengths of the AHP method is that it allows for inconsistent relationships while providing a CR as an indicator of the degree of consistency or inconsistency (Chen et al. 2010; Feizizadeh and Blaschke 2013; Bera et al. 2019). When the consistency ratio is < 0.10, that indicates a fair level of consistency for determining the weights (Table 5) of the respective criteria.

Consistency ratio (CR)

$$= \frac{\text{Consistency index (CI)}}{\text{Random Consistency Index (RI)}}$$

Consistency index (CI) = $(\lambda_{\max} - n) / (n - 1)$

where λ_{\max} is the principal Eigenvalue; n stands for the number of considering factors; $\lambda_{\max} = \sum$ of the products between each element of the priority vector and column totals; Random consistency index (RI) was evaluated from a sample of “randomly generated reciprocal matrices” (Saaty 1990) (Table 6). For this present study, the CR value is 0.06 indicating the characteristics are of a good consistency for weight analysis and appropriate for delineating the GPZ.

Results

Geomorphology

Geomorphology is considered the most essential feature for understanding the occurrence, prospect, and movement of groundwater resources. The geomorphological evolution of a hard rock terrain is mainly controlled by tectonic activities and denudational processes. The Karha river basin comprises the following geomorphic features: moderately and low dissected plateau, floodplain, undulating tableland (mesa and Butte), anthropogenic terrain (reservoir), and pediment-pediplain (Fig. 3). The extreme western part of the basin area is having a low dissected upper plateau. The vast pediment-pediplain complex is found in the central and western part of the basin area, which consists of weathered colluvium material or gravel; this acts as a potential recharge source of groundwater in the study area. It covers 34.66% of the total study area. Dissected plateau and undulating tableland (Mesa and Butte) were given the lesser weighted value since they mainly

Table 2 Description of scales for pair comparison with AHP (source: Saaty 1990)

Scales	Degree of preferences	Descriptions
1	Equally important	The contribution of the two factors is equally important.
3	Slightly important	Experiences and judgment slightly tend to a certain factor.
5	Quite important	Experiences and judgment strongly tend to a certain factor.
7	Extremely important	Experiences and judgment extremely strongly tend to a certain factor.
9	Absolutely important	There is sufficient evidence for absolutely tending to a certain factor.
2, 4, 6, 8	Intermediate values	In between two judgments

have surface runoff than recharge. Floodplain is observed in the eastern portion of the basin, which is about 5.24% (68.98 km²) of the study area. Floodplains are usually associated with well potentials due to the high transmitting rates of the alluvium deposits on a gentle slope. Anthropogenic terrain (reservoir) has been given the highest weighted since; this acts as an excellent groundwater recharge source in the basin area.

Slope

The slope gradient is an important terrain factor for the identification of GPZ. It directly influences the infiltration process of surface water. A lower value of slope angle resembles to flatter terrain, whereas the higher slope values indicate the steeper terrain. Steep slopes are associated with feeble recharge potential, because water flows rapidly downward, so it does not allow sufficient time for rainwater to percolate. Gentle slope areas allow more retention time for groundwater recharge. Hence, the gentle slope dominant region has more prospect of groundwater recharge than steep slopes. The slope map of Karha river basin was classified into five categories (Fig. 4), i.e., steep (> 19.7°), high (10.7–19.7°), moderately high (5.5–10.7°), low (2.4–5.5°), and gentle (< 2.4°). The maximum portion of the basin area falls under a gentle slope category with 556.61 km² area coverage. The overall implication is that the south-western and north-western regions of the

basin are dominated by steep to high slope classes, which is unfavorable for infiltration.

Geology

The Karha river basin is a part of the Deccan Volcanic Province (DVP), which consists of several horizontal basaltic lava flows of varying thickness. Lithologically, the study area typically consists of Poladpur and Ambenali formations of the Wai subgroup (Fig. 5). Poladpur formation (PF) is exposed towards the lowlands of Baramati in the south-east and is overlain by Ambenali formation (AF) which covers the higher elevated regions (mainly Saswad and Jejuri regions) in the north-western part (Beane et al. 1986; Subbarao et al. 1994). The basaltic flows of the two formations are seemingly weathered at the surface extending downwards to the depth of about 10 to 20 m which mainly depends upon local gradient of the region (Kale 2011). Hydrogeologically, these rocks are classified as hard rocks, which characterized by scanty primary porosity and permeability. The primary openings in the basaltic flows namely the lava pipes, vesicles, flow contacts, cavities, and tunnels impart low permeability and porosity. The aquifer media of the study area are moderately porous and fracturing and jointing by way of interconnectivity have rendered secondary permeability and porosity to the structure which allows a complex formation of groundwater reservoirs at places (Bera et al. 2018; Pawar et al. 2008). According to

Table 3 Pairwise comparison matrix for all factors

Factors	GM	SL	G	L	LULC	R	S	C	DD	TWI
Geomorphology (GM)	1	2	3	4	5	6	7	8	8	9
Slope (SL)	1/2	1	2	3	4	5	6	7	8	9
Geology (G)	1/3	1/2	1	2	3	4	5	6	7	8
Lineament (L)	1/4	1/3	1/2	1	2	3	4	5	6	7
Land use/land cover(LULC)	1/5	1/4	1/3	1/2	1	2	3	4	5	6
Rainfall (R)	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5
Soil (S)	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4
Curvature (C)	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3
Drainage density (DD)	1/8	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2
Topographic wetness index (TWI)	1/9	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1

Table 4 Pairwise comparison matrix, weights, and consistency ratio of the data layers used

Factors	GM	SL	G	L	LULC	R	S	C	DD	TWI	Weights
Geomorphology (GM)	0.3385	0.4142	0.3887	0.3450	0.3040	0.2693	0.2407	0.2172	0.1798	0.1667	0.286
Slope (SL)	0.1693	0.2071	0.2591	0.2588	0.2432	0.2244	0.2063	0.1900	0.1798	0.1667	0.210
Geology (G)	0.1128	0.1035	0.1296	0.1725	0.1824	0.1795	0.1719	0.1629	0.1573	0.1481	0.152
Lineament (L)	0.0846	0.0690	0.0648	0.0863	0.1216	0.1346	0.1375	0.1357	0.1348	0.1296	0.110
Land use/land cover (LULC)	0.0677	0.0518	0.0432	0.0431	0.0608	0.0898	0.1032	0.1086	0.1124	0.1111	0.079
Rainfall (R)	0.0564	0.0414	0.0324	0.0288	0.0304	0.0449	0.0688	0.0814	0.0899	0.0926	0.057
Soil (S)	0.0484	0.0345	0.0259	0.0216	0.0203	0.0224	0.0344	0.0543	0.0674	0.0741	0.040
Curvature (C)	0.0423	0.0296	0.0216	0.0173	0.0152	0.0150	0.0172	0.0271	0.0449	0.0556	0.029
Drainage density (DD)	0.0423	0.0259	0.0185	0.0144	0.0122	0.0112	0.0115	0.0136	0.0225	0.0370	0.021
Topographic Wetness Index (TWI)	0.0376	0.0230	0.0162	0.0123	0.0101	0.0090	0.0086	0.0090	0.0112	0.0185	0.016
Principal Eigenvalues, 10.8709											
Consistency ratio (CR), 0.0649											

the National Geophysical Research Institute (NGRI), the porosity of Ambenali formation is 1.2%.

Lineament density

Lineaments are the manifestation of linear or curvilinear features on the earth's surface, which is an align expression of an underlying lithological structure such as a fault, fractures, and cleavages, as identified from the satellite imagery. In total, about 42 lineaments were mapped from the basin area. The major portion of the Karha river basin is underlain by hard rocks, where the lineaments create secondary porosity and permeability, which play a significant role in groundwater recharge. In the study area, two prominent directions of lineaments were identified, i.e., NE–SW and NW–SE trends. Lineament density of the study area have been classified into four classes, i.e., low (0–0.31 km/km²), moderate (0.31–0.62 km/km²), high (0.62–0.93 km/km²), and very high (0.93–1.24 km/km²) (Fig. 6). Areas with very high to high lineament density are having high potential for groundwater development.

Land use/land cover

Land use and land covers have a great impact on hydrogeological geo-hydroclimatic processes in the water cycle, viz., runoff, infiltration process, and evapotranspiration. These processes affect groundwater recharge. The land use/land cover of the Karha river basin is classified into six categories, viz., water bodies, settlement, forest, barren/scrubland, arable irrigated, and arable non-irrigated (Fig. 7). The maximum area is dominated by arable non-irrigated land which is 71.64% of the total basin area. Highly irrigated area was found around the Baramati region, because of various lift irrigation schemes used in the region. Nazare dam (Malharsagar) on the

Karha river near Jejuri is the major water body in the study area. Major settlement patch was found in the extreme eastern portion of the basin area. Settlement areas constitute only 27.78 km² (2.1%) while about 10.6 km² (0.8%) area is covered by water bodies/wetland. Wetland area, arable irrigated land, and forest cover area are good for groundwater percolation, whereas the buildup area and rocky barren land area are closely associated with the poor groundwater potentiality.

Rainfall

Climatically, the Karha river basin is situated in semi-arid and rain-fed region of Maharashtra. Monsoonal rainfall is the principle source of aquifer recharge in this area. For the rainfall distribution map, 10-year rainfall data of seven rain gauge stations in the Karha river basin were considered. The average annual rainfall in the Karha basin is classified into five categories, i.e., very low (421–490 mm), low (490–558 mm), moderate (558–641 mm), high (641–730 mm), and very high (730–827 mm) (Fig. 8). Higher intensity of rainfall (641–827 mm) was found in the western most part of the basin area, and it generally decreases from west to east direction. Higher intensity rainfall areas have high weightage value, which covers about 110.33 km² (8.34%) area, signifying excellent groundwater potential.

Soil

Soil is a significant geomorphic factor for delineating the GPZ of an area. Soil plays an influential role in controlling the rates of runoff and infiltration. The permeability of the soil depends upon the effective porosity of the soil, which is intensely influenced by soil texture, structure, voids ratio, and the degree of saturation. The soils of the Karha river basin mainly constituted of four soil groups, i.e., Lithic Ustorthents, Typic

Table 5 Weights assignment for subcategories of all factors through AHP

Factors	Sub category	1	2	3	4	5	6	7	CR	Weight
Geomorphology	Anthropogenic terrain (reservoir)	1							0.051	0.357
	Flood plain	1/2	1							0.268
	Pediment-pediplain complex	1/3	1/3	1						0.157
	Moderately dissected plateau	1/5	1/4	1/2	1					0.108
	Low dissected upper plateau	1/6	1/5	1/4	1/3	1				0.052
	Butte	1/7	1/6	1/6	1/5	1/2	1			0.034
	Mesa	1/8	1/7	1/7	1/6	1/3	1/2	1		0.025
Slope	0–2.4	1							0.041	0.514
	2.4–5.5	1/3	1							0.217
	5.5–10.7	1/5	1/2	1						0.154
	10.7–19.7	1/6	1/3	1/3	1					0.071
	19.7–56.3	1/7	1/5	1/5	1/2	1				0.044
Geology	Poladpur formation	1							0.000	0.667
	Ambenali formation	1/2	1							0.333
Lineament density	0.93–1.24	1							0.063	0.566
	0.62–0.93	1/3	1							0.267
	0.31–0.62	1/5	1/3	1						0.127
	0–0.31	1/9	1/7	1/5	1					0.040
Land use/land cover	Water bodies	1							0.047	0.390
	Arable irrigated	1/2	1							0.247
	Arable non-irrigated	1/3	1/2	1						0.187
	Forest	1/5	1/3	1/3	1					0.097
	Barren/scrubland	1/6	1/5	1/5	1/3	1				0.051
	Settlement	1/8	1/7	1/7	1/5	1/3	1			0.028
Rainfall	827–730	1							0.006	0.444
	730–641	1/2	1							0.262
	641–558	1/3	1/2	1						0.153
	558–490	1/5	1/3	1/2	1					0.089
	490–421	1/7	1/5	1/3	1/2	1				0.053
Soil type	Lithic Ustorthents	1							0.027	0.582
	Fluventic Ustropepts	1/3	1							0.216
	Typic Ustropepts	1/5	1/2	1						0.137
	Vertic Ustropepts	1/7	1/3	1/3	1					0.065
Curvature	Concave	1							0.007	0.669
	Flat	1/3	1							0.243
	Convex	1/7	1/3	1						0.088
Drainage density	0–0.22	1							0.043	0.415
	0.22–0.45	1/2	1							0.315
	0.45–0.68	1/3	1/3	1						0.157
	0.68–0.91	1/5	1/5	1/3	1					0.075
	0.91–1.14	1/7	1/7	1/5	1/3	1				0.038
Topographic wetness index	15.67–25.44	1							0.016	0.506
	11.66–15.67	1/3	1							0.228
	8.73–11.66	1/4	1/2	1						0.135
	6.45–8.73	1/6	1/3	1/2	1					0.081
	2.16–6.45	1/7	1/5	1/3	1/2	1				0.050

Table 6 Random index value (source: Saaty 1990)

n	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Ustropepts, Vertic Ustropepts, and Fluventic Ustropepts. From the soil map (Fig. 9) of the study area, it is observed that Vertic Ustropepts is the dominant soil group with 566.86 km² area coverage. Lithic Ustorthents and Typic Ustropepts are associated with coarse-grained, well-drained, loamy skeletal, isohyperthermic soils, having high weightage values, signifying high groundwater potential. Vertic Ustropepts and Fluventic Ustropepts soils are clayey loamy, calcareous, and imperfectly drained, developed on plain land and foot slope region.

Curvature

An important aspect to be considered in the case of groundwater hydrology and terrain instability is the curvature of hill slopes representing the morphology of the regional topography. The dynamics of surface and subsurface hydrology and the formation and accumulation of soil are well controlled by the forms and curvatures of a slope. The thickness of the soil is more in the case of concave slopes with respect to convex slopes. Surface and subsurface water accumulate in the concave slope, which in turn increases the pore water pressure in

days of storms and heavy downpours. In the case of the convex slope, a rapid runoff occurs, thereby preventing the accumulation of water. Intervening ridges and side slopes are examples of convex slopes. Planar landforms are the ones falling intermediate to the categories of concave and convex slopes (Fig. 10). The curvature values in the Karha river basin vary from - 10.51 to + 10.08. A positive value of curvature is indicative of the fact that the surface is convex, whereas a negative value of curvature suggests that the slope is concave. The value zero is assigned to linear surfaces.

Drainage density

Drainage density expressed in terms of closeness of spacing of channels. The drainage density of a river basin is an opposite functional character of permeability. Higher drainage density gives more runoff, which in turn leads to lesser the infiltration of water to the subsurface and vice versa (Bera et al. 2019). The drainage density of the Karha river basin has been classified into six classes (Fig. 11), i.e., very low (<0.22 km/km²), low (0.22–0.45 km/km²), moderately low (0.45–0.68 km/km²), high (0.68–0.91 km/km²), and very high (0.91–1.14 km/km²), covering an area of 143.37 km², 389.10 km², 459.01 km², 275.64 km², and 47.84 km², respectively. Areas with low to very low drainage density constitute about 40.49% of the total area, having high weightage values compared with the high drainage density zones.

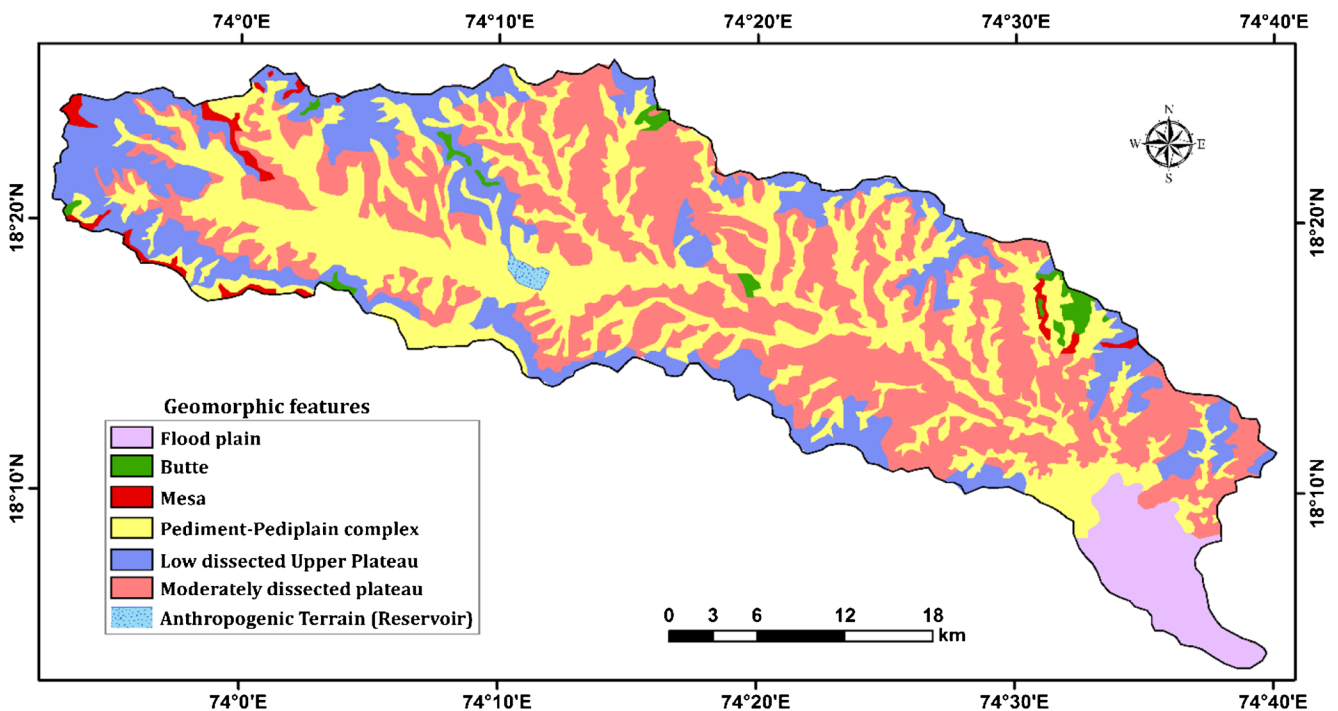


Fig. 3 Geomorphological map of the Karha river basin

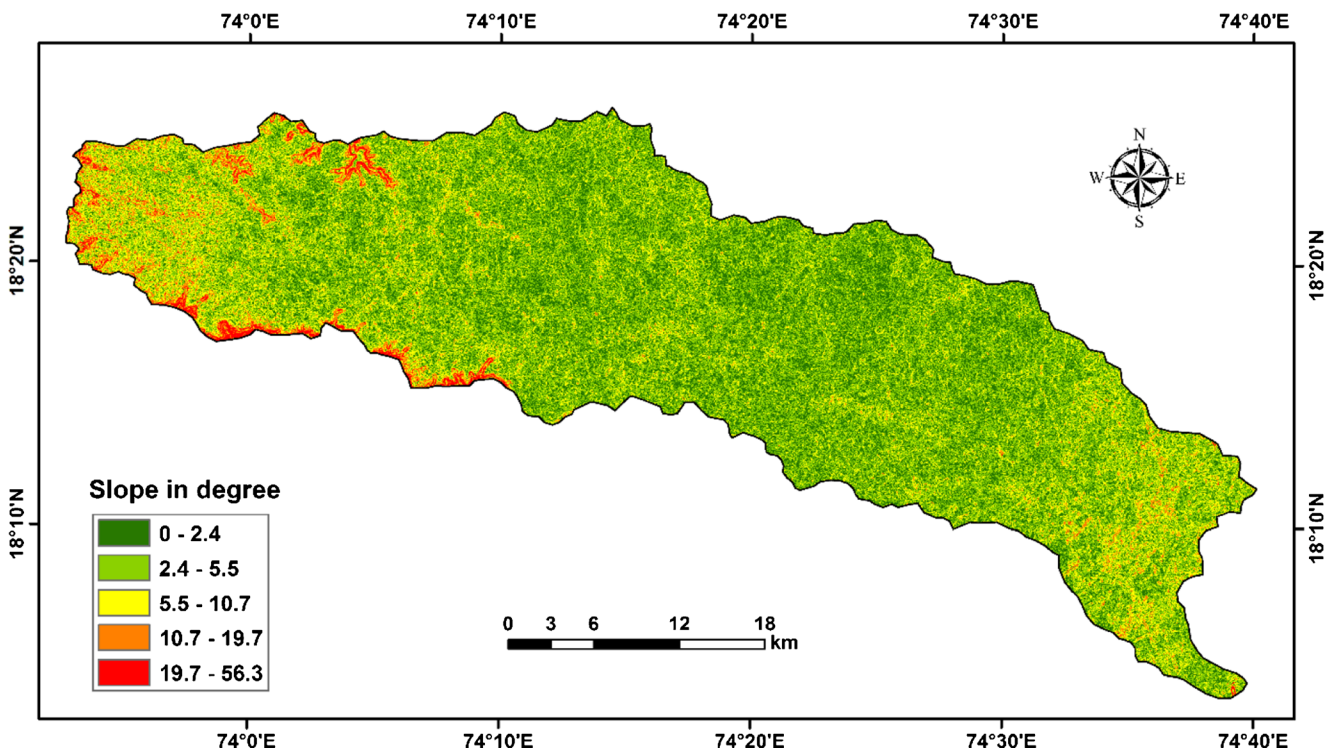


Fig. 4 Slope map of the Karha river basin

Topographic wetness index

Beven and Kirkby (1979) first formulated the topographic wetness index (TWI) within a runoff model. TWI

determines the spatial distribution of wetness conditions in a regional topography. In simple terms, it indicates the ratio of specific catchment area to the slope. This index ascertains the water accumulation tendency and the tendency of

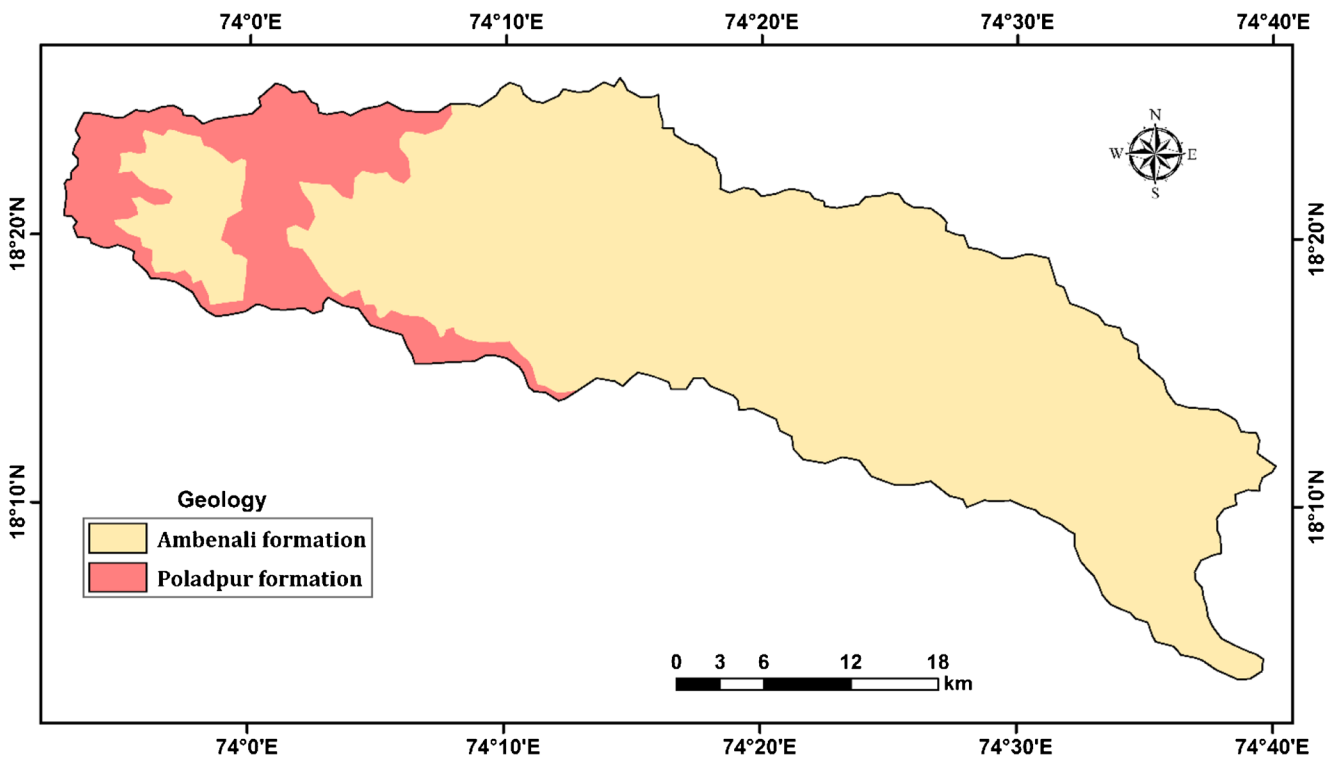


Fig. 5 Geology map of the Karha river basin

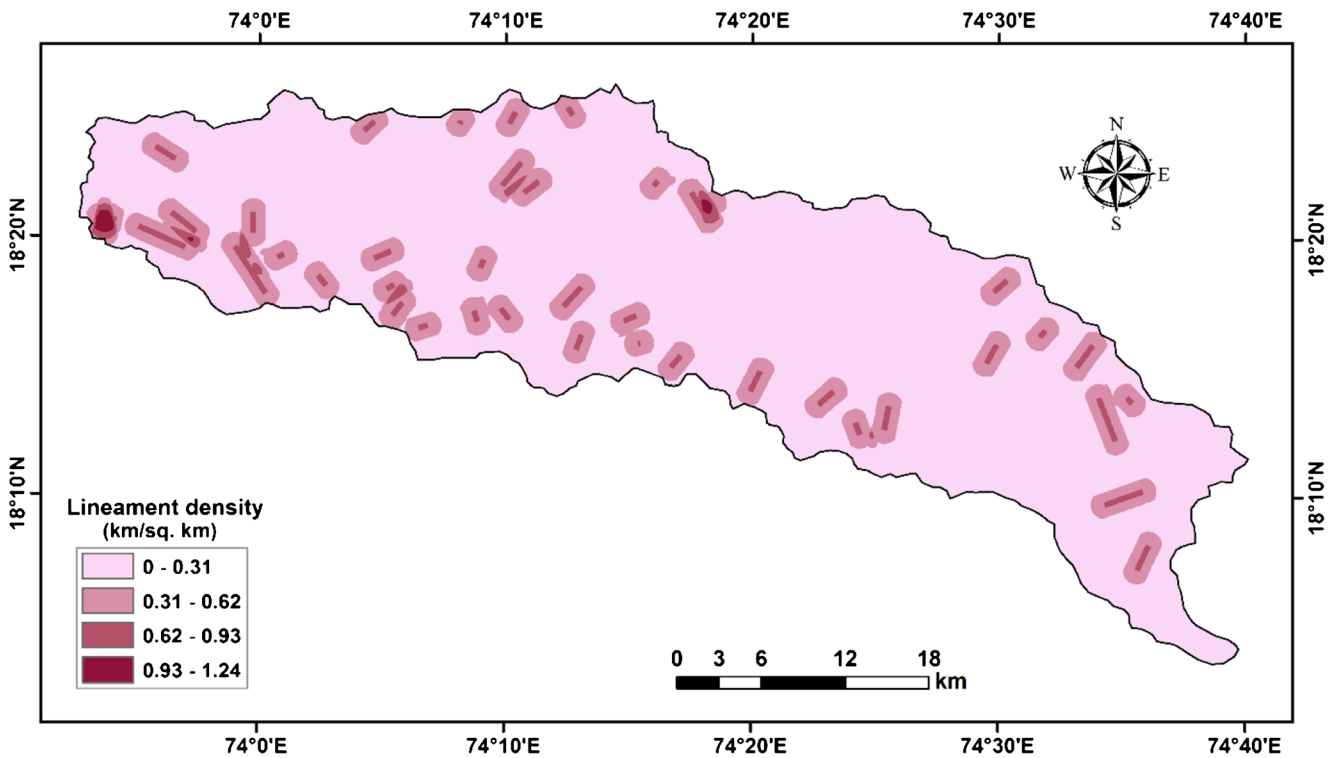


Fig. 6 Lineament density map of the Karha river basin

gravitational attraction to move the water downslope. The TWI values in the Karha river basin vary from 2.16 to 25.44 (Fig. 12). Within the Karha basin, TWI was

classified into five classes, i.e., excessively high (15.67–25.44), high (11.66–15.67), moderate (8.73–11.66), low (6.45–8.73), and very low (2.16–6.45). Normalized TWI

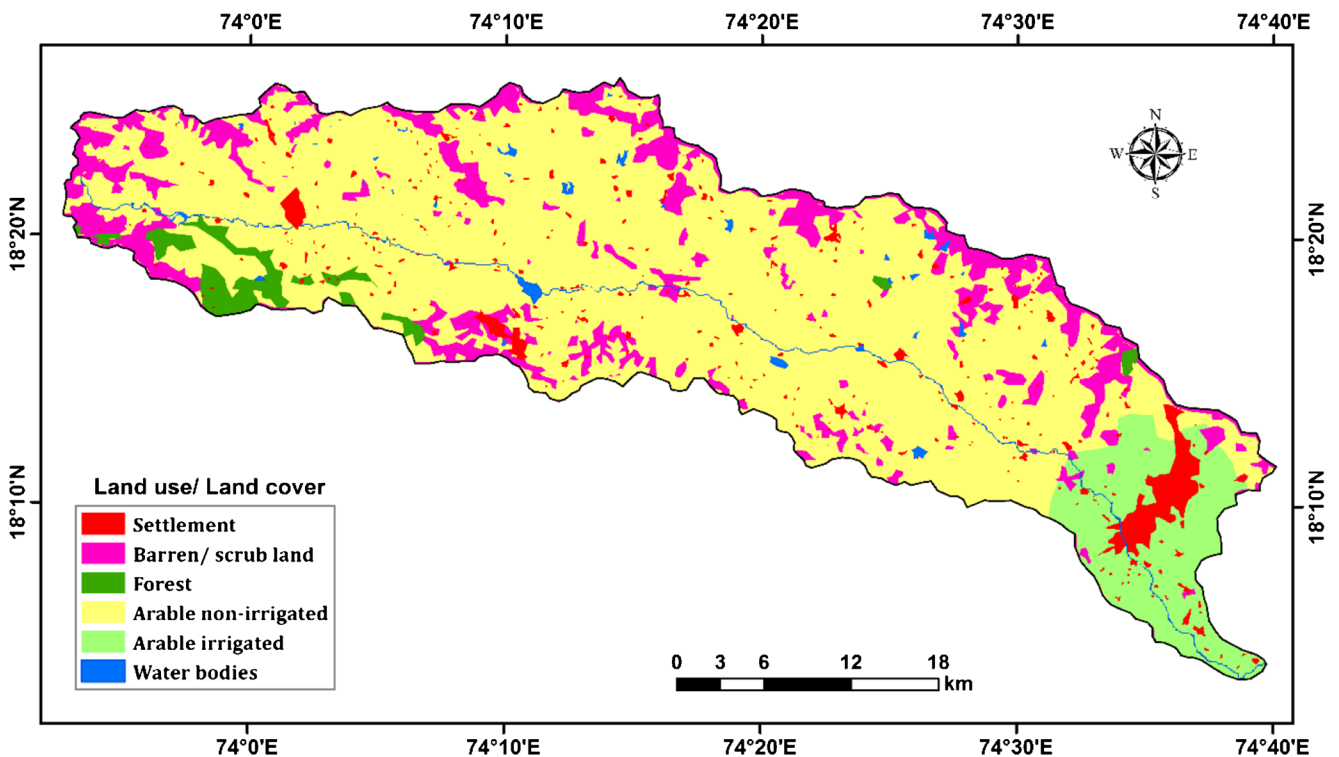


Fig. 7 Land use/land cover map of the Karha river basin

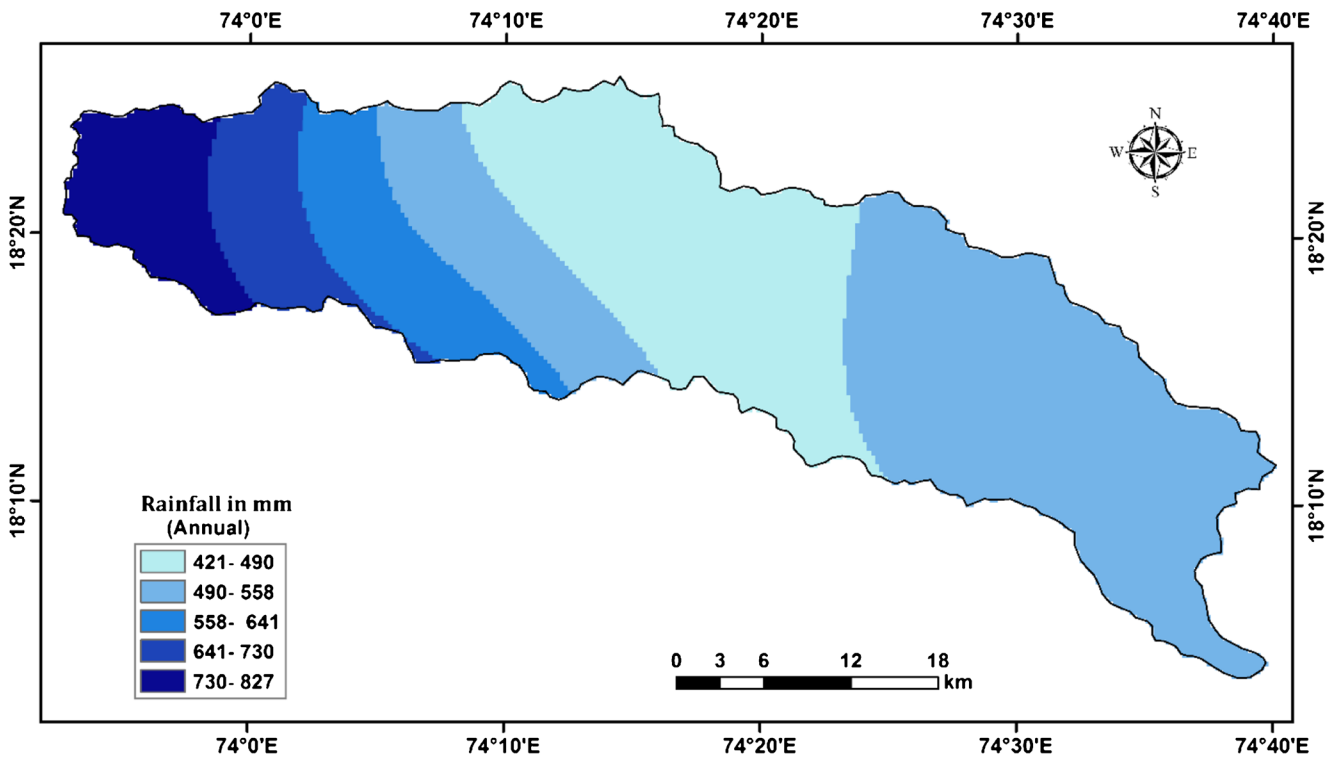


Fig. 8 Rainfall distribution map of the Karha river basin

categorizes recharge zones as discharge zones and probable recharge zones. Regions with high flow accumulation values and linear slopes have high TWI values. Recharge

zones have enough time for water to infiltrate into the soil and thereby passing to the underlying water table, while discharge zones are characterized by rainwater runoff.

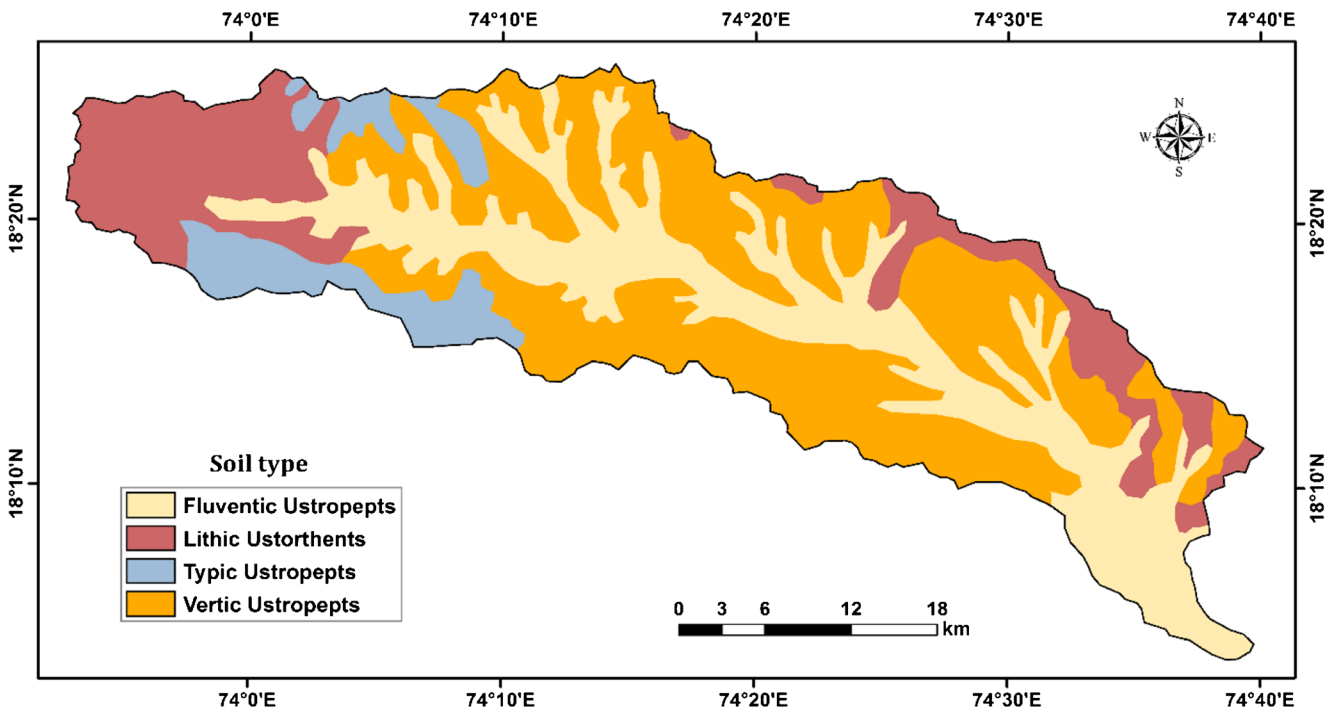


Fig. 9 Soil map of the Karha river basin

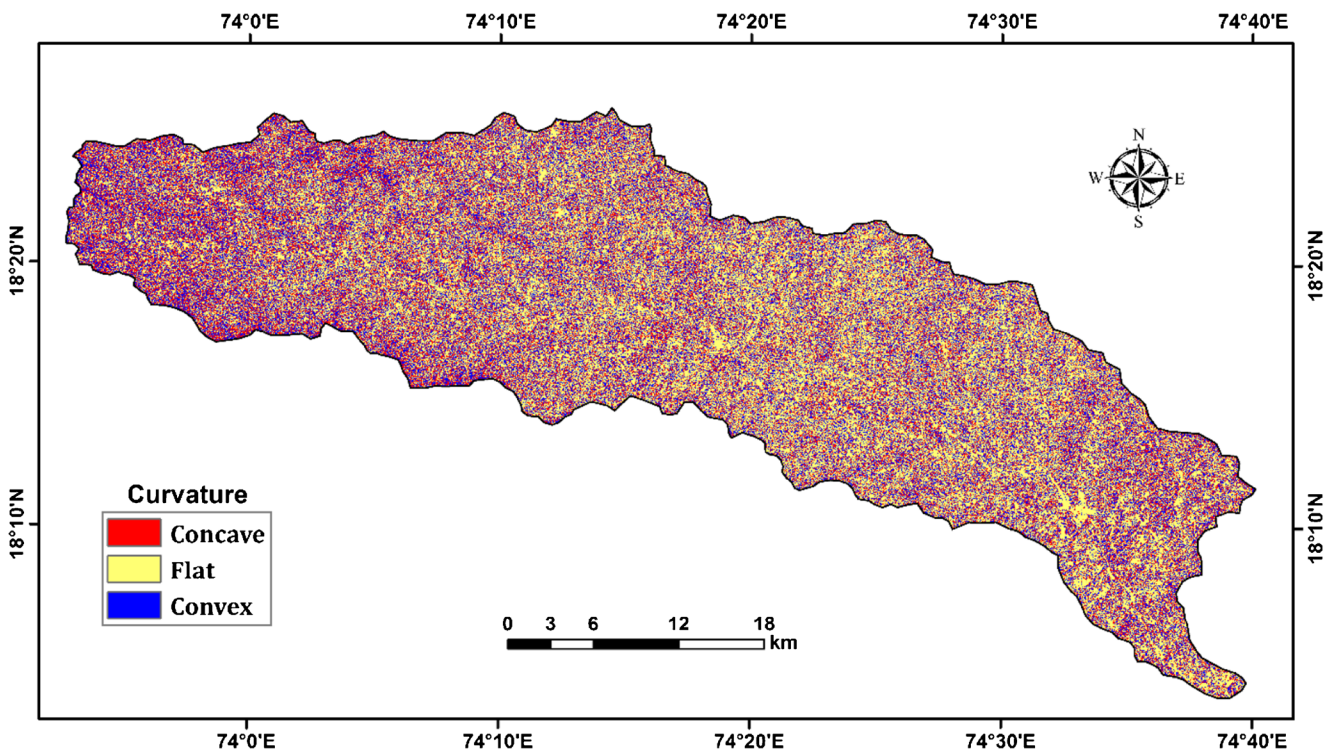


Fig. 10 Curvature map of the Karha river basin

TWI is represented by the following formula:

$$TWI = \ln \left(\frac{A_s}{\tan \beta} \right)$$

where A_s is the specific catchment area; $\tan \beta$ is the slope angle of the specific grid.

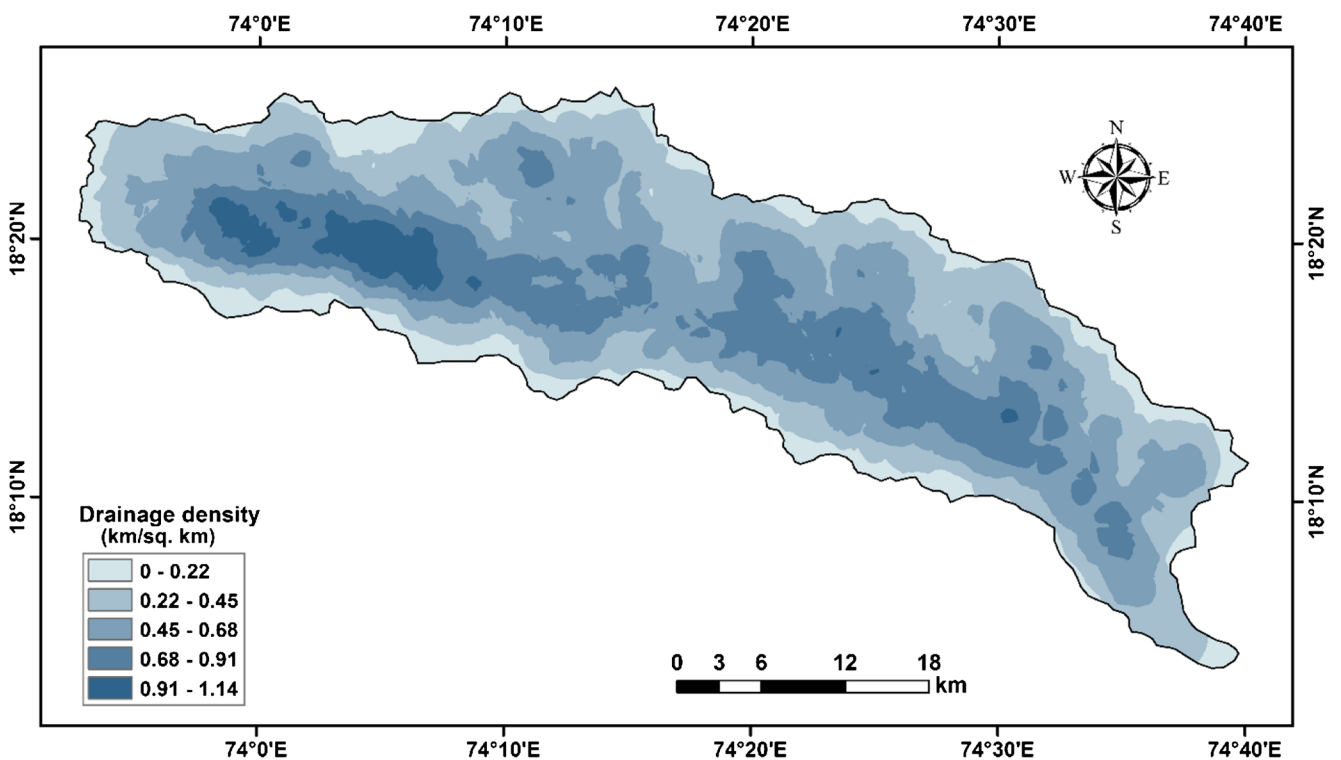


Fig. 11 Drainage density map of the Karha river basin

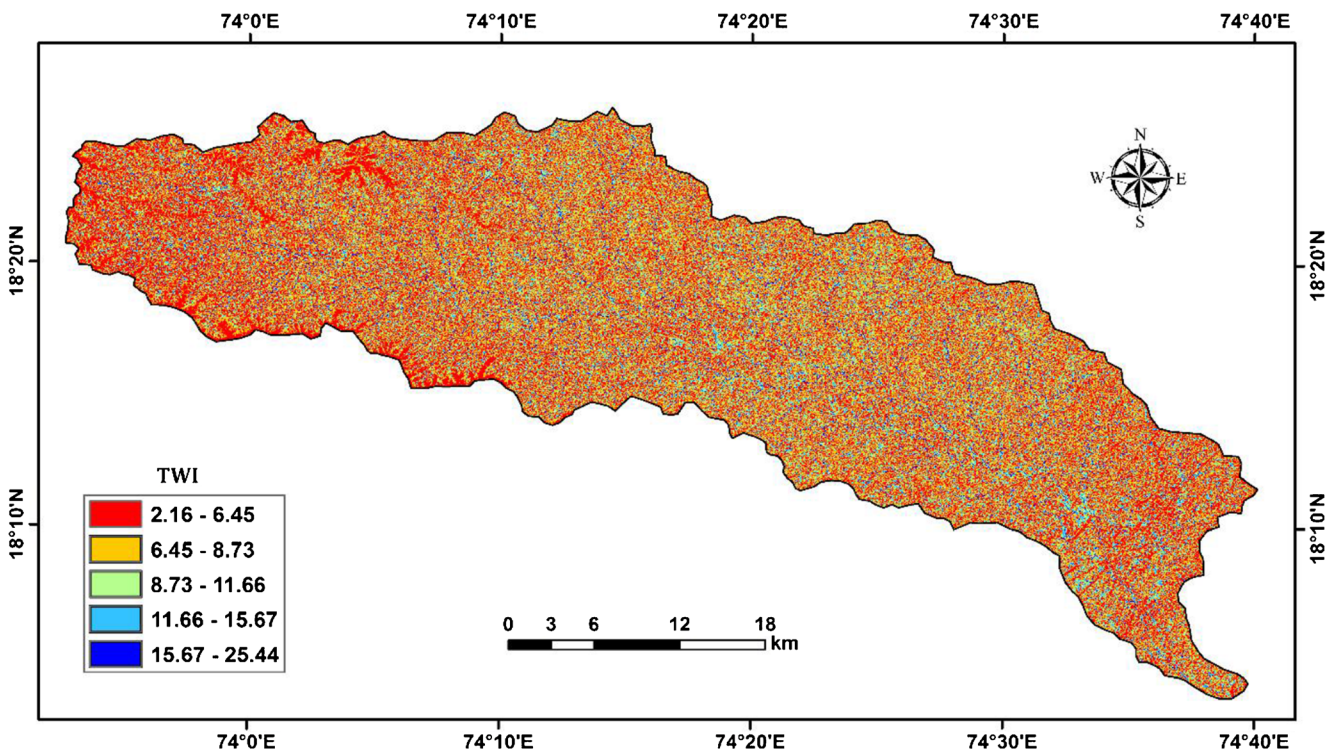


Fig. 12 Topographical wetness index map of the Karha river basin

Groundwater potential zone

Groundwater potential zones (GPZ) of the Karha basin a was prepared by overlay analysis of weighted factors, viz.,

geomorphology, geology, land use, drainage, slope, lineament, soil and rainfall curvature, topographic wetness index using AHP and GIS techniques in spatial analysis tool of Arc GIS 10.0. A multi-criteria analysis carried out with the

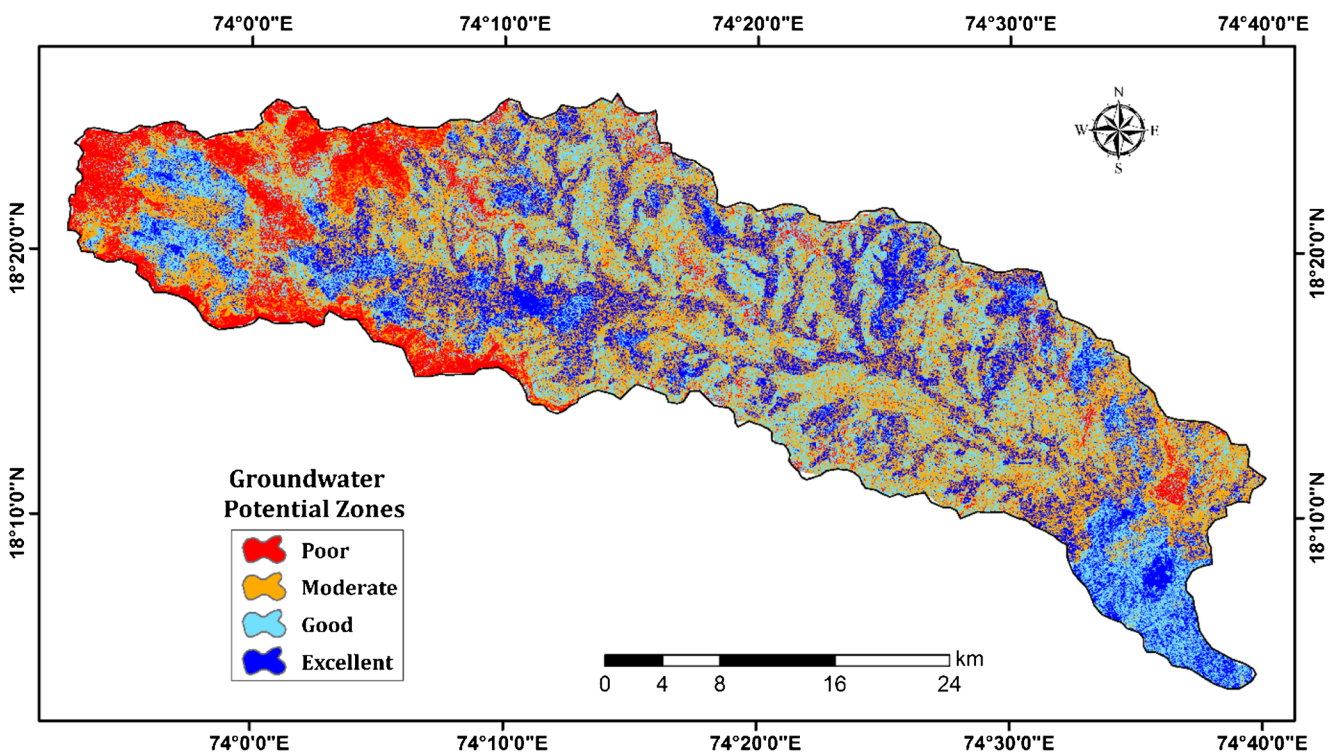


Fig. 13 Groundwater potential zone of the Karha river basin

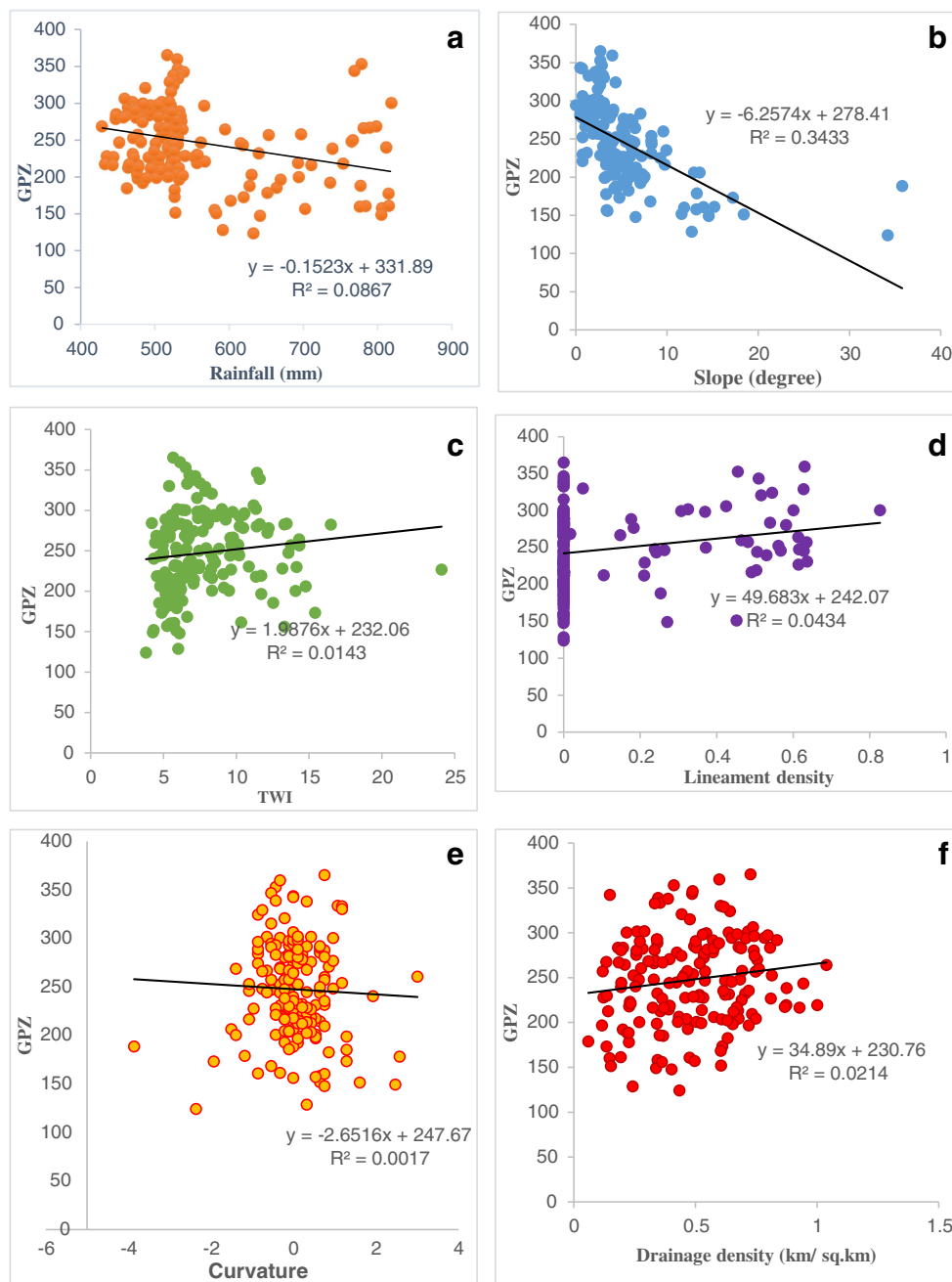


Fig. 14 a–f Relationship between the influencing factors for ground water recharge (grid based) and the Groundwater potential zone (GPZ). **h–j** Bar graphs represent the mean GPZ values for each influencing (vector based) factors and each sub-category (for **g**: AT, anthropogenic terrain (reservoir); FP, flood plain; LDUP, low dissected upper plateau;

M, mesa; MDP, moderately dissected plateau; PPC, pediment-pediplain complex; for **h**: AI, arable irrigated; ANI, arable non-irrigated; BS, barren/scrub land; F, forest; S, settlement; W, water bodies; for **i**: FU, Fluventic Ustropepts; LU, Lithic Ustorthents; TU, Typic Ustropepts; VU, Vertic Ustropepts)

help of assignment of rank to the individual factors and then assigning a weightage of sub-factors to that individual feature considering its influence over the criteria is referred to overlay analysis (Barik et al. 2016). Predicted GPZ of the Karha river basin was classified into four distinct zones, such as poor (10.81% of the area), moderate (38.41% of the area), good (28.82% of the area), and excellent (21.96% of the area) (Fig. 13). The results demonstrate that the

excellent GPZ was concentrated in the central and eastern part of the basin, particularly in Dorlewadi, Baramati, and Jawlarjun regions, due to the availability of loamy textured well-drained soil, high intensity of rainfall, presence of lineament, gentle slope, and vast agricultural land with an excellent infiltration capability. The western part of the basin receives the highest rainfall, but owing to steeper slopes, the water cannot infiltrate much and occurs mostly as

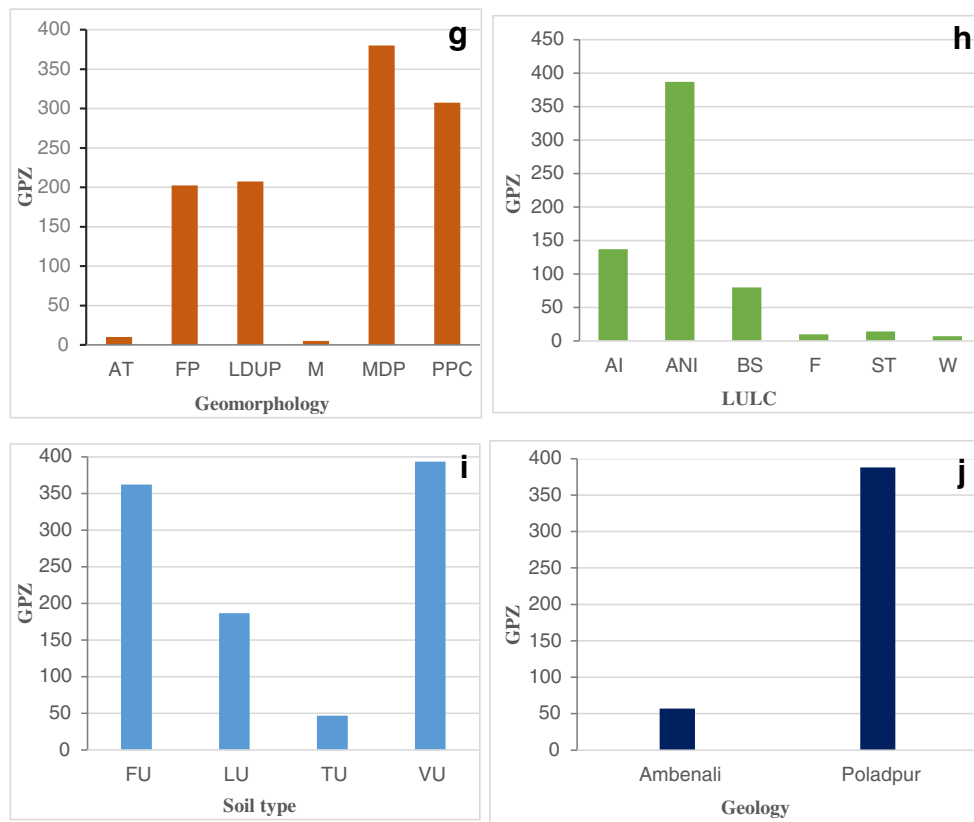


Fig. 14 (continued)

runoff. The western part (Askarwadi, Sakurde, Zendewadi, Narayanpur, Thapewadi regions) of the study area illustrates

very poor or low potential due to the presence of poorly drained soil and fine-grained basaltic hard rock underneath,

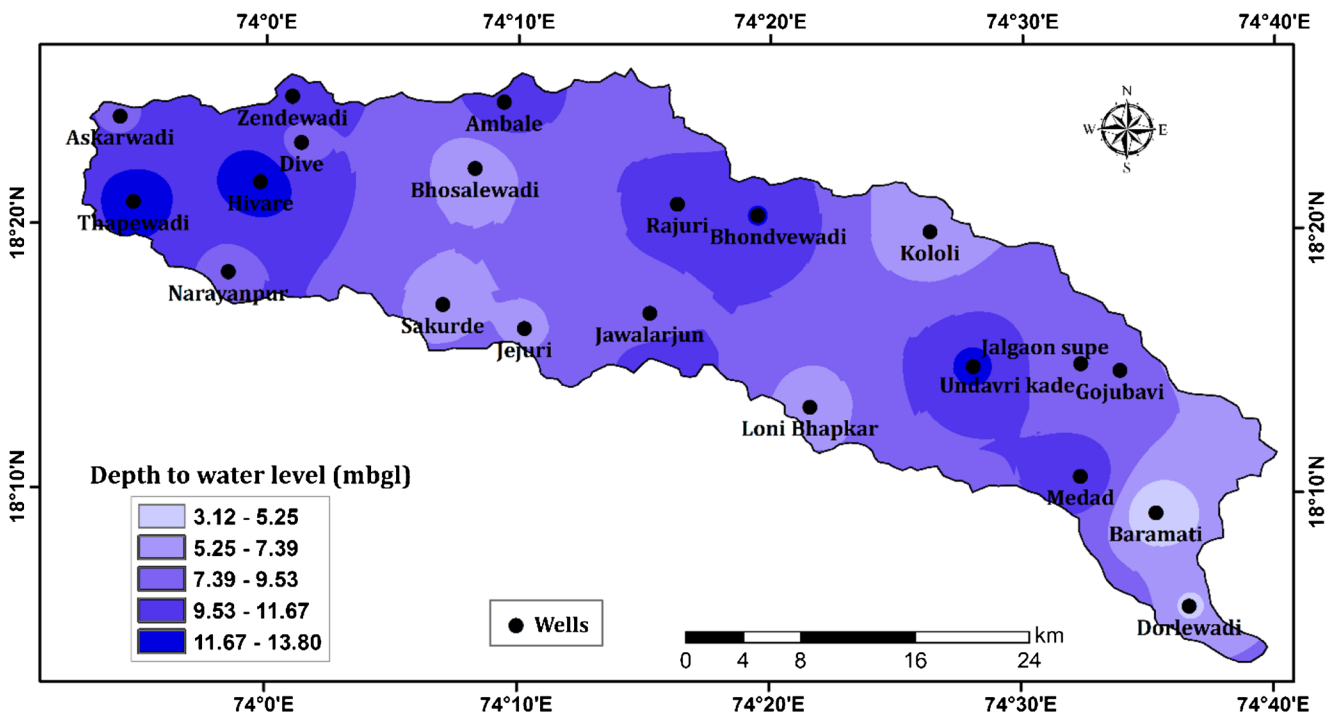


Fig. 15 Spatial distribution of groundwater depth of the Karha basin during pre-monsoon season in 2016

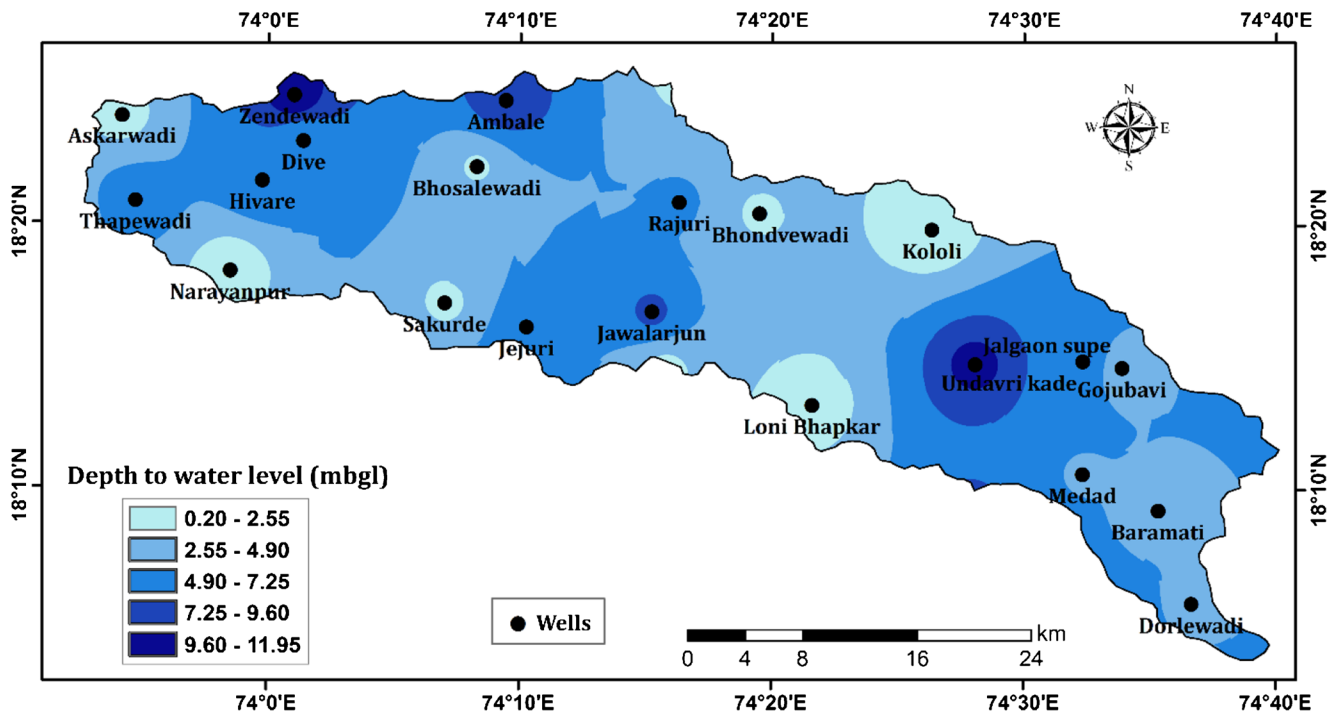


Fig. 16 Spatial distribution of groundwater depth of the Karha basin during post-monsoon season in 2016

which is less favorable for groundwater recharge. The scatter plots (Fig. 14) show which factors have a positive correlation on the GPZ. The scatter and bar graphs are plotted based on few random points created on the basin map, for which values of the influencing factors for groundwater

recharge and the groundwater potential zone (GPZ) are plotted. The main factors which have probable influence on the groundwater potential in this region are geomorphology, slope, land cover, and soil type. This conclusion can also be tallied with the scatter plots.

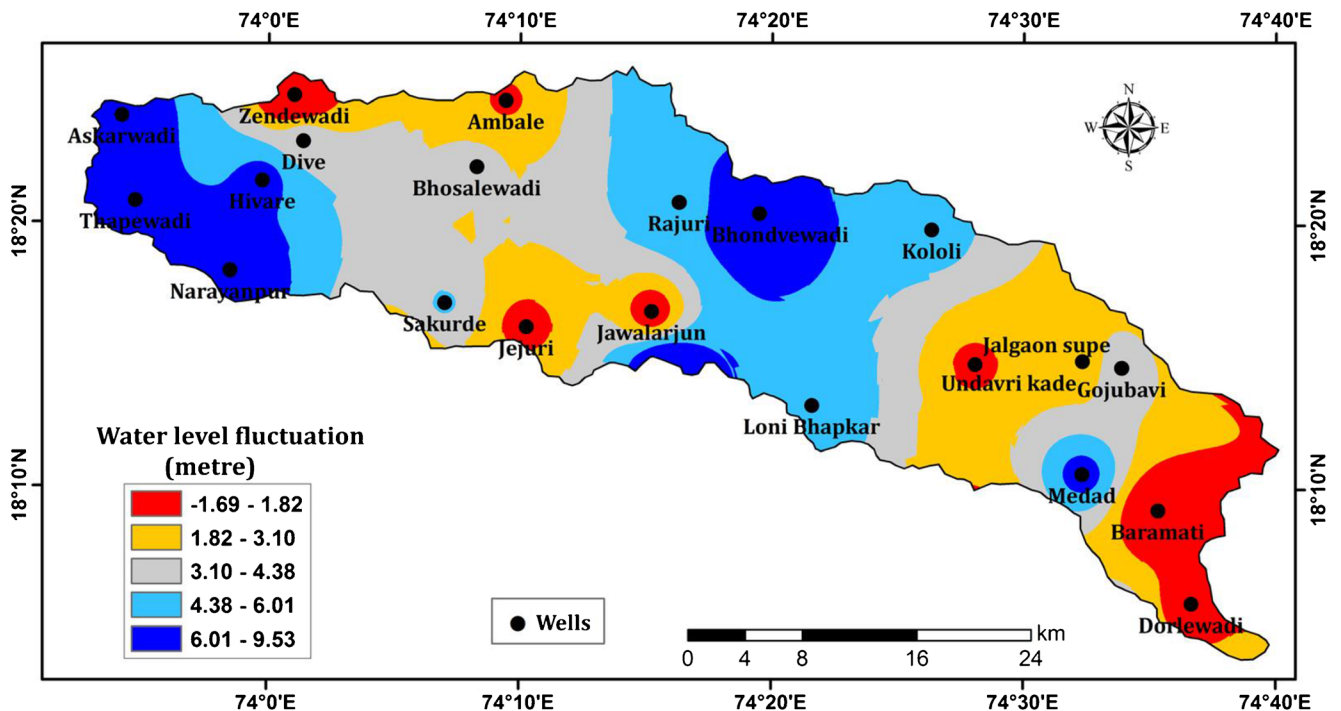


Fig. 17 Water level fluctuation map of the Karha river basin

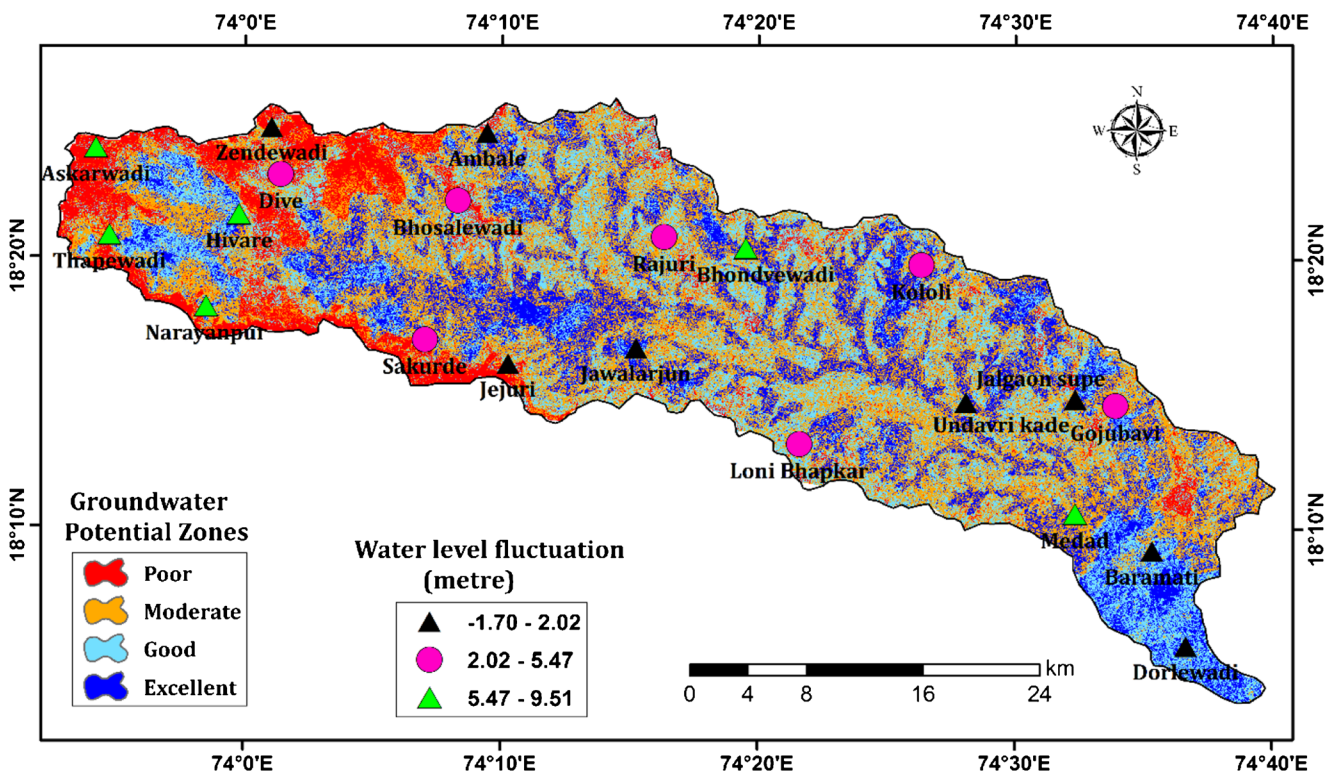


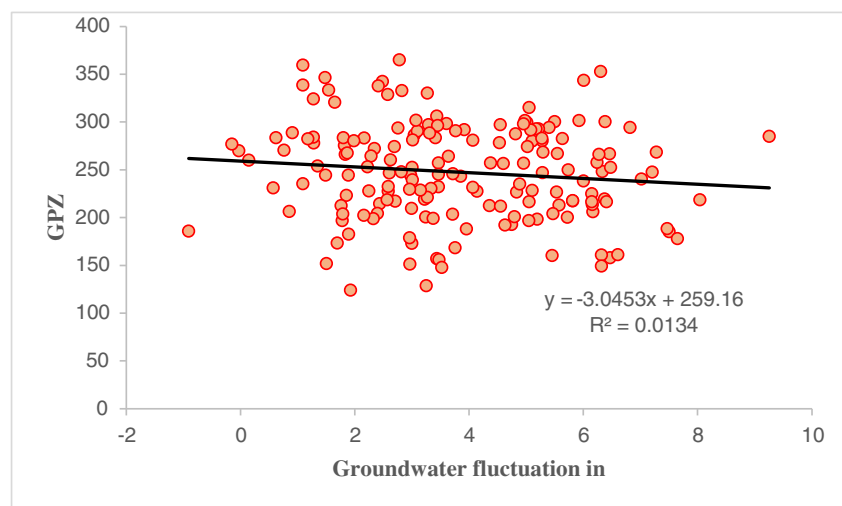
Fig. 18 Groundwater potential zone with water-level fluctuation of the Karha river basin

Validation

By studying the seasonal groundwater fluctuation of a region, the groundwater potential map can be validated. Usually, the regions having greater fluctuation in water level have low groundwater potential and regions having less fluctuations show a high groundwater potential. In this present study, 21 wells were observed for the investigation of the depth to water level data for the year 2016. Based on the collected data, pre- and post-monsoon groundwater level maps were created. The maps indicate the spatial variation in groundwater level of the

observed wells for both the seasons of the Karha river basin. From the pre-monsoon map (Fig. 15), it is observed that the western region of the basin shows deeper depth to water level compared with other parts. While in the post-monsoon (Fig. 16), the central to east region shows a shallower depth to water level compared to the eastern portion of the basin. However, greater fluctuation in the water level (Fig. 17) is observed in the north-western part of the basin indicating a low groundwater potential zone. The central and the south-east regions show a moderate to excellent water potential zone. From the maps (Fig. 18), it is observed that around

Fig. 19 Relationship between the water level fluctuation and the groundwater potential zone (GPZ)



71% of the wells are located in the part of the basin where there is high to moderate groundwater potential, which is mostly in the south-east and central regions, while the wells showing greater groundwater fluctuation are mostly concentrated in the western region of the basin, which has a low groundwater potential zone. From the scatter graphs (Fig. 19), it can be made out that the groundwater potential zone has a negative relation with groundwater fluctuation. Hence, the resultant groundwater potential map shows a high level of accuracy with the groundwater fluctuation maps and therefore can be used in planning the groundwater exploration and management purpose in the Karha river basin.

Conclusions

Groundwater is a vital resource in semi-arid drought-prone areas. As a part of semi-arid region, the Karha river basin area suffers scarcity of suitable surface water resources; therefore, groundwater in this region is widely used and is the principal source of drinking water. In the present study, delineation of the groundwater potential zone in Karha river basin using AHP and geospatial techniques with the help of conventional and remotely sensed geospatial data is found efficient to reduce the time, costs, efficiency, and manpower and thereby enabling proper decision-making for groundwater resources management and development. The groundwater potential map of the Karha river basin would assist the planners, engineers, and decision-makers in the monitoring and management of groundwater resources. The present research work brings out the intimate relationship among the hydrogeological, geomorphological, and meteorological parameters of groundwater. The entire basin falls in four potential zones ranging from excellent to poor. It is found that almost all major towns such as Saswad, Dorlewadi, Jalgaon, Loni Bhapkar, and Baramati are located in excellent to good groundwater potential zones. This simple and systematic method successfully gives a satisfactory result concerning the delineation of groundwater potential areas. In addition, this method can widely be used for groundwater exploration, artificial recharge zone identification, and sustainable water resource management in different parts of the world, where hard rock aquifers and semi-arid climatic conditions are observed.

Acknowledgments The authors are thankful to the United States Geological Survey (USGS), Central Ground Water Board (CGWB), National Remote Sensing Centre (NRSC), and Geological Survey of India (GSI). We are thankful to Prof. Dr. Broder J. Merkel (Editor in Chief, *Arabian Journal of Geosciences*) for suggesting modifications. The authors also extend their thanks to anonymous reviewers for the valuable constructive comments and suggestions.

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