RESEARCH PAPER

GROUNDWATER POTENTIAL ZONE DELINEATION IN HARD ROCK TERRAIN FOR SUSTAINABLE GROUNDWATER DEVELOPMENT AND MANAGEMENT IN SOUTH MADHYA PRADESH, INDIA

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ABSTRACT. In view of the vital significance of water resources and issues emerging from their temporal and spatial distribution and utilization posing serious problems to the land resources and to the society United Nations has identified sustainable management of water resources (SDG 6) as one of the seventeen major Sustainable Development Goals (SDGs). In this perspective, the purpose of the study is to identify the groundwater potential zones in the hard rock terrain of Betul-Chhindwara Region, Madhya Pradesh, India, using AHP technique. The study area comprises the sub-watersheds of Tawa river (Narmada basin), Tapi river (Tapi basin), Kanhan and Pench rivers (Godavari basin). Various thematic layers such as geomorphology, geology, physiography, rainfall, soil, slope, lineament, drainage density, groundwater depth, and land use/land cover were developed. The analytical hierarchy process helps to delineate groundwater prospect zones, which are categorized into five classes, i.e. very poor, poor, moderate, good, and very good based on objective, criteria, and preference. The good, moderate, and poor groundwater potential zones cover 4815 sq. km., 6423 sq. km, and 4857 sq. km, respectively, comprising 22.46%, 29.96%, and 22.65% of the entire region under study. The result indicates that 15.22% of the area comprising 3262.10 sq. km have very good groundwater potential whereas 9.71% (2080 sq. km) has very poor groundwater potential. The obtained result has been verified through field check based on the yield data collected from 16 bore wells in the study area. The accuracy of the results was 75% that proves the efficiency of the adopted techniques. Thus, this study will be efficient for the sustainable development and management of groundwater in the study area.

KEY WORDS: SDGs, Groundwater Potential Zones, Geographical Information System, Analytic Hierarchy Process, Betul-Chhindwara region

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INTRODUCTION

The concept of sustainable development connotes the utilization and management of resources to meet the needs of humanity at present without compromising the potentiality for the future generation. As such, sustainable development planning entails inventory, evaluation, and physical planning of development. Resource inventory, entailing survey, mapping, and assessment of quantity and quality of resources, is a prerequisite for sustainable development planning. Water resources occupy a unique place in the array of natural resources. Their temporal and spatial distribution and utilization also have posed serious problems to the land resources and the society. These problems include land degradation, salinization, waterlogging and lowering of the water table, and depletion of groundwater resources. Because of the vital significance of water resources, one of the seventeen Sustainable Development Goals (SDGs) of the United Nations is to ensure availability and sustainable management of water and sanitation.

Sustainable development of water resources is impossible until we study the fast deteriorating groundwater potential and address the issue practically and scientifically. Groundwater is vital resource and significant factor in meeting the water prerequisites of different segments, including their real users in agricultural, industrial, and domestic sectors. The manageable improvement of groundwater requires exact quantitative evaluation depending upon technically legal standards. The escalated use of groundwater in some areas of India has caused a rapid decrease in groundwater level. The estimated groundwater potential in India is 399 billion cubic meters (MOWR 2009). Therefore, significant steps for the tapping of potential groundwater sites need to be assessed at the utmost to fulfill the ever increasing demands of freshwater.

The groundwater availability and movement depend on different factors such as the density of lineament, Land Use Land Cover (LULC), geomorphology, geology, soil type, drainage density, slope etc. (Jaiswal et al. 2003; Shankar and Mohan 2005; Dwivedi 2007; Shekhar et al. 2014; Tirkey et al. 2016). Several researchers globally used geospatial technique to map groundwater prospect zone by incorporating the above mentioned layers of hard rock terrains (Gupta and Srivastava 2010; Jha et al. 2010; Mukherjee P. et al 2012; Fashae et al. 2014; Tirkey et al. 2016; Das 2017; Dwivedi et al. 2017). The emerging geospatial techniques are an inevitable and reliable tool in hydrogeological studies, especially for modelling and monitoring groundwater resources (Krishnamurthy et al. 1996; Chowdhury et al. 2009; Machiwal et al. 2011).

Groundwater prospect zones delineation through appropriate analytic methods becomes essential to manage, monitor, and balance the use of groundwater resources. The multi-criteria decision-making technique (MCDM) supports the proper sustainable management of groundwater resources of the region. MCDM involves many complex criteria for handling the problem and gives a realistic solution based on field investigation, pilot studies, and experienced consultancies (Dunning et al. 2000; Flug et al. 2000; Joubert et al. 2003). There are numerous MCDM techniques such as Analytical Hierarchy Process (AHP), Fuzzy AHP, and Multiple Attribute Utility Theory (MAUT). Among them AHP technique developed by Saaty (1980) is more reliable to manage the real-world problem and the natural resource-related problems such as structuring, prioritizing, distributing, and selecting resources, , and thematic ranking. (Saaty 1980; Malczewski 2006; Malczewski and Rinner 2015).

Numerous investigators have successfully applied the concept of Saaty's Analytical Hierarchy Process in GIS techniques for evaluating the probable zones of groundwater resources in various regions (Jha et al. 2010; Machiwal et al. 2011; Shekhar and Pandey 2015; Machiwal et al. 2015; Jhariya et al. 2016; Chowdhury et al. 2009). They found that the GIS technique and AHP are advantageous to plan sustainable utilization of groundwater resources in hard rock areas.

Groundwater is a vital component of the environment being a major source of supply throughout the world. Groundwater occurrence depends on geology, topography, drainage, land use, land cover, lineament, etc. We revealed rapidly increasing reliance on groundwater to meet the increasing water demands. This leads to water exhaustion and groundwater overconsumption causing ecological problems such as decreased water levels and water pollution. Therefore, there is a strong need to investigate groundwater occurrence using advanced techniques for sustainable development and management of this precious resource.

The Betul-Chhindwara region of Madhya Pradesh, India, faces water-related issues such as water scarcity, intermittent droughts, and groundwater depletion. The study area witnessed drinking water shortage and water deficiency during summer. The crop yield reduction observed in the study area is due to water shortage (Galkate et. al. 2008). The major part of the study area covering hard rocks gives less scope for groundwater occurrence due to poor aquifer conditions and high runoff. These precondition impose droughts therefore groundwater potential sites in the region need to be delineated using advanced techniques for sustainable development and management.

This study aims to investigate groundwater potential zones in the Betul-Chhindwara region using the AHP-based geospatial techniques for proper development and management of groundwater resources.

STUDY REGION

The Betul-Chhindwara region is positioned in the southern part of Madhya Pradesh, India, between 21° 28′ N and 21° 54′ 40.3092″ N latitudes and between77° 54′14.2308″ E and 79°24′E longitudes covering an area of 21440.8 km2. The location map of the study area is given in Figure 1.

The Betul-Chhindwara region is a part of the Middle Satpura Region. Geologically the whole area is covered by hard-rock

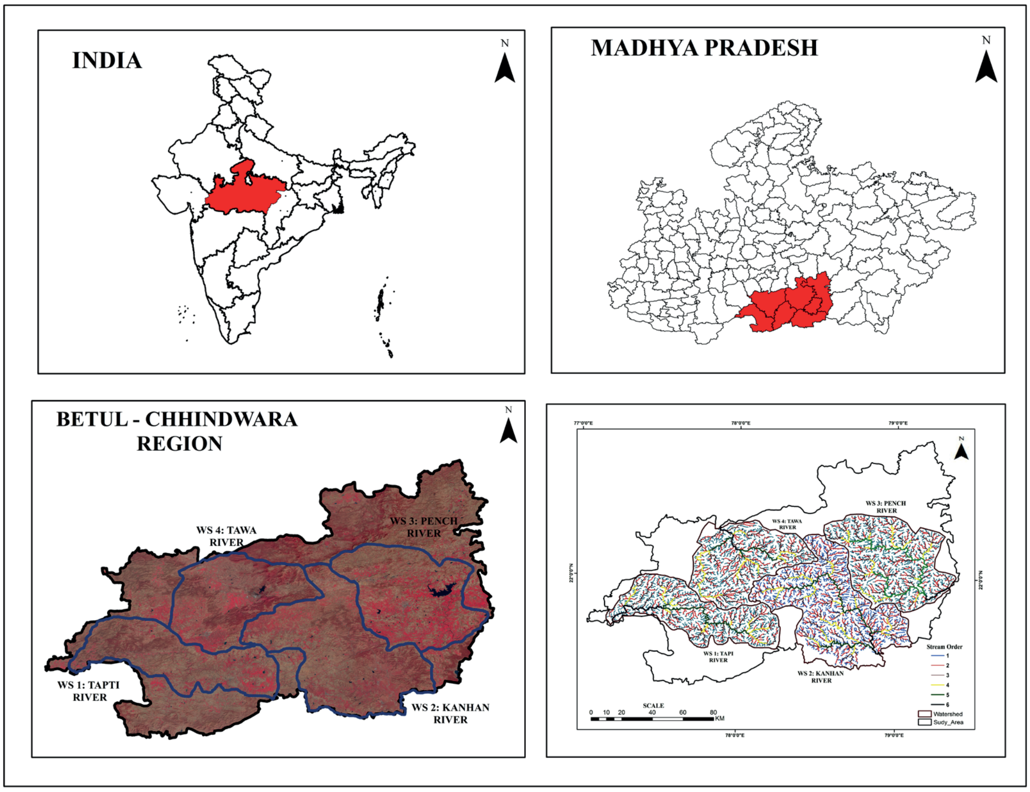

Fig. 1. Study area location with delineated watersheds

formations (CGWB 2009). This area is drained by seasonal rivers such as Pench, Tawa, Kanhan, and Tapi. Topographically entire region is undulating and dissected; many elongated hillocks are elevated to an altitude of from300 meters to 900 meters above MSL (Dehriya, 2014). The climate of the region is tropical with three main periods such as winter, summer, and monsoon. In May the temperature rises to 44ºC while January is considered the coldest month, in which the temperature lowers up to 12ºC. The study region receives maximum rainfall in July. The reported average annual rainfall of the region is 1,130 mm while spatial distribution is very uneven. The annual rainfall in most of the area (approx. 89 % of total area) is less than 850 mm, which is a scanty amount.

MATERIALS AND METHODS

To delineate groundwater prospect zone in the study using ten thematic layers such as geomorphology, geology, rainfall, physiography, soil, slope, lineament, drainage density, land use/land cover, and groundwater depth we used the multi-criteria decision method based on the Analytical Hierarchy Process (AHP).

The comprehensive flowchart representing the adopted methodology is illustrated in Figure 2.

Sentinel-2 satellite data was downloaded from the USGS website and thereby rectified and geo-referenced to prepare LULC and the investigated area's lineament map using ERDAS 9.3 ArcGIS 10.4 software. LULC map was generated using supervised classification with maximum likelihood classifier in ERDAS Imagine 9.3. The drainage map was digitized from the Survey of India's toposheet and rationalized with Sentinel-2 imagery for mapping recent stream networks. ASTER DEM data was used to develop a slope map of the area. The geology and geomorphology map of the investigated area was made using published data procured from GSI. The soil map was prepared from the existing data sets of the National Bureau of Soil Survey and Land-Use Planning (NBSS and LUP). Groundwater level data for 2018 were provided by the Central Groundwater Board and were subsequently imported in the GIS environment and spatially interpolated to prepare the groundwater level map of the study area. Rainfall data for 2018 collected from the Tropical Rainfall Measuring Mission (TRMM), NASA, were sorted with the purpose of development of rainfall map.

All thematic layers were selected for evaluation and assignment of weights with the help of Saaty's AHP keeping in view the comparative significance of each segment in the occurrence of groundwater.

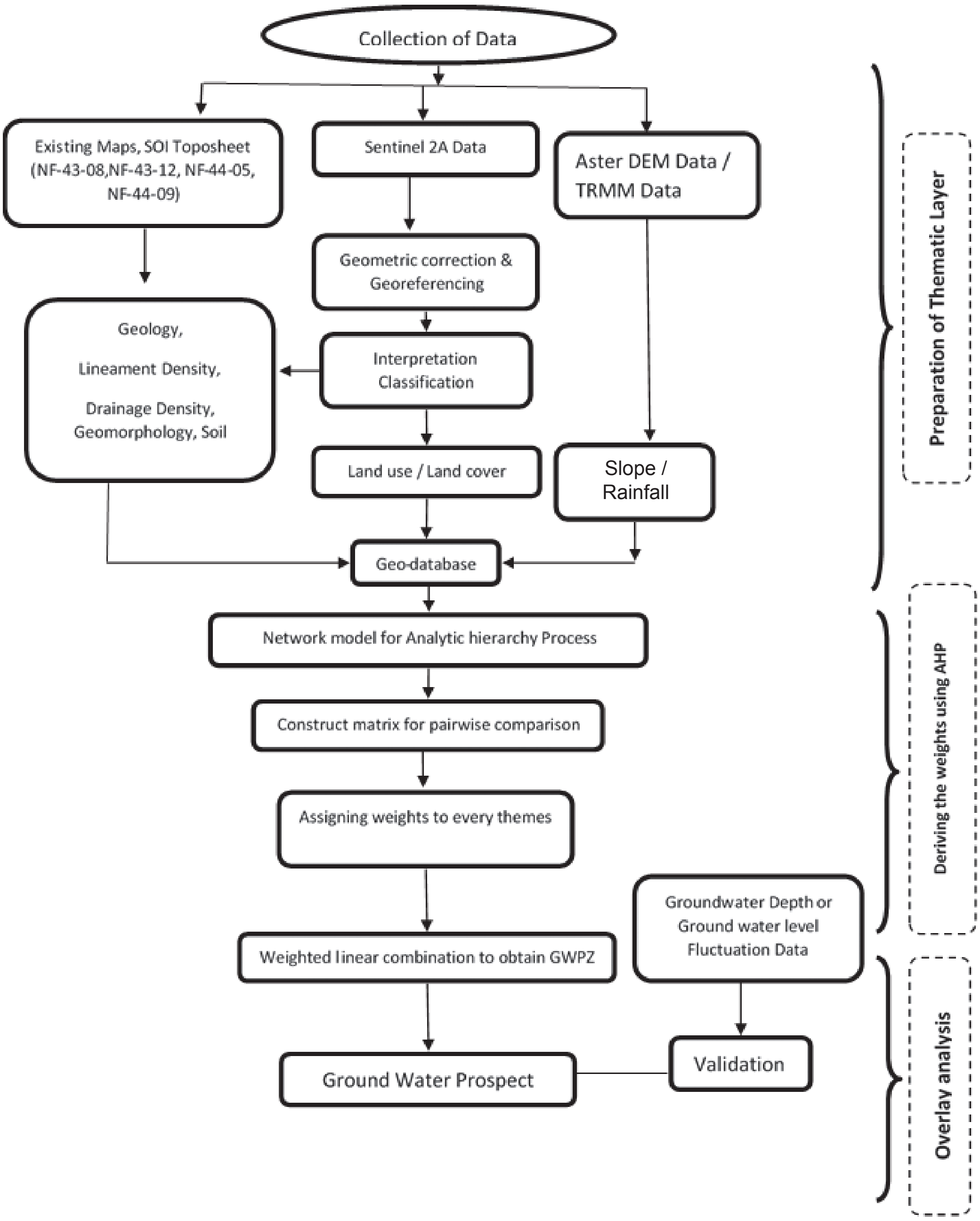

Fig. 2. Study area location with delineated watersheds

Thematic Layers Development Geomorphology

Geomorphology of the region provides evidence of structural evolution and geomorphic process in the geological past (King 1962). The spatial occurrence and movement of groundwater depend on geomorphological features and its genesis (Dwivedi,2007). Based on landforms origin, the area under investigation was classified into seven distinct geomorphological units viz. pediment and pediplain complex, vertically dissected plateau, dissected hills and valleys, alluvial plain, dam, and reservoir (Fig. 3).

Pediment-Pediplain Complex unit is of denudational origin. It covers the major part of the study region occupying approximately 9542.65 sq. km (43.58% of the area). Pediment has an erosional and undulating surface at the foot of hills while pediplain is an extended part of pediment with slopes varying from moderate to gentle (below 10 degrees) and formed by deep weathering and stream erosion. Pediment-pediplain complex unit are dispersed over the large area of Chhindwara, Betul, and Morabd plateau. Its groundwater potential varies from moderate to good . It is based on the underlying geological structure, lineament density, and weathering conditions of the region.

The dissected plateau is flat-topped, uneven with eroded structures, which are represented in the study region in a large quantity. We classified them into three classes: highly dissected, moderately dissected, and low dissected plateau. The second-largest geomorphological unit of the region is a moderately dissected plateau, which covers an area of 7742.83 sq. km. (35.36% of the area). It is spread over the basaltic terrain of the region and has medium groundwater prospect due to vesicular, fracture porosity, and moderate runoff.

A highly dissected plateau is steep-sloped structures, which occupy approximately 9.6% of the area (2121.95 sq. km) of the region. It indicates poor groundwater prospects due to high runoff while steep escarpments with high relief features are recognized as dissected hills and valleys formed due to an intense erosional process and reflects that the region has low groundwater prospects.

All these landforms, on the basis of their origin can be classified under two broad categories viz. denudational and structural landforms. Denudational landform includes pediment, pediplain, dissected plateau etc. extended over upper and lower Gondwana sandstones. Groundwater potential of gneiss/granite rocks varies from moderate to good due to primary and secondary porosity (CGWB 2013). While structural landforms comprise dissected hills, valleys, escarpment, etc. capped with the Deccan trap with a thickness varying from 7 m to 21 m (CGWB 2013) they have a low groundwater potential due to steep slopes. Weightage was assigned as per the groundwater occurrence response of different geomorphic units of the study area.

Rainfall

Rainfall is considered an essential factor in hydrological studies. The groundwater level is directly dependent on the received rainfall amount in a particular area; therefore, spatial variability of rainfall often affects the aquifer's recharging rate (Guhathakurta and Rajeevan 2007).

High rainfall zone is characterized by a high weight while low rainfall zones are characterized by a low weight. The study region receives maximum rainfall from the southwest monsoon – 1130 mm annually. However, the study area is characterized by a high spatial variability as Amarwada and Chhindwara plateaus are receiving a large amount of rainfall (above 950 mm) while Betul plateau and Gwaligarh hills receive very small amount of rainfall (less than 600 mm). The rainfall of the region was categorized into nine classes (Fig. 4).

Geology

The study area consists of Archaens and recent geological formation (CGWB 2009). The main geological units are metamorphic crystalline complex, Gondwana Supergroup, and Deccan Trap.

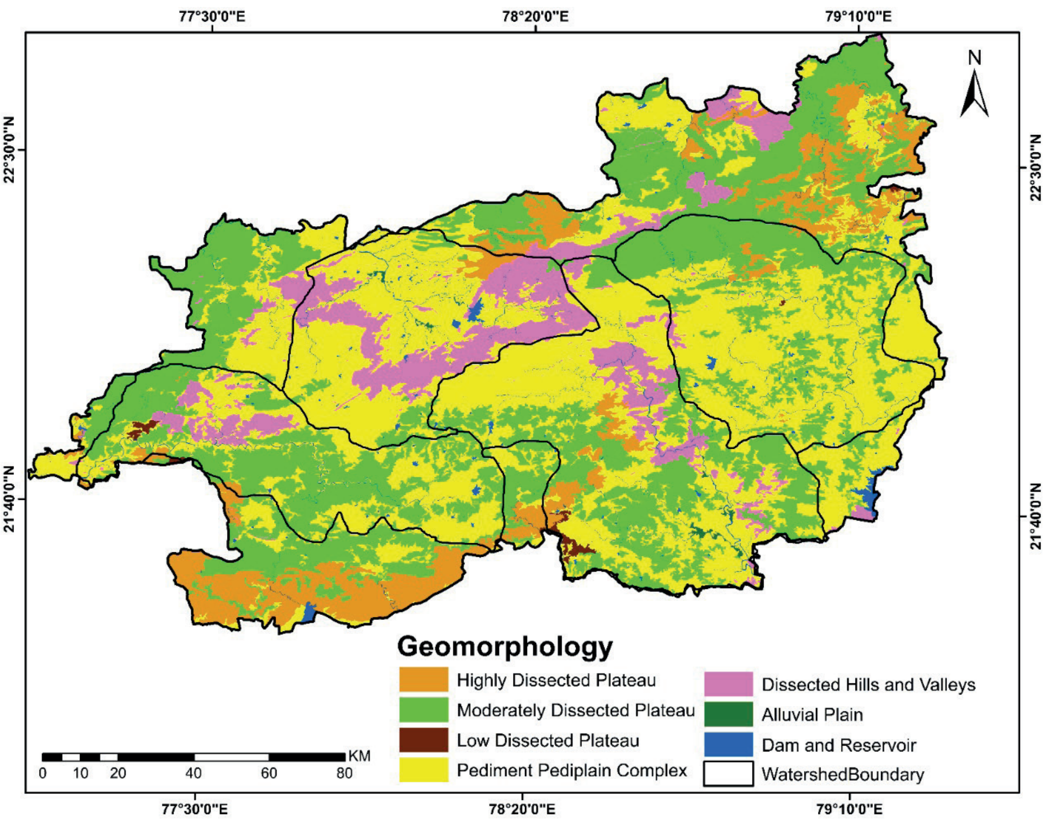

Fig. 3. Geomorphological setting of the selected study area

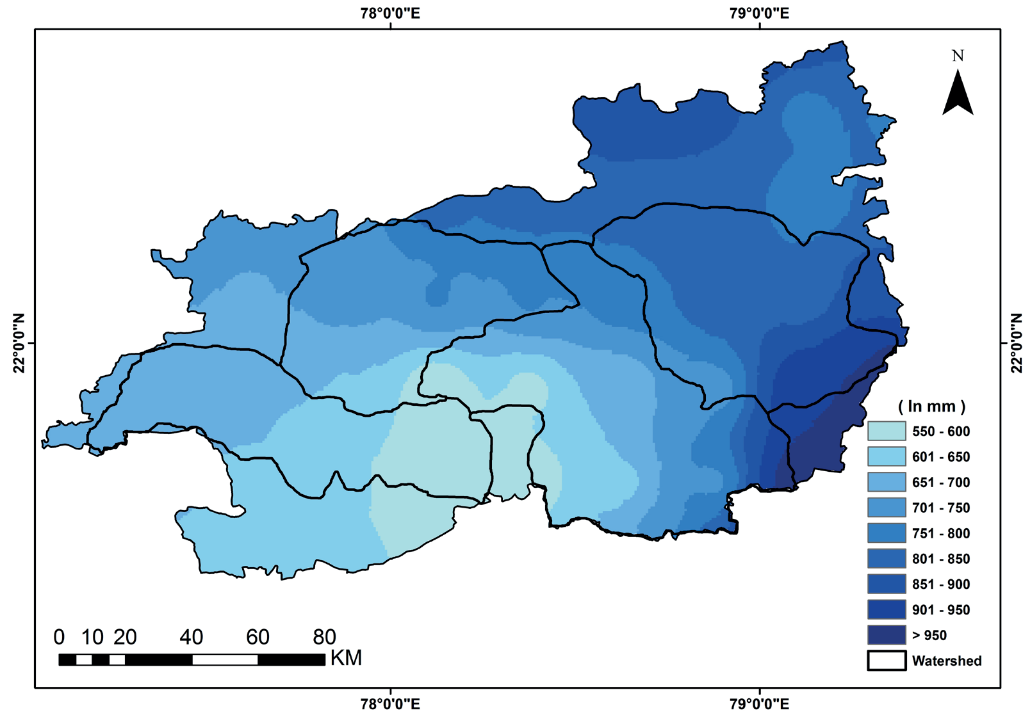

Fig. 4. Rainfall pattern in the selected study area

Low grade metamorphosed crystalline rocks are the basement rocks, including Sausar Series, granite, and gneiss rocks (Rajeeva et al. 2012). They are well exposed in the Sausar plateau and along the valley of the Kanhan river. Conditions in the lower and upper Gondwana sandstones are favourable for groundwater storage, which overlies the basement rock and Gondwana rock overlain by the Deccan trap (Murkute and Joshi 2015). The Deccan Trap covers the maximum portion of the study area, approximately 65% (14309 sq. km.) of the whole region (Fig. 5). It is observed that lower and upper Gondwana rocks have high groundwater potential due to their intergranular porosity, while the granitic, basaltic, and gneissic rocks are characterized by a lower porosity due to their impermeable nature. In hard rock terrain, groundwater is mainly found in secondary porosity structures like fractures, joints, cleavage, and weathered surfaces. Therefore, these parameters have been assigned with corresponding weightage values due to their greater inclination to determine the groundwater potential.

Physiographic division

The study area is categorized into eight dominant physiographic units (Fig. 6). The Betul and Chhindwara plateaus are characterized by good groundwater conditions, followed by the Amarwara plateau.

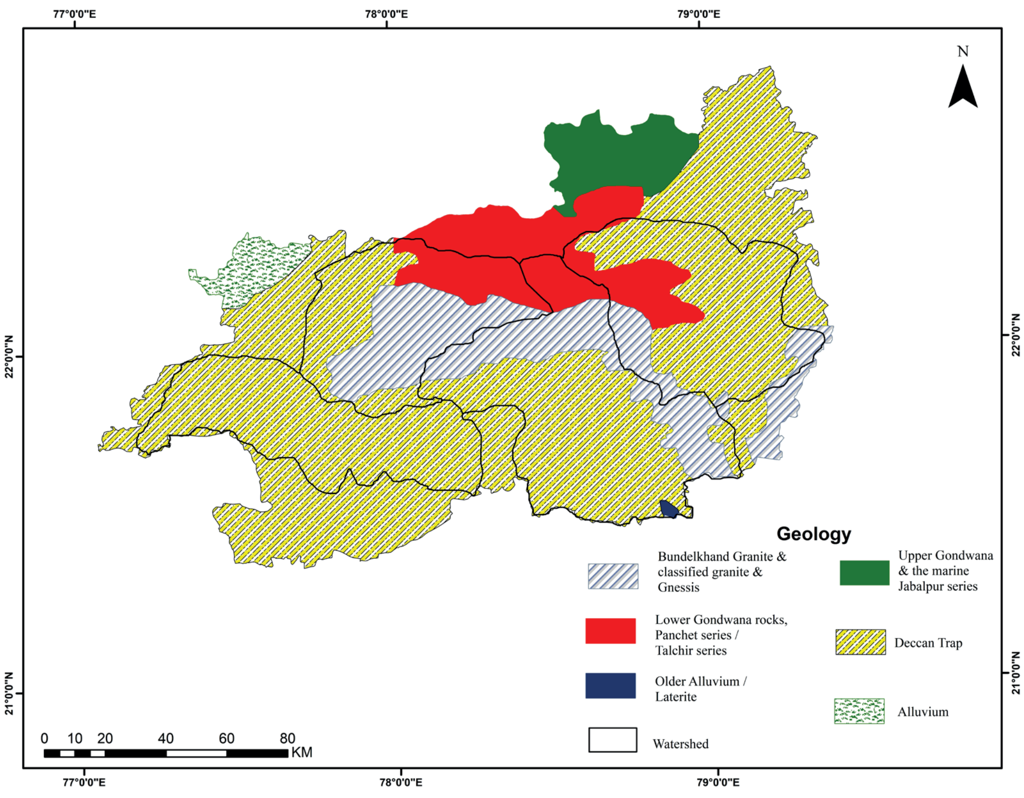

Fig. 5. Geology map of the selected study area

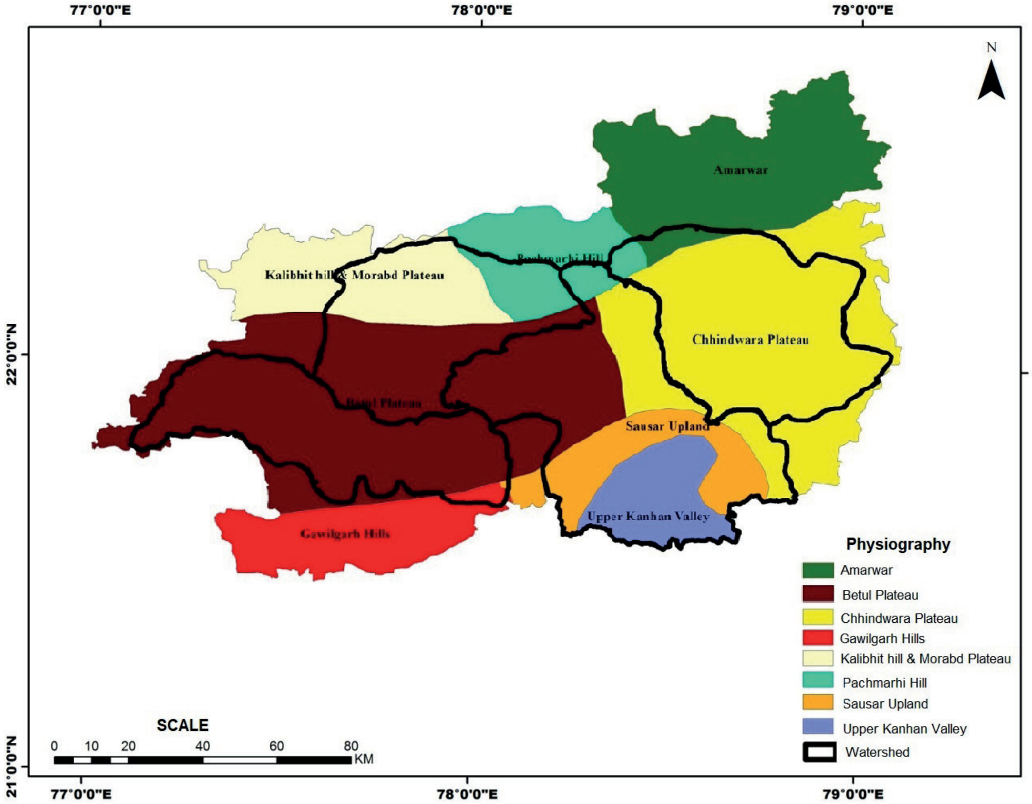

Fig. 6. Physiographic map of the selected study are

The Upper Kanhan valley has a moderate groundwater occurrence whereas Sausar upland and hills have a poor groundwater condition; the weightage values to these features was assigned accordingly.

Soil

Four dominant soil textures – sandy, silt, clay, and loamy – are observed in the study region (Fig. 7).

The soil rich in sand is usually characterized by a comparatively high rate of infiltration. Therefore, it is given higher priority; on the other hand, the soil with high clay material is characterized by a minimum infiltration rate; hence, its priority is the least. Weightage to soil layers was assigned as per their infiltration rate and transmission capacity, which allows for groundwater recharge.

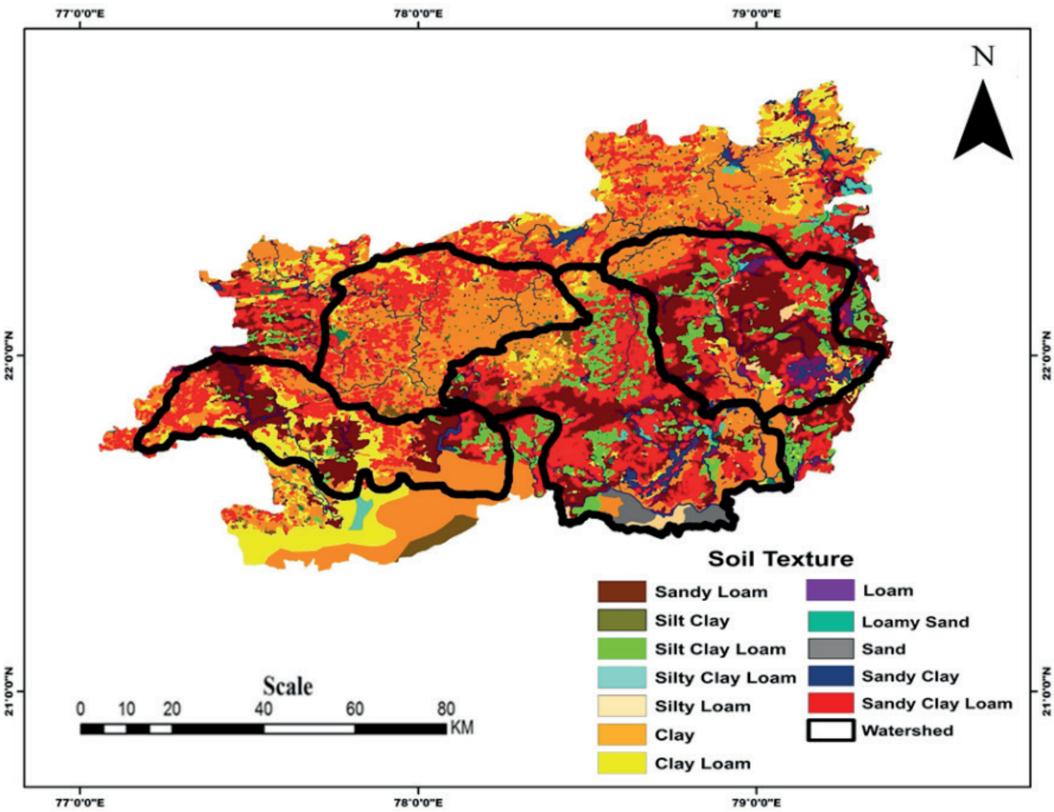

Fig. 7. Distribution of soil in the selected study area

Drainage density

In hydrological studies, drainage density is an important parameter because of its direct relation to the slope and an inverse relationship with permeability (Ghosh and Jana 2017). Drainage density represents the ratio between stream length and unit area of the basin (Strahler 1952). It indicates the total volume of streams in a watershed. Drainage density is heterogeneous because of variation in lithology, relief, slope, and precipitation from one region to another. In this paper, drainage density has been categorized into five classes (Fig. 8). Areas with higher drainage density indicate a favourable condition for the surface runoff; therefore, it is deemed a low-potential groundwater zone. Thus, regions with low drainage density are given high weightage and vice versa.

Lineament density

As detected in satellite images simple or complex properties of a linear geological structure such as faults, joints, fractures, or any other discontinuities on the surface are considered lineaments. Lineaments in the study area have aligned into NW-SE, NE-SW, NNE-SSE, and ENE-WSW direction. Lineament density, intersection point, and lineaments along the drainage lines are essential factors for determining groundwater potential in any area, as they are used as a tool to understand the occurrence and movement of the groundwater in hard rock terrain.

The lineament density of the study area was grouped into five classes (Fig. 9). The high lineament density areas (from 0.69 km/sq. km to 1.29 km/sq. km) are thereby assigned the highest weightage values in assessing the groundwater prospect zones of the Betul-Chhindwara region whereas the low weight is assigned to low-density areas (0 km/sq. km to 0.17 km/sq. km) (Table 4).

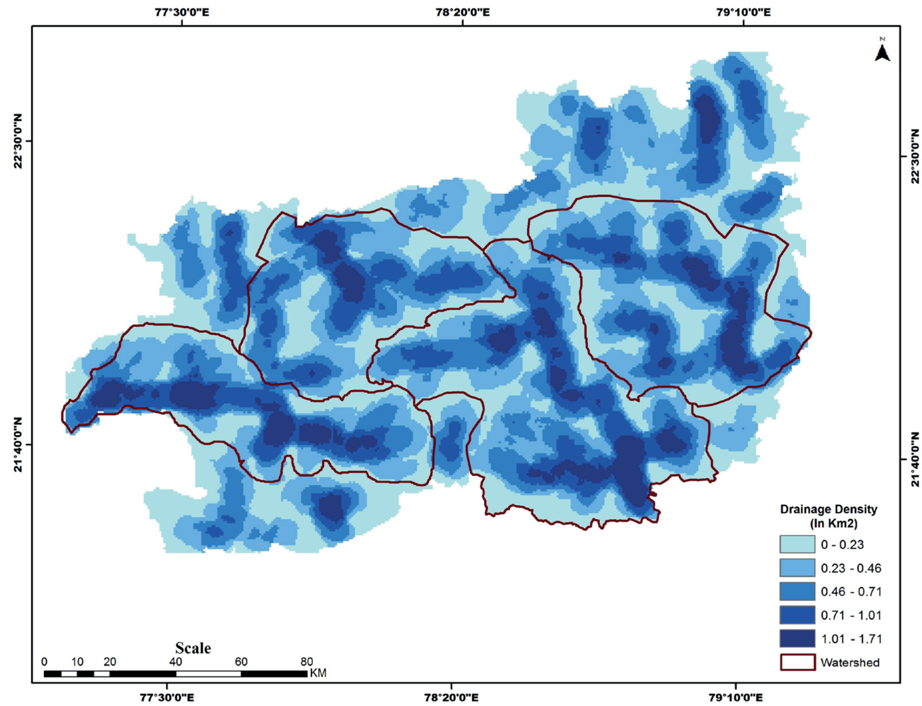

Fig. 8. Drainage density map of the selected study area

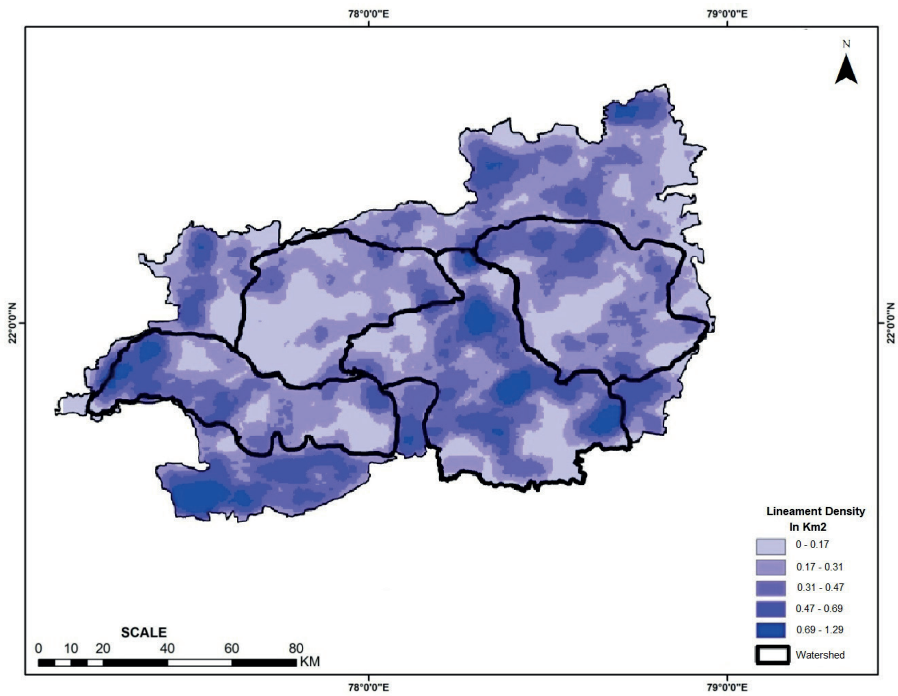

Fig. 9. Lineament density map of the selected study area

Slope

The study area's slope ranges from 0 degrees to 65 degrees and has been categorized into five classes (Fig.10). Most of the region (72.87% of total area of the region) comes under a 10-degree slope. An area with a gentle slope (0–5 degrees) could be useful for groundwater potential because the slope directly relates to runoff while we established an inverse relationship with the infiltration rate. The high slope class is assigned low weight whereas the low slope is given high weightage as per its responses on groundwater occurrence.

Land use and land cover (LULC)

LULC influences hydrological cycle and fluctuation of the water table and groundwater occurrence (Cook et al. 1989; Phillips 1994; Tyler et al. 1996; Pandey and Dwivedi 2014). Many investigations related to groundwater recharge and its impact on LULC have been conducted to understand the hydrological behaviour (Roark and Healy, 1998). Land use/land cover is directly associated with factors controlling the groundwater recharge, such as soil, vegetation, slope, rainfall, etc. Seven land use/ land cover classes were recognized as sparse forest, dense forest, cropland, waterbody, fallow land, settlement, and barren land (Fig.11). Waterbody, dense forest, sparse forest, and cropland area have good groundwater potential. Therefore, maximum weightage is given these classes while barren land, settlement, and fallow land have an inadequate response to groundwater recharge to assign low weightage to these features.

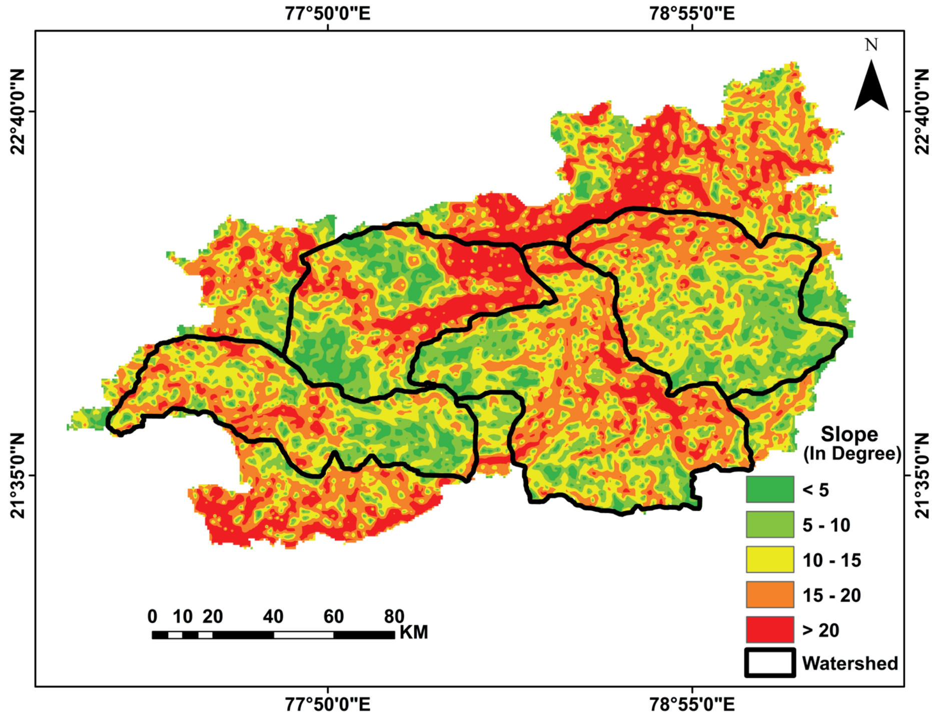

Fig.10. Variation of slope in the selected study are

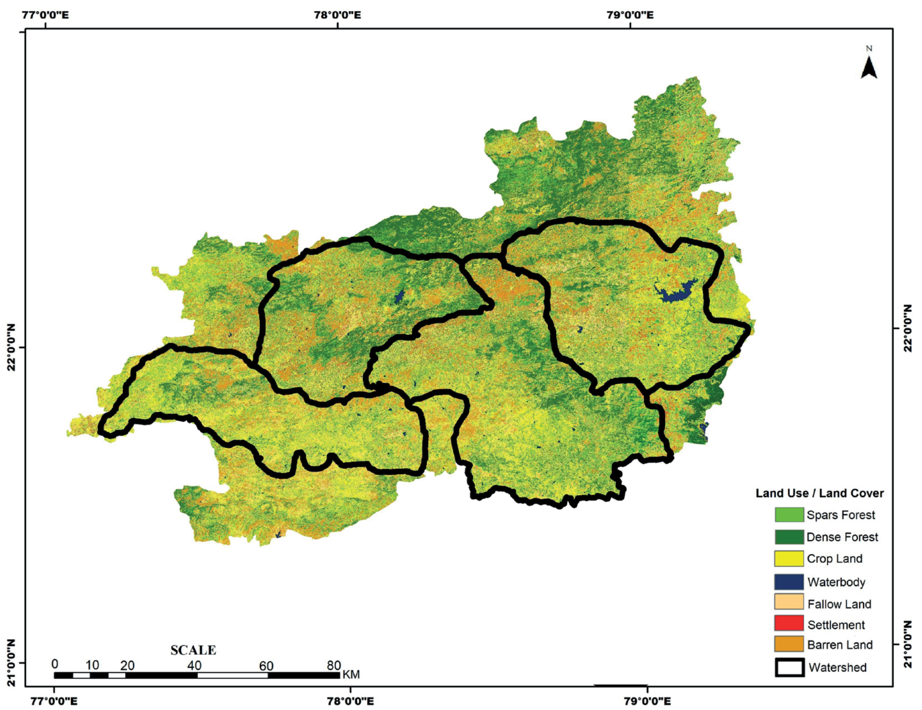

Fig. 11. Land use / land cover map of the selected study area

Groundwater depth

The map showing the groundwater level of the pre-monsoon season was developed using the groundwater level data.

Fig. 12: Groundwater depth map of the selected study area
During the pre-monsoon season, the average depth of the water level varies from <5 m to >35 m. The northern part of the study area is characterized by a good water level in comparison to other regions. On the obtained groundwater level map the study area is divided into eight sub-classes (Fig. 12).

Weights assignment using AHP

A three-level hierarchy of goals, criteria attributes, and alternatives was considered to demonstrate the spatial AHP procedure and to evaluate potential groundwater zones. Ten thematic layers such as geomorphology, geology, rainfall, lineament, drainage density, physiography, soil, slope, groundwater level, and LULC were selected for assessing the status of groundwater availability in the study region. The weightage assigned to these layers is based on their role in the occurrence of potential zones of groundwater in the study region.

The methodology, which was adopted to execute AHP, mainly consists of (a) development of a GIS digital database, which included all spatial information (b) determination of the criteria of evaluation and hierarchical structure formation and criteria of multiple formations (c) implementation of the AHP method in the calculation of the criteria relative importance weights; and (d) implementation of the weight – sum method (WSM) in the estimation of potential groundwater zones.

Generation of comparison matrix

The (1–9) Scale of Thomas L. Saaty determines the relative importance values.
(a) Indication of the score as one (1) means that both the themes are equal in importance whereas the indication of the score as nine (9) means that one theme is more significant in comparison to the other (Saaty, 1980)
(b) Matrix is constructed by assigning the values from 1 to 9 to each layer's relative importance. The basic concept is that if the 'x' layer is more important than the 'Y' layer, then the assigned value will be 9. Meanwhile, 'Y' will be less important than 'x', then the value assigned will be 1/9 (Saaty 1980). The matrix is shown in Table 2.
(c) After assigning relative weight, the vector of weight (Eigen value) was calculated on a judgment base (Saaty, 1980)
(d) Finally, the Consistency Index (CI) is derived using the Equation-1 S (Saaty 1980) –

$$CI = (\lambda \max - n) / (n - 1) \quad (1)$$

'λmax' indicates the largest Eigenvalue of matrix and 'n' indicates the total classes. After calculating the Eigen value of the matrix the largest value was 11.21, which represents λmax. Consistency Ratio (CR) was calculated using Equation 2.

$$CR = (CI) / (RI) \quad (2)$$

Consistency Index (CI) computed by equation
(1) = (11.21-10) / (10-1) = 0.134
Consistency Ratio (CR) = (0.134) / (1.49) = 0.0835

RI indicates the Random Consistency Index, which varies upon the order of the matrix (Table 3). Saaty (1980) suggests that if the 'CR' value is lesser or equivalent to 0.1, the inconsistency is reliable. The consistency of the matrix in the present study was tested to confirm the consistency of decisions in the pair-wise comparison, wherein the value of CR was computed to be 0.083, which is less than 0.1.

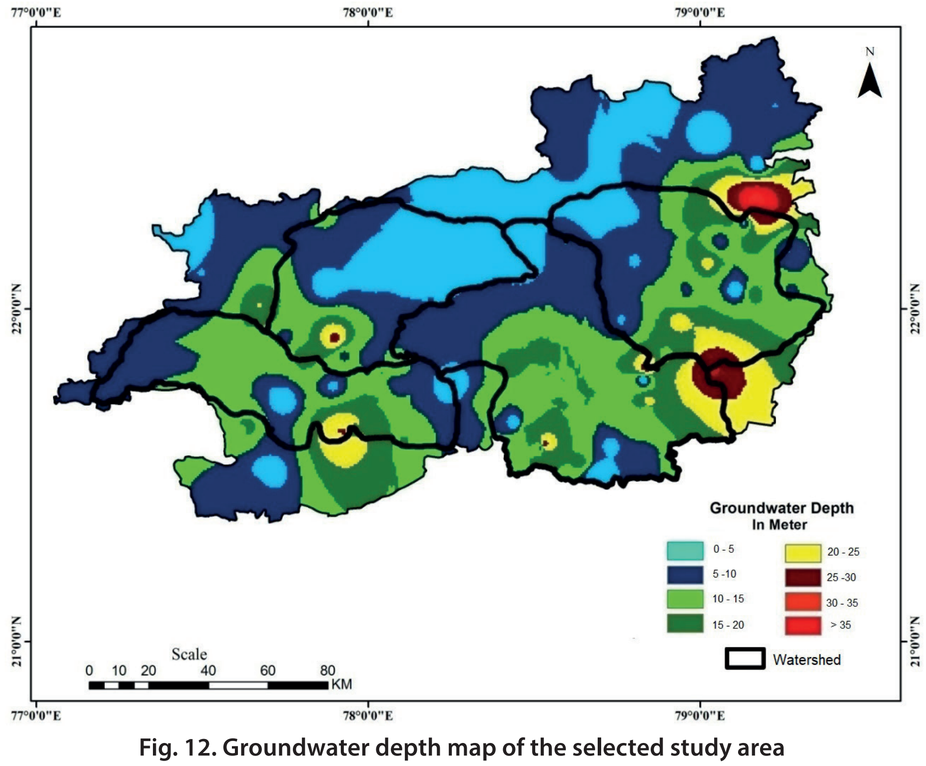

Fig. 12. Groundwater depth map of the selected study area

Table 1. Scale of Saaty (1–9)

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal importance	Weak	Moderate importance	Moderate plus	Strong importance	Strong plus	Very strong importance	Very, very strong	Extreme importance

When obtaining the pair-wise comparison matrix according to the preference values (Table 2), the matrix was analyzed to find each criterion's performance ratings in achieving the related weights. The normalized weights are obtained by using the Weight Sum Model (WSM), which computes the Groundwater Potential Index (GWPI) by multiplying AHP weights with the corresponding ratings (Equation 3).

Overlay analysis

The groundwater potential index (GWPI) in this study is computed using the WSM method (Malczewski 1999; Machiwalet al.2011) and is shown in Equation 3.

$$GWPI = \sum_{i=1}^{n}\sum_{j=1}^{m}\left[a_i\left(\beta_{ij}x_{ij}\right)\right] \quad (3)$$

β_{ij} indicates the weight of j^{th} class of i^{th} theme taken by AHP and αi shows the weight of ith theme, while 'n' and 'm' denotes the total number of thematic layers classes in the thematic layer and x_{ij} represent the value of a pixel of j^{th} class of i^{th} theme.

Table 2. Pair-wise comparison matrix of thematic layers, weight sum, and consistency ratio

Parameter	Geomorphology	Rainfall	Geology	Physiography	Soil	Drainage density	Lineament density	Slope	LU/LC	Groundwater depth	Weighted sum	Consistency ratio
Geomorphology	1	1.125	1.285	1.384	1.5	1.636	1.8	2.25	2.571	3	17.55	6.38
Rainfall	0.888	1	1.142	1.230	1.333	1.454	1.6	2	2.285	2.666	15.60	7.18
Geology	0.777	0.875	1	1.076	1.166	1.272	1.4	1.75	2	2.333	13.65	8.21
Physiography	0.722	0.812	0.928	1	1.083	1.181	1.3	1.625	1.857	2.166	12.67	8.84
Soil	0.666	0.75	0.857	0.923	1	1.090	1.2	1.5	1.714	2	11.70	9.58
Drainage density	0.611	0.687	0.785	0.846	0.916	1	1.1	1.375	1.571	1.833	10.72	10.45
Lineament density	0.555	0.625	0.714	0.769	0.833	0.909	1	1.25	1.428	1.666	9.75	11.5
Slope	0.444	0.5	0.571	0.615	0.666	0.727	0.8	1	1.142	1.333	7.80	14.37
LU/LC	0.388	0.437	0.5	0.538	0.583	0.636	0.7	0.875	1	1.166	6.82	16.42
Groundwater depth	0.333	0.375	0.428	0.461	0.5	0.545	0.6	0.75	0.857	1	5.85	19.16

Table 3. Saaty's Ratio Index for Different Values of 'n'

n	1	2	3	4	5	6	7	8	9	10
Ratio Index	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Table 4. Assigned weightages of thematic layers and normalized weights and rank

Thematic parameters	Sub-classes	Weight	Normalized weight	Rank	Area (km^2)	Area (%)
Geomorphology	Highly dissected plateau	1	0.047	0.156	2121.95	9.69
	Moderately dissected plateau	2	0.09		7742.83	35.36
	Lowly dissected plateau	3	0.14		72.06	0.32
	Pediment pediplain complex	4	0.19		9542.65	43.58
	Dissected hills and valleys	1	0.047		2044.05	9.33
	Alluvial plain	5	0.23		31.69	0.14
	Dam and reservoir	5	0.23		341.41	1.55
Rainfall (mm)	550–600	4	0.06	0.139	1965.9	8.96
	601– 650	5	0.07		3545.8	16.17
	651–700	6	0.09		3939.4	17.96
	701–750	7	0.10		3279.7	14.95
	751–800	8	0.12		2268.7	10.34
	801–850	8	0.12		4524.3	20.63
	851–900	8	0.12		556.0	2.53
	900–950	9	0.14		567.3	2.58
	.>950	9	0.14		1276.9	5.82
Geology	Upper Gondwana	3	0.14	0.121	1309.94	5.98
	Lower Gondwana	4	0.19		2481.22	11.33
	Recent alluvium	6	0.28		490.945	2.24
	Deccan trap	2	0.095		14309.9	65.35
	Older alluvium / Laterite	5	0.24		18.2458	0.08

	bundelkhand granite / gneiss	1	0.047		3285.89	15.0
Physiography	Betul plateau	6	0.214	0.113	6679.6	30.50
	Chhindwara plateau	6	0.214		5185.93	23.68
	Amarwara	5	0.178		2964.19	13.54
	Gawilgarh hill	1	0.035		1506.36	6.87
	Kalibhit hill and Marabdi plateau	2	0.071		1947.48	8.89
	Pachmari hill	1	0.035		1391.14	6.35
	Sausar upland	3	0.107		1176.04	5.39
	Upper Kanhan valley	4	0.143		1048.05	4.78
Soil	Clay loam	1	0.017	0.104	2856.83	12.95
	Sandy loam	9	0.157		4515.53	20.48
	Loam	6	0.105		423.479	1.92
	Clay	1	0.017		7157.8	32.46
	Sandy clay loam	4	0.701		4712.13	21.37
	Silt clay loam	3	0.052		1014.85	4.60
	Silty loam	5	0.087		144.43	0.65
	Silt loam clay	2	0.035		111.19	0.50
	Loamy sand	8	0.140		179.168	0.81
	Sand	10	0.175		209.839	0.95
	Sandy clay	7	0.122		537.747	2.43
	Silt clay	1	0.017		182.272	0.82
Drainage density	0–0.234	5	0.333	0.095	6324.03	29.09
	0.234–0.469	4	0.266		6392.194	29.41
	0.469–0.717	3	0.200		4445.615	20.45
	0.717–1.012	2	0.133		3182.322	14.64
	1.012–1.710	1	0.066		1389.074	06.39
	0–0.177	1	0.066		5169.97	23.63
Lineament density	0.177–0.314	2	0.133	0.086	7789.42	35.61
	0.314–0.471	3	0.200		5601.32	25.64
	0.471–0.699	4	0.266		2614.43	11.95
	0.699–1.292	5	0.333	0.069	695.14	3.17
Slope	<5	5	0.416		8669.27	39.59
	5–10	3	0.250		7287.64	33.28
	10–15	2	0.166		3717.64	16.97
	15–20	1	0.083		1669.73	7.62
	>20	1	0.083		552.18	2.54
LU/LC	Dense forest	6	0.272	0.060	5129.75	23.41
	Sparse forest	5	0.227		2705.55	12.34
	Crop land	4	0.181		5023.48	22.93
	Fallow land	3	0.136		4214.59	19.23
	Water body	7	0.31		160.248	0.73
	Settlement	1	0.045		308.236	1.40
	Barren land	1	0.045		4365.79	19.92
Groundwater depth	0–5	8	0.22	0.052	3864.47	17.65
	5–10	7	0.19		8226.77	37.58
	10–15	6	0.16		5552.11	25.36
	15–20	5	0.14		2667.75	12.18
	20–25	4	0.11		1114.61	05.09
	25–30	3	0.08		373.588	01.71
	30–35	2	0.05		75.5539	0.35
	35>	1	0.02		18.4908	0.08

Finally, the themes were rasterized based on their evaluated normalized weights in the GIS platform for measuring the prospective groundwater area of the Betul-Chhindwara region. The layers were overlaid using a spatial analysis tool in ArcGIS software to appraise the potential groundwater zones. The obtained potential areas have been categorized into five zones: very good, good, moderate, poor, and very poor prospect zone (Fig. 13).

Validation with actual yield data

The result was validated by evaluating the relationship between the obtained result and the actual yield data collected from 16 wells from various locations of the study area. The location of wells with yield information is shown on the map (Fig.14). Actual yield has been classified into five classes: below 5 m.bgl. (very good), from 5 m.bgl. to 10 m.bgl. (good), from 10 m.bgl. to 15m.bgl. (moderate), from15 m.bgl. to 20 m.bgl. (poor), and above 20 m.bgl. (very poor). The classification is based on the shared information collected from the field hydrogeologist working in the study area. Validation was completed through the successful evaluation of prospect zone maps and actual yield data of wells (details are shown in Table 5).

Expected accuracy indicators are as follows

Claimed total well location of yield for accuracy estimation = 16

Satisfied well location on the reference map (groundwater prospect map) = 12

Unsatisfied well location on the reference map = 04

Predicted accuracy = (satisfied well location) / (claimed total well location) * 100

Predicted accuracy = 12/16*100 = 75%

Predicted accuracy reflects that the AHP method is suitable for the identification of groundwater potential zone mapping.

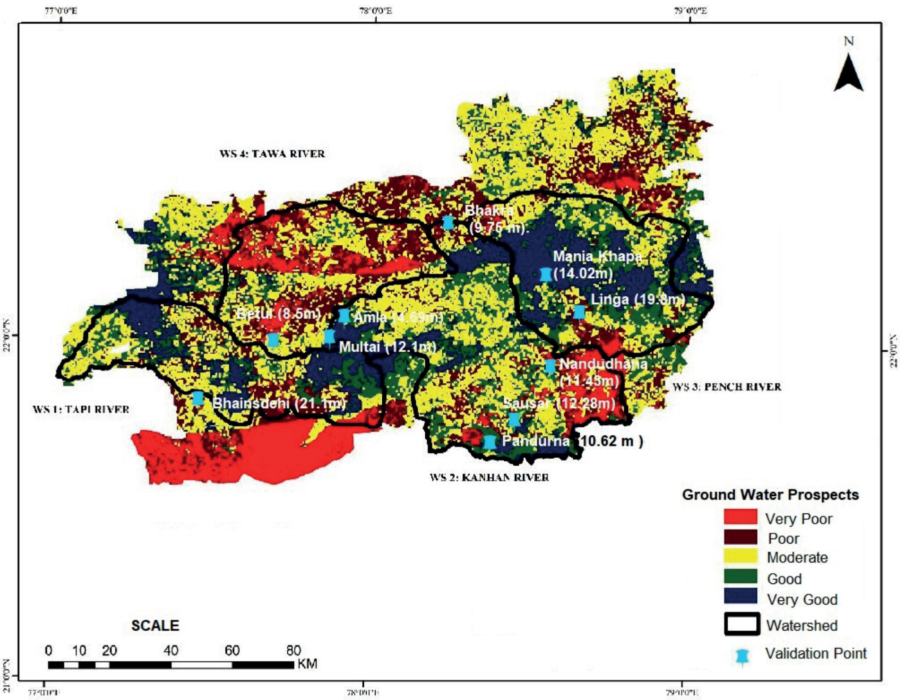

Fig. 13. Groundwater prospect zones of the region and field validation point

Table 5. Actual yield from observation well point during the Field Visit

S.N.	Lat (N)	Long (E)	Area	Actual yield (mbgl)	Description of yield data	Expected yield description for prospect map	Validation between actual yield and expected yield
1	21.964827	78.92926	Linga	19.8	Low	Low	Satisfied
2	21.538921	78.643784	Pandurna	10.62	Good	Moderate	Dissatisfied
3	21.572483	78.707146	Gangatwara	10.66	Good	Good	Satisfied
4	21.599154	78.74572	Sausar	18.28	Poor	Poor	Satisfied
5	21.767147	78.828255	Nandudhana	11.43	Moderate	Moderate	Satisfied
6	22.081533	78.853058	Mania Khapa	14.02	Moderate	Moderate	Satisfied
7	22.219461	78.477982	Bhakra	9.75	Good	Moderate	Dissatisfied
8	21.64444	77.63667	Bhainsdehi	21.1	very poor	very poor	Satisfied
9	21.92361	78.12417	Amla	5.69	Very good	very good	Satisfied
10	21.84667	78.09194	Multai	12.1	Moderate	very Good	Dissatisfied
11	21.76861	77.89389	Betul	8.5	Good	Moderate	Dissatisfied
12	22.348139	78.662231	Tamia	11.8	Moderate	Moderate	Satisfied
13	22.386095	78.777107	Sidauli	18.3	Poor	Poor	Satisfied
14	22.192768	78.598717	Junnardeo	14.5	Moderate	Moderate	Satisfied
15	22.014781	77.672993	Chicholi	12.6	Moderate	Moderate	Satisfied
16	22.289212	79.170394	Amarwada	13.2	Moderate	Moderate	Satisfied

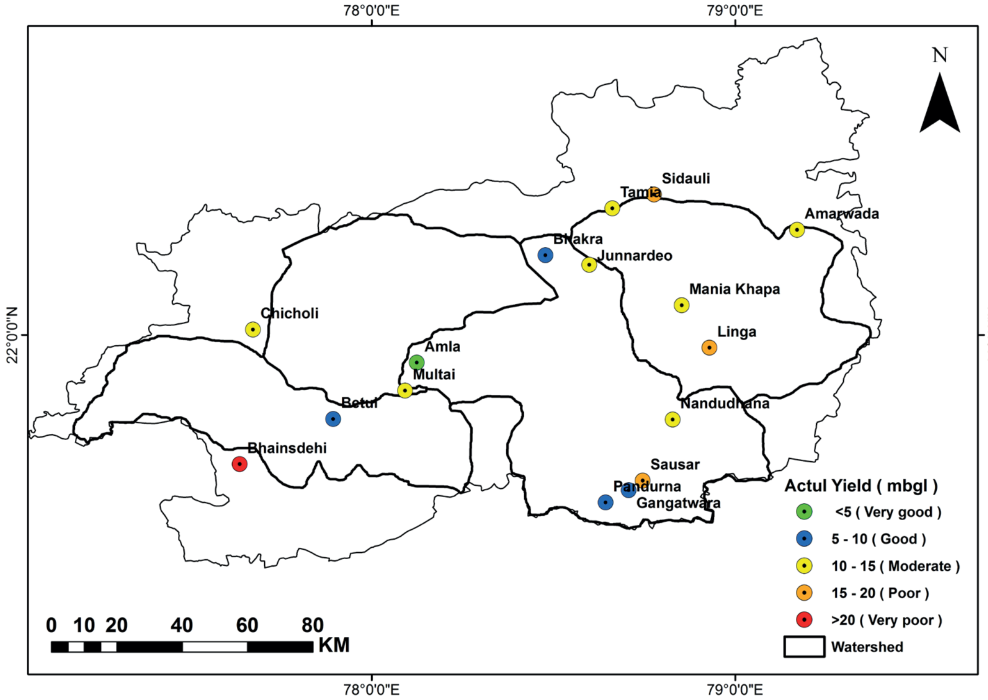

Fig. 14. Field observation points

Results and discussion

The results show that groundwater potential on two-thirds of the study area varies from moderate to very good. Among them very good potential zone covers 15.22% (3262.191 sq.km), good potential zone covers 22.46% (4815.35 sq. km), and moderate groundwater potential zone covers 29.96% (6423.02 sq.km) of the study area whereas approximately one-third of the study area has poor (22.65% or 4857.26 sq.km) and very poor (09.71%, 2082.975 sq.km) groundwater potential. Figure13 shows that out of the four watersheds in the Betul-Chhindwara region, the WS 1 (watershed of the Tapi river) was ranked the second that corresponds to a very good groundwater potential zone. It was noted that groundwater potential zone in the maximum areas of the Tapi river watershed varies from a very good to good. On the other hand, the maximum regions of WS 2 (the Kanhan river watershed) belong to moderate groundwater potential zones. The WS 3 is the Pench river watershed, which has a considerable extent of very good groundwater potential zones; however, groundwater prospect zones in the lower watershed regions vary from low to very low. The groundwater potential zones of the Tawa river watershed (WS 4) mostly vary from moderate to very low. Therefore, to establish a balance between high and low potential zones concerning water resource utilization is an urgent task.

The results reveal that low and medium groundwater potential areas are suffering from the severe scarcity of water and fail to meet the demand for freshwater in the region. The water resource of these regions needs to be urgently and properly managed. The outcome of the present inventory study can be used as the basis for further planning of the sustainable development and management of water resources and solving issues related to water resources.

The study focuses on hard rock, which is characterized by low porosity and permeability hence the study area faces water scarcity due to high runoff, less annual rainfall, etc. There is a strong need to adopt different rainwater harvesting structures and artificial recharge structures such as Check Dams, Nala Bunds, Percolation Tanks, Injection Wells, Induced Recharge, Contour Bunding, Contour Trenching, and Gully Plugging as per geological and topographical conditions to improve the groundwater conditions of the study area. The structures mentioned above need to be developed in the places where groundwater potential is low, whereas high potential zones can be used for extraction, drinking, and irrigation purposes (Table 6).

Table 6. Actual yield from observation well point during the field visit

No.	Groundwater potential zone			Suitable zone and critical zone for groundwater development and management
	Zone	Area covered	Area percentage	
1.	Very good	3262.191 sq.km	15.22%	Suitable for goundwater extraction
2.	Good	4815.35 sq.km	22.46%	Suitable for goundwater extraction
3.	Moderate	6423.02 sq.km	29.96%	Suitable for groundwater extraction and recharge as per the needs of the area
4.	Poor	4857.26 sq.km	22.65%	Critical zone and an urgent need for groundwater recharge through harvesting structures
5.	Very poor	2082.975 sq.km	09.71%	Critical zone and an urgent need for groundwater recharge through harvesting structures
	Total	21440.8 sq.km	100.00%	

Agriculture is the main economic activity in the Betul-Chhindwara region therefore there is high water demand for irrigation. Because of easy and timely accessibility, ubiquitous availability, and cheap drafting technology, groundwater is a significant source of water supply not only for drinking and domestic purposes but also for irrigation. Since water is a vital resource for the use and maintenance of other resources, it can only be developed to a certain extent without affecting other resources and ecological conditions. It is also highly variable across the study area. Therefore, it is crucially essential that this resource is developed and managed sustainably.

This study found that a gentle slope with low drainage density gives more scope for high groundwater development. There is a need to adopt proper artificial recharge practice with geological and topographical consideration in the region as most of the area possesses adequate groundwater recharge capacity.

CONCLUSIONS

The groundwater potential zones mapping is beneficial for sustainable groundwater development and management planning. The present study fulfils these necessities. The need for groundwater resources is high, but due to rocky terrain, their availability is limited. In this study, favourable zones for groundwater occurrence and storage were delineated based on various thematic layers such as geomorphology, geology, physiography, rainfall, soil, slope, lineament, drainage density, and groundwater depth and land use/land cover of this region. This study expressed the competences of remote sensing and GIS and the integration of analytical hierarchy process techniques to identify potential groundwater zones in the Betul-Chhindwara region. The obtained result is validated with groundwater well yield data to ensure that the obtained result is accurate.

There is wide spatial variation in groundwater resources in the region. Only one-third of the area possesses high and very high potential, and hence it is safe to plan sustainable use of water in those areas. The high groundwater potential areas may be used with the help of modern technology to optimize the use and to reduce the wastage and misuse of water while the needs of the low groundwater potential areas can be met with conjunctive use of groundwater with surface water for reducing pressure on groundwater resource. At the same time, measures to improve groundwater potential must be taken in these areas. Possibilities of transfer of water from high potential areas to low potential areas can also be explored. Thus, the outcome of the present inventory study may be used as the basis for further planning of the sustainable development and management of water resources and solving issues related to water resources.

Because of the nature of the distribution and degree of the potentiality of groundwater in the region, it is evident that there is a strong need for sustainable groundwater development and management planning to effectively manage and develop available resources to ensure freshwater supply as SDGs target 6.4 for the present and the future without making undesired impacts on the study area's environment. The findings of the present study provide an authentic assessment of the potential groundwater zones of the Betul-Chhindwara region, which can be used for planning sustainable development and management of groundwater resources. The results of this study will be helpful for government officials and decision-makers in articulating an effective groundwater utilization plan in the study area. ■

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