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ORIGINAL ARTICLE

# Multi-criteria decision analysis for planning and management of groundwater resources in Balod District, India

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**Abstract** Present study is carried out to assess potential groundwater recharge zone and to identify artificial groundwater recharge sites in the Balod district of Chhattisgarh State, India using Remote sensing (RS), Geographical information system (GIS) and Multi-criteria decision analysis (MCDA) technique. In this study different thematic layers were considered viz. drainage, lineament, geology, geomorphology, soil texture, soil depth, land use/land cover, rainfall, groundwater depth and slope for identification of groundwater recharge zones and sites, which are generated in the RS and GIS environment. The relative weights were assigned to different thematic layers using Analytical hierarchical process (AHP), which is a MCDA technique. While determining the weightage of the various parameters, expert opinions were taken and the artificial groundwater recharge zones and suitable sites for groundwater recharge were deduced. In the present study, five categories of groundwater recharge zones were identified viz. very poor, poor, moderate, good and very good according to their suitability of area for groundwater recharge purposes. It was found that about 31, 14, 12, 15 and 28 % of the study area falls under very poor, poor, moderate, good and very good areas for artificial groundwater recharge, respectively. In this study a total of 178 number of suitable recharge structures with their sites were found for water harvesting to enhance the groundwater conditions of the study area.

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**Keywords** Artificial groundwater recharge zone · Water resource development plan · Multi-criteria decision making · Remote sensing · Geographic information system

## Introduction

Planning of groundwater recharge is capturing and storing of runoff for later water requirements of drinking, irrigation, domestic and industrial use. The arid and semi-arid regions are particularly dependent on groundwater as it has turned into the only fresh water source because of the limited availability of surface water. In this context and with increasing demand for water in different sectors, especially in agriculture, appropriate structures and sites for artificial recharge need to be considered for better availability of groundwater. The lack of effective groundwater recharge structures in a region usually brings adverse effects on groundwater. Master plan of India (CGWB 2013a) recommended different recharge structures to increase the natural replenishment of surface water into groundwater aquifers. Suitability of recharge structures depend on various factors, which can be identify using Remote sensing (RS) and Geographical information system (GIS) techniques (Ramakrishnan et al. 2009).

As groundwater is dynamic in nature, integrated approach of RS and GIS techniques is very helpful in groundwater studies. Satellite data can be handled and analyzed in GIS environment very efficiently (Chowdhury et al. 2010). GIS is capable of developing information in various formats and integrating them in a very short period of time (Jha et al. 2007; Chowdary et al. 2013; Krois and Schulte 2014; Nnaji and Mama 2014; Rais and Javed 2014). The combination of remote sensing and GIS techniques along with different thematic layers which control occurrence and movement of groundwater have been proved to be an efficient tool in identifying recharge zones worldwide (Krishnamurthy et al. 2000; Jha et al. 2007; Kumar et al. 2008, 2014; Murthy and Mamo 2009; Gupta and Srivastava 2010; Machiwal et al. 2011; Oh et al. 2011; Adiat et al. 2012; Rahman et al. 2012; Agarwal et al. 2013a; Mallick et al. 2015). Application of remote sensing and GIS in groundwater management have been reported by many researchers throughout the world (Jha et al. 2007; Ghayoumian et al. 2007; Madrucci et al. 2008; Murthy and Mamo 2009; Chowdhury et al. 2010; Chen et al. 2011; Manap et al. 2013; Mallick et al. 2015). In this study, the artificial groundwater recharge zone of the Balod district was delineated using GIS based Multi-criteria decision analysis (MCDA) approach. Analytical hierarchy approach (AHP) is the commonly used method of MCDA. The concept of AHP is proposed by Saaty (1980), which provides a method for input judgment and measurement to obtain ratio scale priorities for the distribution of influence among the different factors (Saaty 1980, 2008; Mendoza and Martins 2006).

In the present study different thematic layers were considered such as drainage, lineament, geology, geomorphology, soil texture, soil depth, land use/land cover, rainfall, groundwater depth and slope. These different thematic layers were integrated in the GIS environment to identify suitable zones for artificial recharge of groundwater using MCDA approach. The main objective of the present study is delineation of the artificial groundwater recharge zones and suggestion of suitable recharge structures with their locations for proper planning and management of groundwater resources of the study area.

## Study area

Present study is carried out in the Balod district, which is situated in the center of Chhattisgarh state in India (Fig. 1). Balod district has experienced rapid urbanization and increased demand for groundwater reserves. It is located between 20°19′–21°29′ N latitude and 80°52′–81°34′ E longitude, covering an area of 3395 km$^2$. Climate of the district is of tropical type. Rise of temperature begins from the month of March–May. May is the hottest amongst all other months and average annual rainfall of the Balod district is 1150 mm.

## Methodology

### Generation of thematic layers

To delineate artificial groundwater recharge zones, different thematic layers were prepared using remote sensing data, topographic maps, geological maps reports and data from different sources. The satellite data, Landsat 8 geocoded imagery pertaining to May 2013 was downloaded from Glovis site (http://glovis.usgs.gov/). Land use/land cover classification map was generated from the Landsat 8 data in ERDAS IMAGINE software using supervised classification techniques. The different layers such as geology, geomorphology, lineament, drainage soil texture from satellite imagery were digitized using ERDAS IMAGINE and ArcGIS software. Cartosat-1 DEM (digital elevation model) has been used to prepare the slope map of the study area. The pre-monsoon and post-monsoon groundwater level maps were prepared from the data taken from the CGWB (Central Groundwater Board) of the bore wells and the inventory wells using interpolation techniques with the help of ArcGIS software. Rainfall data collected from the Indian Meteorological Department (IMD) and rainfall map also prepared with the help of ArcGIS software using interpolation techniques.

A total of ten numbers of factors, i.e. drainage, lineament buffer map, geology, geomorphology, soil texture, soil depth, land use/land cover, rainfall, groundwater depth and slope and their interrelationship, which is implied to be influencing groundwater storage potential in the Balod District, were selected. The methodology flowchart of the present study is given in Fig. 2.

### Drainage density

Drainage density is the length of stream channel per unit area of drainage basin (Horton 1932, 1945; Strahler 1952). The streams have been ordered using Strahler's (1952) ordering system in the present study. The study area drainage pattern map has been derived with the help of satellite data and Survey of India (SOI) toposheets (Fig. 3). The derived drainage density map reveals that in the study area drainage density value ranges from 1.00 to 6.99 km/km$^2$. These are reclassified into five categories, i.e. 1.00–1.68, 1.68–2.08, 2.08–2.57, 2.57–3.48 and 3.48–6.65 km/km$^2$ as shown in Fig. 4. High drainage density is recorded in the north-western parts of the study area. With respect to groundwater occurrences, the higher drainage density is related to impermeable rock formations which in turn lead to higher run off and less infiltration of water intto the ground and vice versa (Chowdhury et al. 2009).

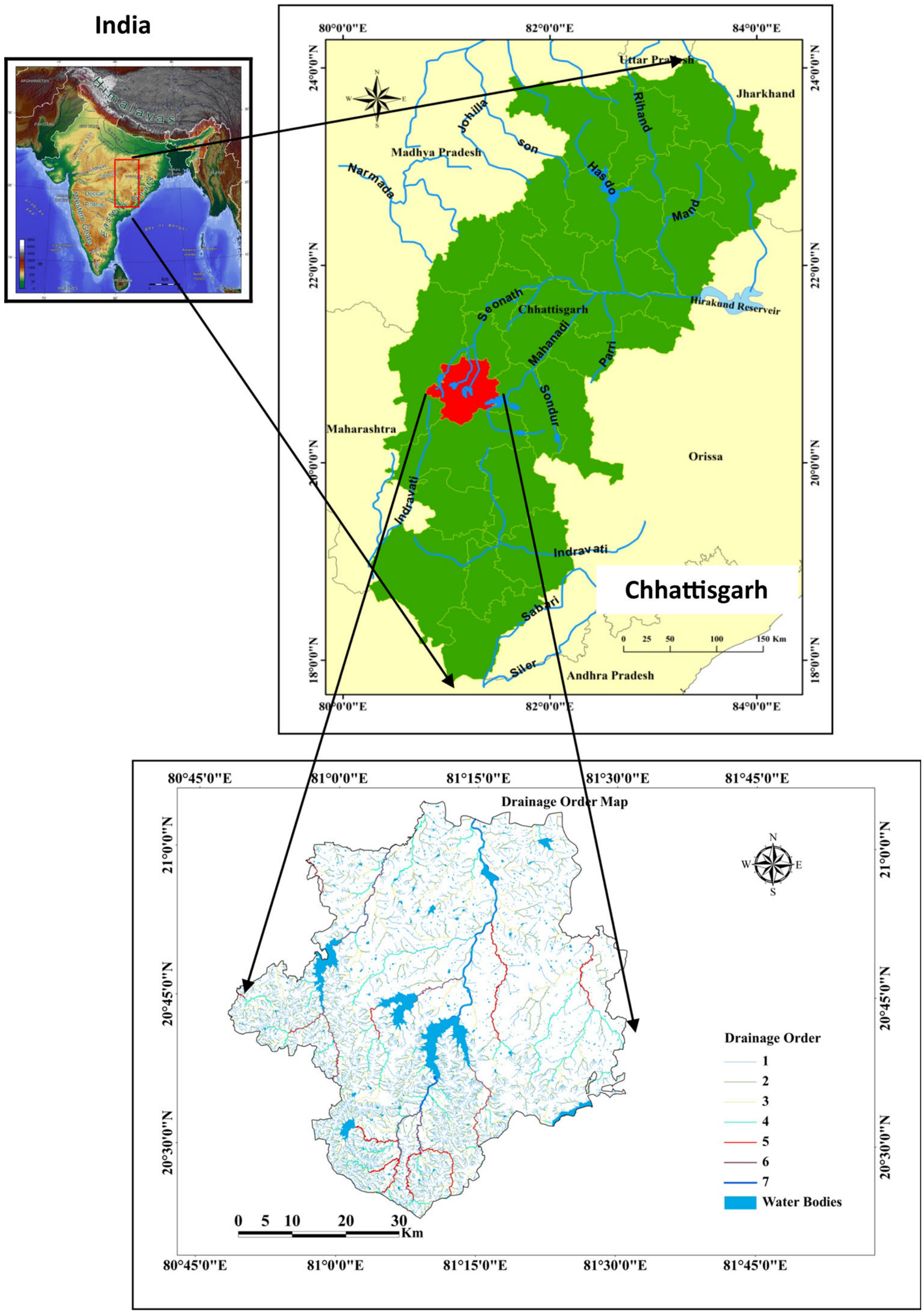


**Fig. 1** Location map of the study area

## Lineament buffer map

Lineaments are tectonic originated linear, rectilinear, curvilinear features observed in satellite data. Lineaments are generally used as an indicative tool for delineating groundwater potential zones (Lewis et al. 2007; Madani and Niyazi 2015). In this study lineaments were interpreted using satellite data and buffers have been given to these lineaments at distances of 50, 100, 150, 200, 250 m, as shown in Fig. 5.

## Geology

Groundwater occurrence and its movement mainly depend on the geological setting. Geologically, the district comprises Archaean rocks of Meso to Neo-Proterozoic ages; recent to sub-recent aged alluvial deposits comprising gravel, sand, clay and laterite also occurs in this area. Geological features of the study area are visually interpreted and delineated from the satellite image and

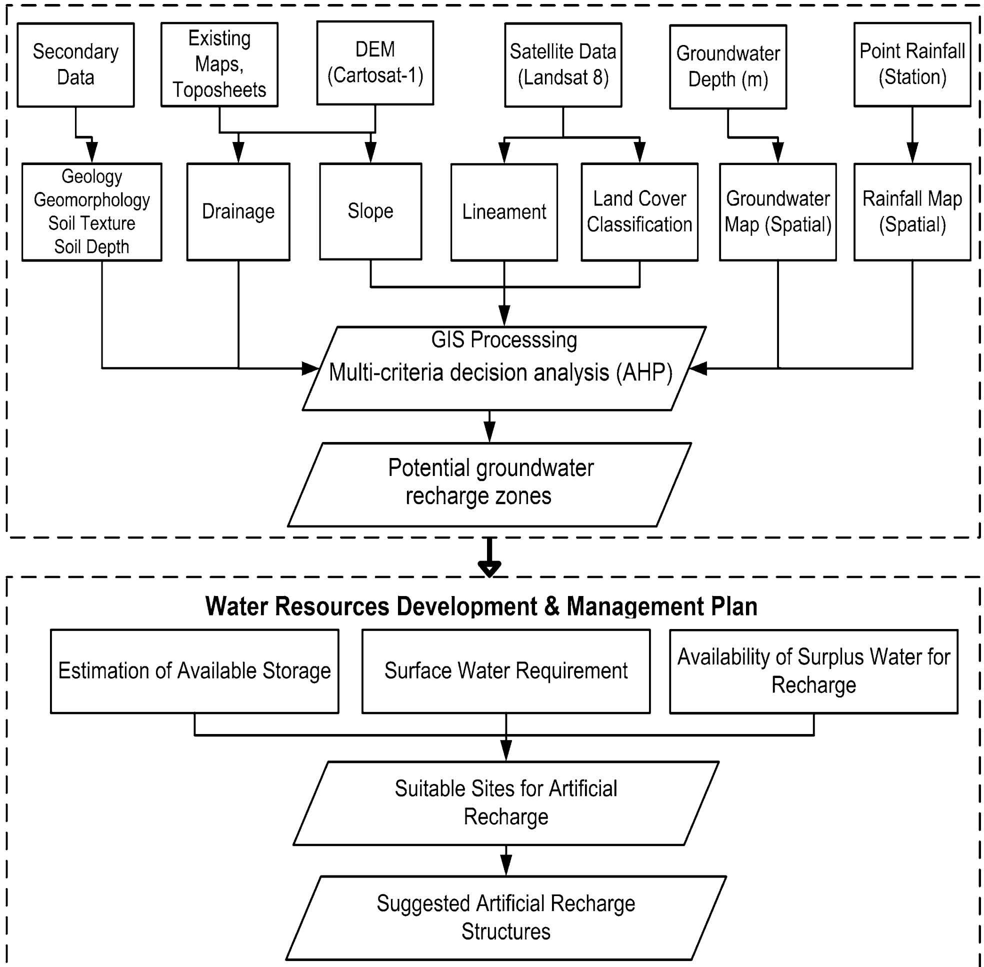


**Fig. 2** Methodology of the present study

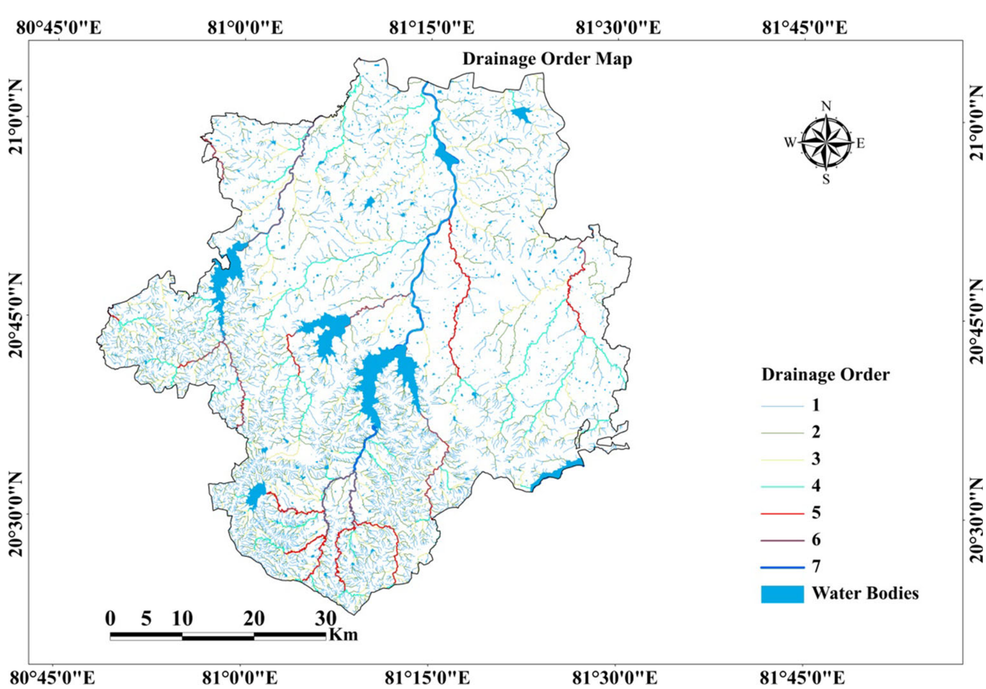


**Fig. 3** Drainage map of the Balod district

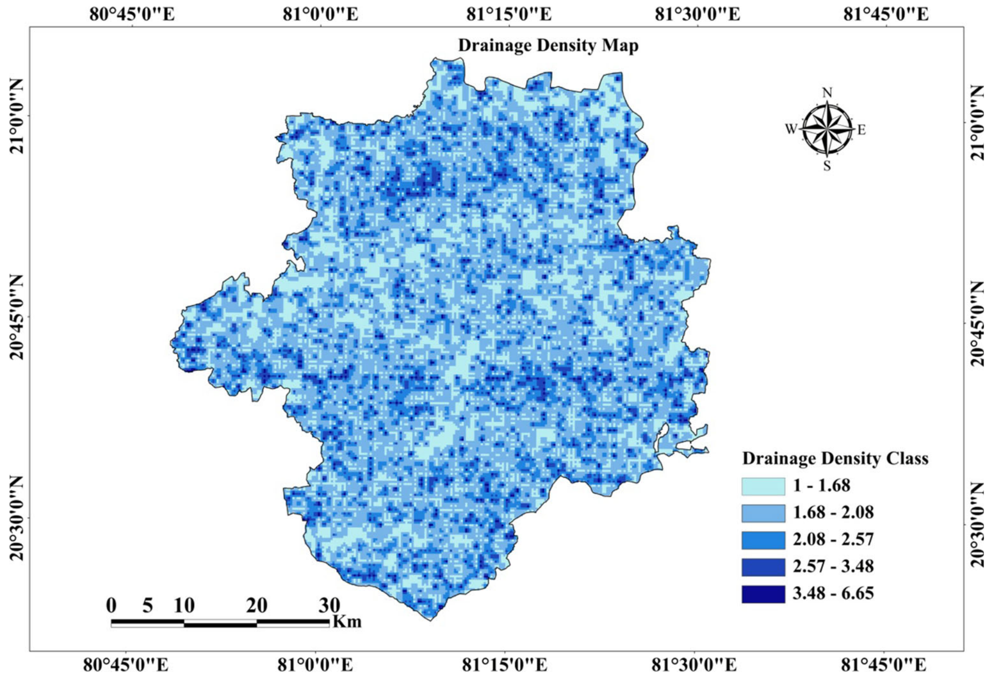


**Fig. 4** Drainage density map of the Balod district

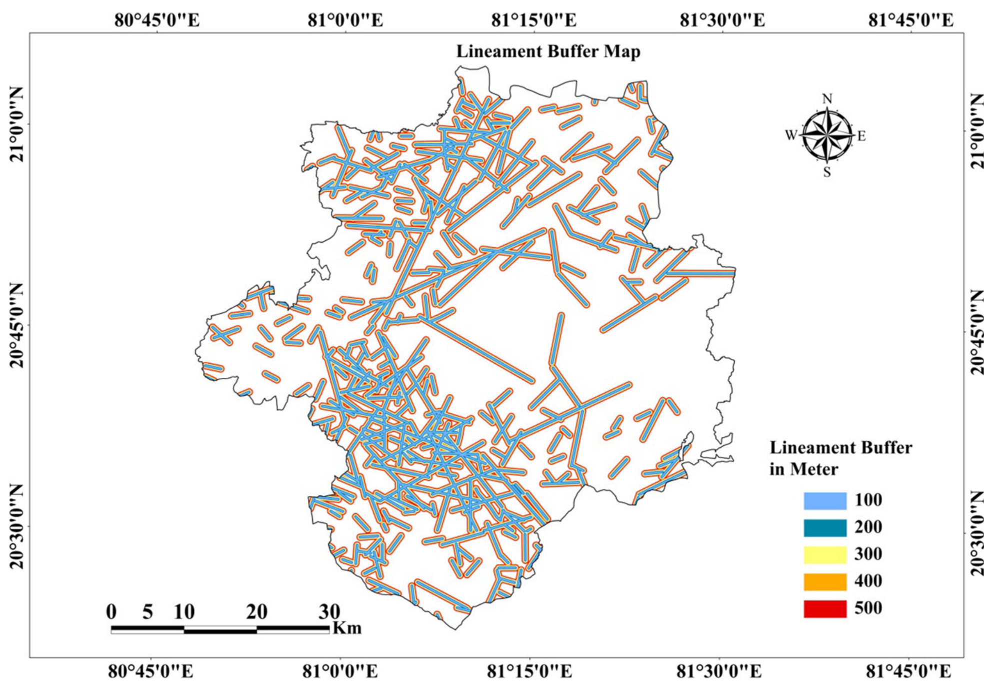


**Fig. 5** Lineament buffer of the Balod district

geologically classified into eight classes viz. alluvium, basic dyke, basic rock, acidic rock, laterite limestone, quartzite and shale as shown in the Fig. 6.

## Geomorphology

Geomorphologically the district displays structural plains, structural hills and valleys, pediment/pediplain, denudational slope and flood plain. In the study area ten types of geomorphic units were identified as given in Fig. 7. Alluvial plain moderate and flood plain shallow are suitable for groundwater recharging and hence good landforms for suitable sites for artificial recharge.

## Soil texture and soil depth

Soil is an important factor for delineating and suitability studies of the potential artificial groundwater

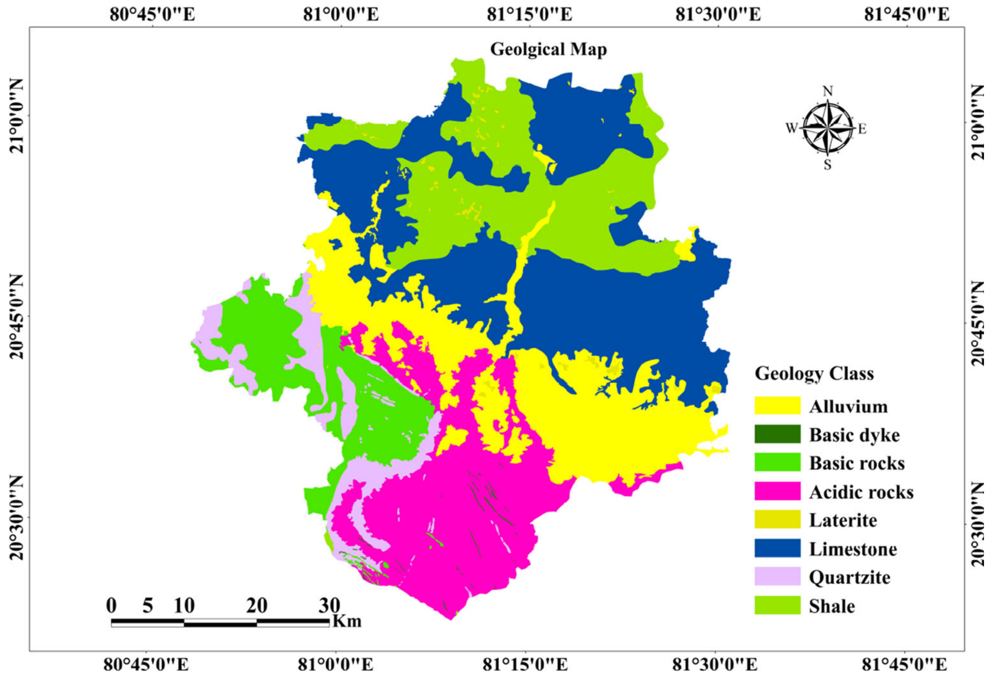


Fig. 6 Geological map of the Balod district

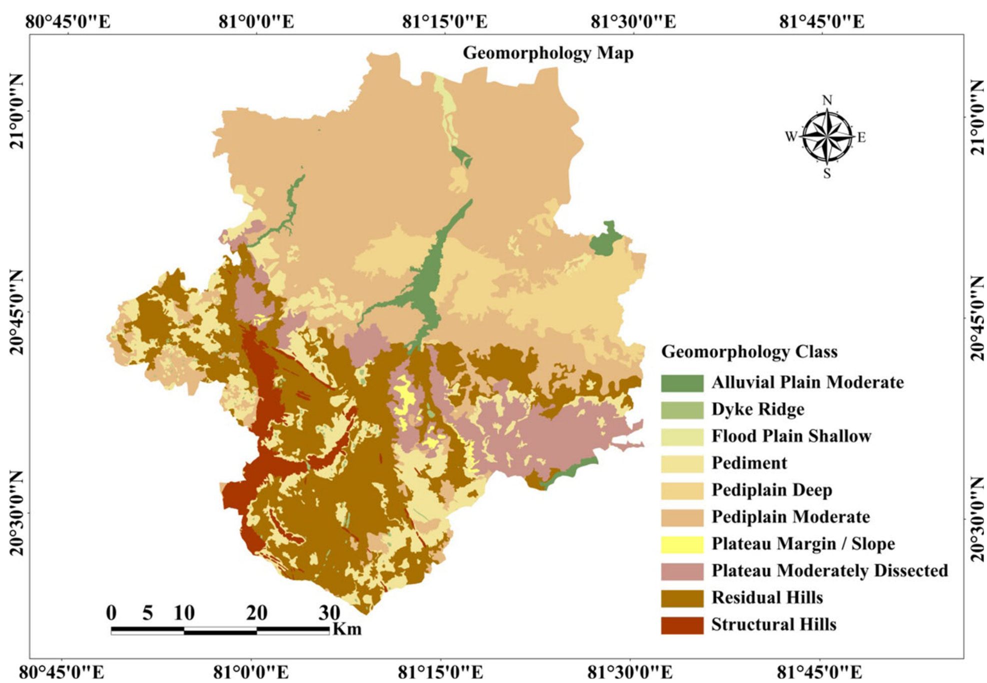


Fig. 7 Geomorphological map of the Balod district

recharge zones. The soil texture map of the Balod district was prepared by digitizing the soil map obtained from the Agriculture department, Government of Chhattisgarh. The soil map of the Balod district reveals eight soil categories as shown in Fig. 8. Rank of soil has been assigned according to their infiltration rate. Depth of soil includes topsoil and subsoil. Soil depth of the study ranges between 9 and 110 cm. as shown in Fig. 9.

## Slope map

Slope is an important terrain parameter and it affects the surface runoff and land stability (Bhunia et al. 2012; Kumar et al. 2014; Manikandan et al. 2014; Sar et al. 2015). Overall the topography in the district varies between 256 and 635 m. above mean sea level. The five classes of slope mapped, namely, 0–3, 3–6, 6–12, 12–18 and >18 % are identified in the study area as shown in Fig. 10.

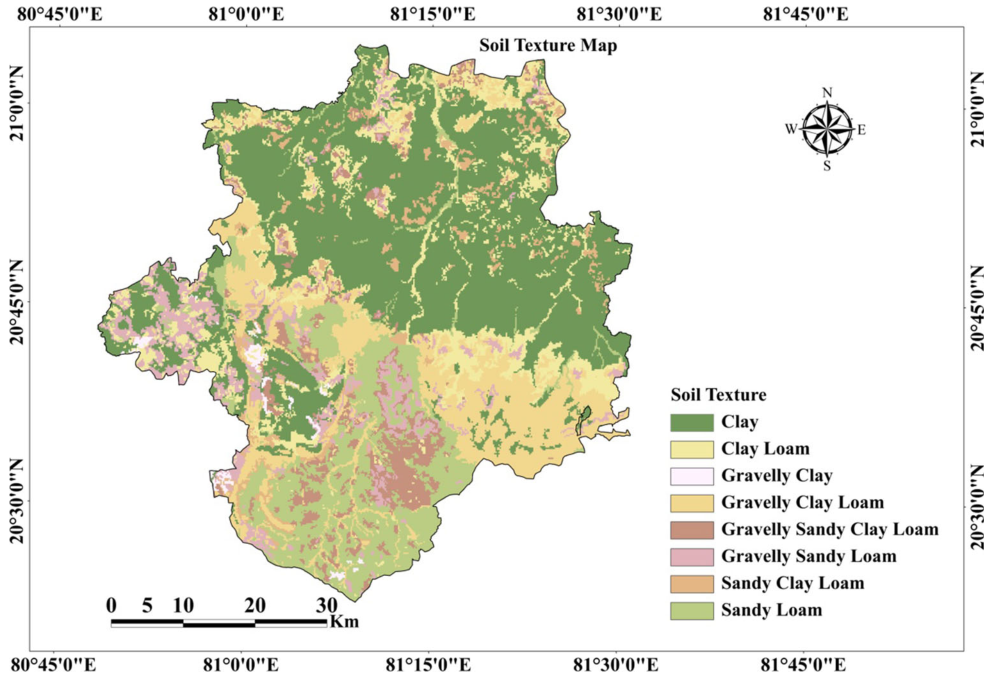


**Fig. 8** Soil Texture map of the Balod district

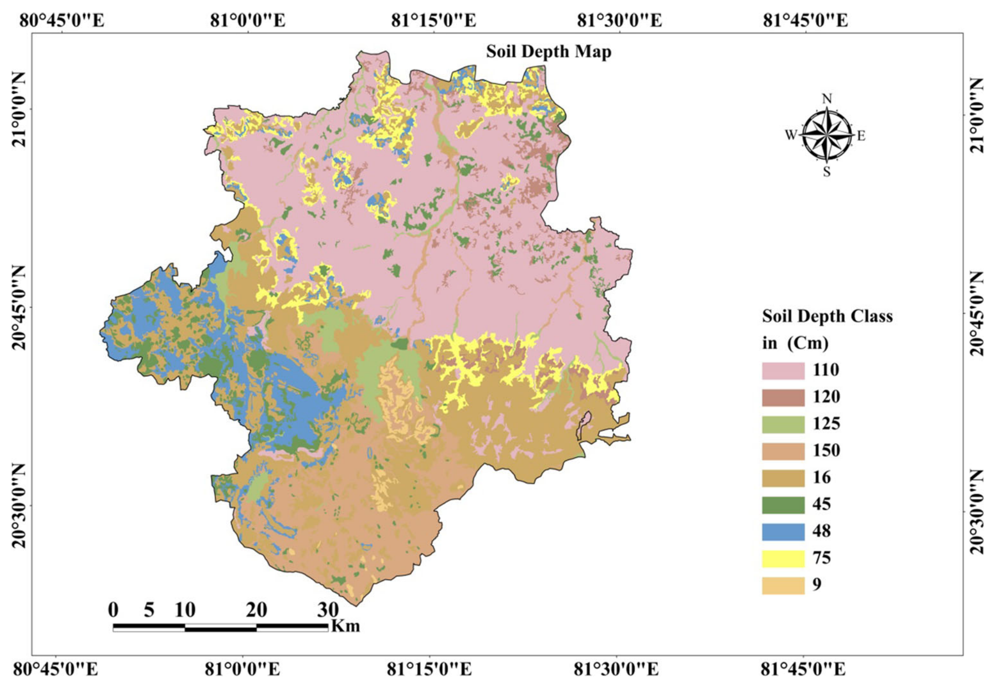


**Fig. 9** Soil depth map of the Balod district

## Land use/land cover (LULC) classification

Land use/land cover (LULC) gives an idea about groundwater requirement and groundwater utilization; it is also helpful in the selection of artificial recharge sites of groundwater (Glendenning and Vervoort 2010; Kadam et al. 2012; Agarwal et al. 2013b). In this study LULC map is prepared using supervised classification. Five classes of LULC viz. built-up, water bodies, agricultural, wasteland, forest land were identified and demarcated as shown in Fig. 11.

## Depth of water level map of pre and post-monsoon

Groundwater depth during pre-monsoon and post-monsoon were monitored and collected from the wells of study area which gives idea about groundwater recharging and discharging conditions. Pre-monsoon and post-monsoon water

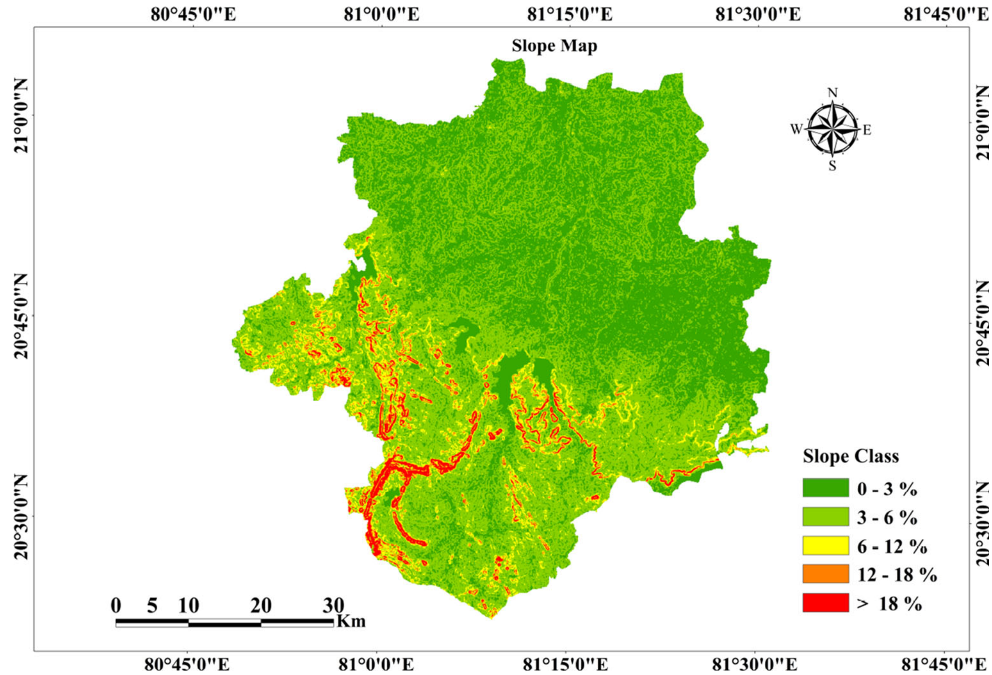


**Fig. 10** Slope map of the Balod district

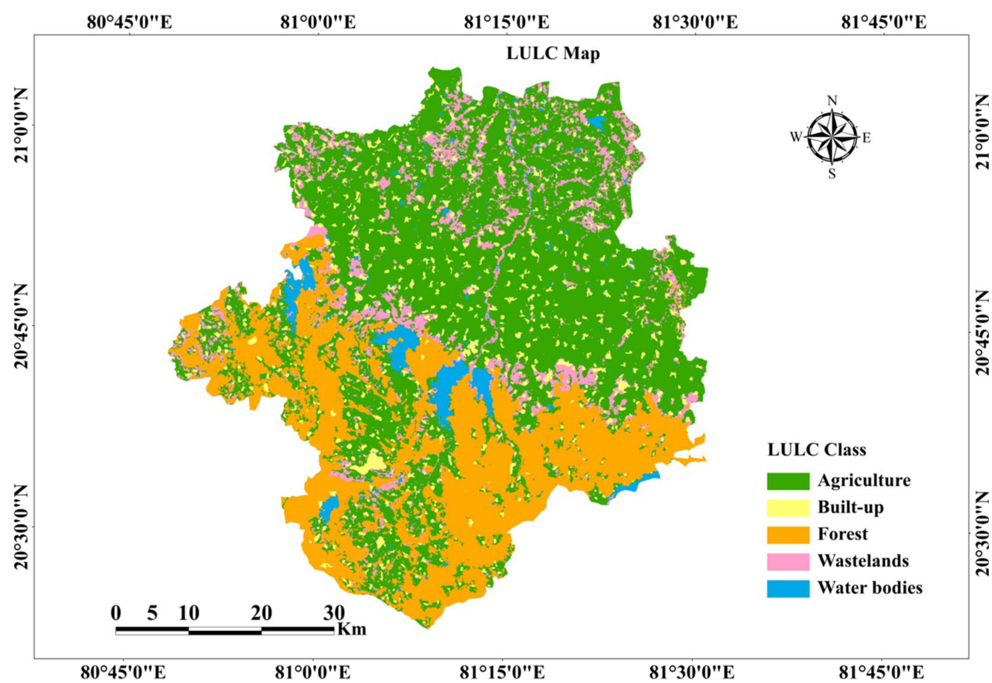


**Fig. 11** Land use/land cover map of the Balod district

level maps were prepared in GIS environment as shown in Figs. 12 and 13. There is variation in the water levels during the post-monsoon and pre-monsoon period due to recharge and discharge of groundwater.

## Rainfall

Rainfall is the direct recharge source of groundwater. The rainfall of the study area mainly depends on north-east monsoon. The annual average rainfall of the study area is around 1150 mm. The rainfall map of the study area is prepared in GIS environment as shown in Fig. 14.

## Generation of pair wise comparison matrices

A pairwise comparison matrix is derived using Saaty's (1980, 2008); 1–9 importance scale (Table 1) based on different thematic layers used for demarcation of the groundwater recharge potential zone. The assigned weights are based on the response of thematic layers to

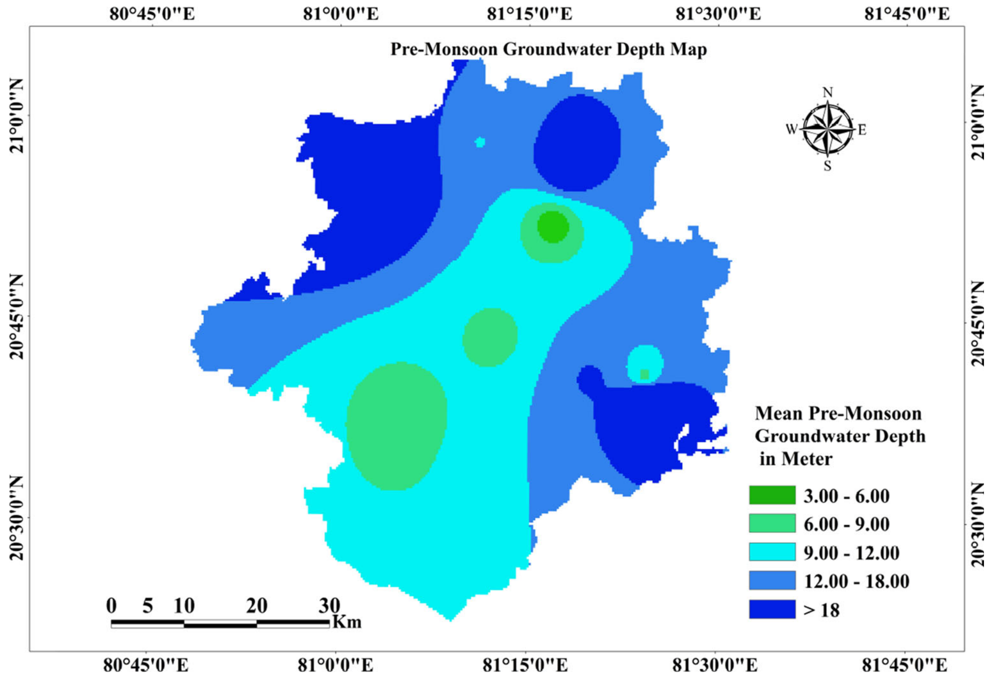


**Fig. 12** Pre-monsoon groundwater depth map of the Balod district

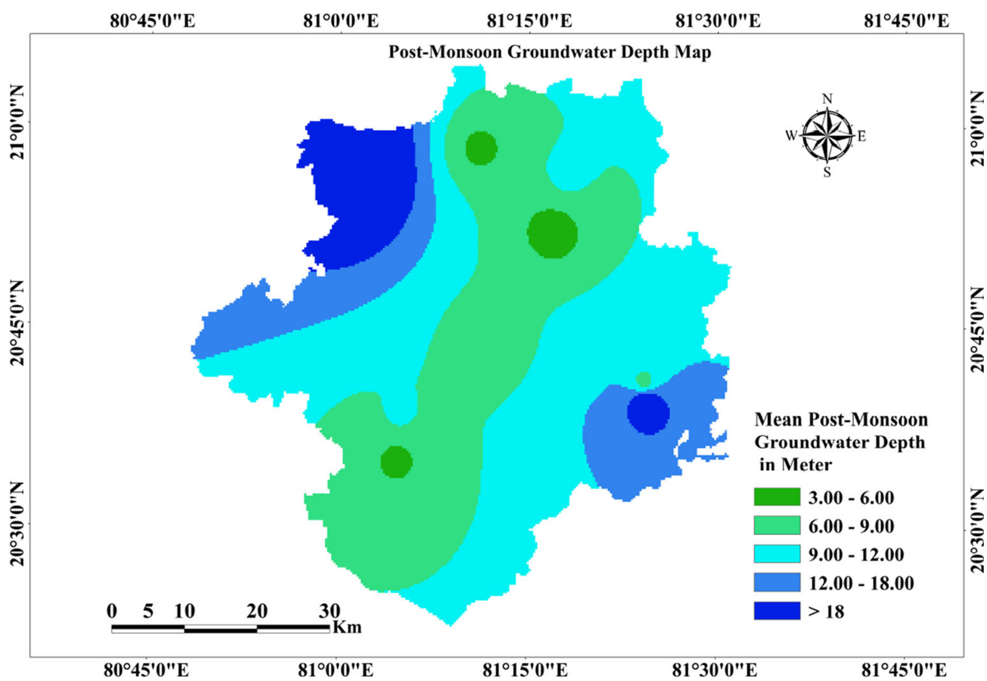


**Fig. 13** Post-monsoon groundwater depth map of the Balod district

groundwater recharge and expert's opinions. The AHP captures the idea of uncertainty in judgments through the principal eigenvalue and the consistency index (Saaty 2004). Saaty has given a measure of consistency, known as consistency index (CI) as deviation or degree of consistency derived using Eq. 1.

$$CI = \frac{\lambda \max - n}{n - 1} \quad (1)$$

where, $\lambda$max is the largest eigenvalue of the pairwise comparison matrix and $n$ is the number of classes.

Consistency Ratio (CR) is a measure of consistency of pairwise comparison matrix and is given in Eq. 2.

$$CR = \frac{CI}{RI} \quad (2)$$

where RI is the ratio index, which is the consistency index of a randomly generated pair wise comparison matrix. It

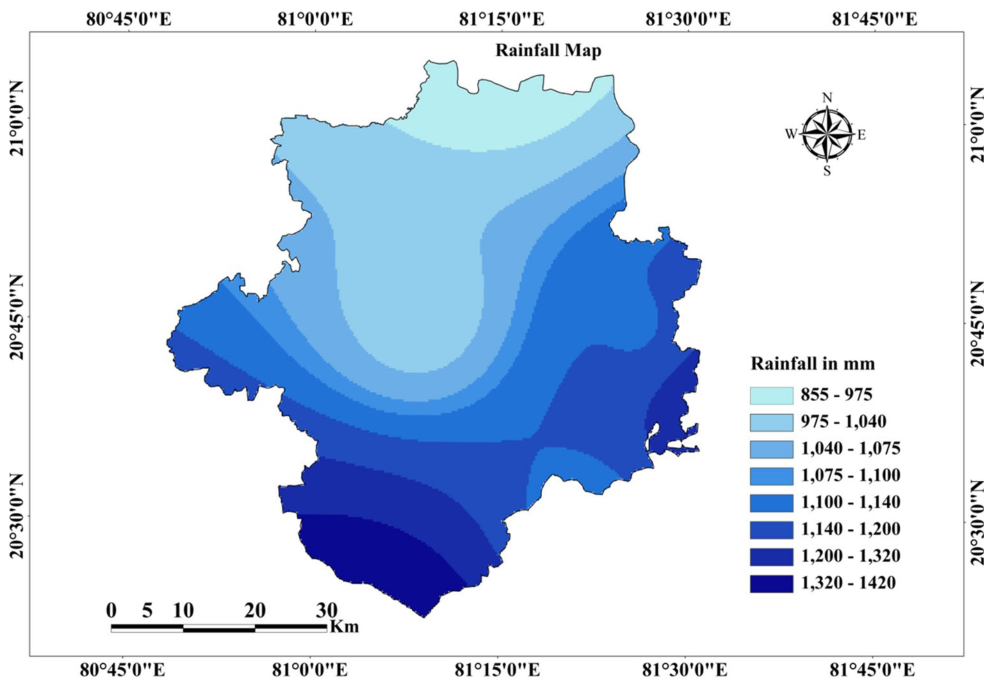


**Fig. 14** Rainfall map of the Balod district

**Table 1** Saaty's 1–9 scale of relative importance

| 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 |

**Table 2** Saaty's ratio index for deferent values of n

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

depends on the number of elements being compared. The value of RI for different n values is given in Table 2. If CR is less than 0.1, the estimate is only accepted. In this study for $n = 10$, RI = 1.49

## Delineation of groundwater potential zones

Artificial groundwater recharge zones of the study area were delineated in this study using weighted overlay operation of different thematic layers viz. drainage, lineament buffer map, geology, geomorphology, soil texture, soil depth, land use/land cover, rainfall, groundwater depth and slope in GIS environment. The weights assigned for these ten themes are given in Table 3a–c. The normalized weights for different factors are shown in Table 4.

Artificial groundwater recharge zones (AGRZ) were derived using Eq. 3.

$$\begin{aligned}\mathrm{AGRZ} = {} & \mathrm{LU}_w\mathrm{LU}_{\mathrm{wi}} + \mathrm{DD}_w\mathrm{DD}_{\mathrm{wi}} + \mathrm{SL}_w\mathrm{SL}_{\mathrm{wi}} \\ & + \mathrm{GM}_w\mathrm{GM}_{\mathrm{wi}} + R_wR_{\mathrm{wi}} + \mathrm{GG}_w\mathrm{GG}_{\mathrm{wi}} + \mathrm{S}_w\mathrm{S}_{\mathrm{wi}} + \mathrm{GD}_w\mathrm{GD}_{\mathrm{wi}} \\ & + \mathrm{SD}_w\mathrm{SD}_{\mathrm{wi}} + \mathrm{LB}_w\mathrm{LB}_{\mathrm{wi}}\end{aligned} \quad (3)$$

where, '*w*' normalized weight of a theme, 'wi' normalized weight of the individual features of a theme, LU land cover, DD drainage density, SL slope, GM geomorphology, *R* rainfall, GG geology, *S* soil, GD groundwater depth, SD soil depth and LB lineament buffer.

## Preparation of groundwater recharge plan

### *Artificial recharge*

There is strong need of proper scientific investigations and feasibility study of an area for planning and implementation of a successful artificial recharge project (CGWB 2002, 2007). The hydro-geological parameters and hydrological data were taken under consideration to prepare the plan for artificial recharge in this study. The following steps have been adopted in this study.

**Table 3** Detailed weights and relative weights of various thematic layers (a: Lineament density, land cover and drainage density, b: Geology, slope, soil texture and rainfall, c: Geomorphology, groundwater depth and soil depth) and their corresponding classes

| Influencing factors | Category (classes) | Rating | Sub-criteria weights | Normalized weight |
|---|---|---|---|---|
| *Panel a* | | | | |
| Lineament density | 100 m | 5 | 0.439 | 0.109 |
| | 200 m | 4 | 0.151 | |
| | 300 m | 3 | 0.139 | |
| | 400 m | 2 | 0.136 | |
| | 500 m | 1 | 0.133 | |
| Land use/Land cover | Agriculture | 5 | 0.420 | 0.078 |
| | Water bodies | 4 | 0.167 | |
| | Forest | 3 | 0.156 | |
| | Wastelands | 2 | 0.130 | |
| | Built-up | 1 | 0.120 | |
| Drainage density | 3.48–6.65 | 5 | 0.500 | 0.070 |
| | 3.48–2.57 | 4 | 0.260 | |
| | 2.57–2.08 | 3 | 0.140 | |
| | 2.08–1.68 | 2 | 0.075 | |
| | 1.68–1.00 | 1 | 0.025 | |
| *Panel b* | | | | |
| Geology | Alluvium | 5 | 0.220 | 0.178 |
| | Laterite | 3 | 0.175 | |
| | Acidic rocks | 2 | 0.150 | |
| | Basic rocks | 2 | 0.135 | |
| | Basic dyke | 2 | 0.117 | |
| | Limestone | 2 | 0.112 | |
| | Quartzite | 1 | 0.069 | |
| | Shale | 1 | 0.020 | |
| Slope | 0–3 % | 5 | 0.332 | 0.081 |
| | 3–6 % | 4 | 0.232 | |
| | 6–12 % | 2 | 0.220 | |
| | 12–18 % | 1 | 0.124 | |
| | >18 % | 1 | 0.092 | |
| Soil texture | Sandy loam | 5 | 0.179 | 0.120 |
| | Gravelly sandy loam | 4 | 0.174 | |
| | Sandy clay loam | 3 | 0.142 | |
| | Gravelly sandy clay loam | 2 | 0.121 | |
| | Gravelly clay loam | 1 | 0.117 | |
| | Gravelly clay | 1 | 0.108 | |
| | Clay loam | 1 | 0.098 | |
| | Clay | 1 | 0.063 | |
| Rainfall (mm) | 1420–1200 | 5 | 0.428 | 0.202 |
| | 1200–1100 | 4 | 0.160 | |
| | 1100–1000 | 3 | 0.150 | |
| | 1000–900 | 2 | 0.139 | |
| | 900–880 | 1 | 0.121 | |
| *Panel c* | | | | |
| Geomorphology | Alluvial plain moderate | 5 | 0.183 | 0.070 |
| | Flood plain shallow | 5 | 0.168 | |
| | Dyke ridge | 4 | 0.124 | |
| | Pediplain deep | 4 | 0.106 | |
| | Pediment | 3 | 0.907 | |
| | Pediplain moderate | 2 | 0.084 | |
| | Plateau margin/slope | 1 | 0.077 | |
| | Plateau moderately dissected | 1 | 0.070 | |
| | Residual hills | 1 | 0.068 | |
| | Structural hills | 1 | 0.026 | |

Table 3 continued

| Influencing factors | Category (classes) | Rating | Sub-criteria weights | Normalized weight |
|---|---|---|---|---|
| Groundwater depth | 3.00–6.00 m | 1 | 0.05 | 0.026 |
| | 6.00–9.00 m | 2 | 0.110 | |
| | 9.00–12.00 m | 3 | 0.260 | |
| | 12.00–18.00 m | 4 | 0.290 | |
| | >18.00 m | 5 | 0.320 | |
| Soil depth | 7.5–22.5 | 1 | 0.331 | 0.060 |
| | 22.5–45 | 3 | 0.285 | |
| | 45–90 | 4 | 0.265 | |
| | >90 | 5 | 0.120 | |

**Table 4** Pair wise comparison matrix finial weight

| Suitability criterion | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 1.00 | 0.20 | 0.17 | 0.20 | 0.25 | 0.20 | 0.25 | 0.29 | 0.43 | 0.39 | 0.026 |
| T2 | 5.00 | 1.00 | 3.67 | 2.03 | 3.60 | 2.73 | 1.82 | 2.10 | 2.54 | 1.44 | 0.202 |
| T3 | 4.00 | 0.27 | 1.00 | 0.40 | 0.45 | 0.33 | 0.38 | 0.40 | 1.00 | 0.83 | 0.060 |
| T4 | 6.00 | 0.49 | 2.50 | 1.00 | 3.40 | 2.52 | 2.30 | 2.27 | 2.40 | 2.50 | 0.178 |
| T5 | 4.00 | 0.28 | 2.20 | 0.29 | 1.00 | 0.50 | 0.71 | 0.70 | 0.83 | 1.00 | 0.070 |
| T6 | 3.00 | 0.37 | 3.00 | 0.40 | 2.00 | 1.00 | 2.70 | 1.10 | 1.90 | 1.20 | 0.120 |
| T7 | 4.00 | 0.55 | 2.60 | 0.43 | 1.40 | 0.37 | 1.00 | 0.35 | 0.96 | 1.00 | 0.081 |
| T8 | 3.40 | 0.48 | 2.52 | 0.44 | 1.42 | 0.91 | 2.85 | 1.00 | 1.25 | 1.45 | 0.109 |
| T9 | 2.30 | 0.39 | 1.00 | 0.42 | 1.20 | 0.53 | 1.04 | 0.80 | 1.00 | 1.00 | 0.070 |
| T10 | 2.55 | 0.69 | 1.20 | 0.40 | 1.00 | 0.83 | 1.00 | 0.69 | 1.00 | 1.00 | 0.079 |

* CI 0.085877, R.I 1.49, C.RATIO 0.053156, *T1* groundwater depth, *T2* rainfall, *T3* soil depth, *T4* geology, *T5* geomorphology, *T6* soil texture, *T7* slope, *T8* lineament buffer, *T9* drainage density, *T10* land use land cover

**Table 5** Estimation of sub-surface storage capacity

| Project area | Geographical area (sq.km) | Area identified for artificial recharge ($km^2$) | Depth to waterlevel (post-monsoon) belowcut-off level (m) | Volume of unsaturated zone (M $m^3$) | Average specific yield | Total Storage potential as volume of water (M $m^3$) |
|---|---|---|---|---|---|---|
| Balod District | 3394.85 | 1744.22 | 3–6 = 1.5 | 2616.31 | 0.02 | 52.32 |
| | | 1023.00 | 6–9 = 4.5 | 4603.45 | 0.02 | 92.06 |
| | | 245.00 | 9–12 = 7.5 | 1837.42 | 0.02 | 36.74 |
| | | 214.76 | 12–18 = 12 | 2577 | 0.02 | 51.54 |
| | Total | | | | | 232.66 |

*Identification of need based area for artificial groundwater recharging* The field survey of study area was also carried out to find out the suitability and location of proposed artificial groundwater recharge structures. It has been observed that about 83 per cent area was suitable for locating the artificial recharge structures in a study area.

*Estimation of available storage space* The total volume of unsaturated strata is estimated and actual amount of water required to recharge the aquifer up to 3 m. has been calculated by multiplying with average specific yield of rocks existing in the area, i.e. 0.02 % (CGWB 2006). Standard formulae have been used in this study to calculate the volume of surface water required to recharge the aquifer (Table 5). In the study area approximately 232.66 M $m^3$ vadose zone area is available for artificial recharge.

*Surface water requirement* Assessment of surface water requirement is possible by analyzing the monsoonal rainfall pattern, its frequency and its variation in space and time. To determine surplus surface water availability the variations in rainfall pattern and its relevance in relation to the scope for the artificial recharge to groundwater can be

Table 6 Availability of surplus water for recharge

| S. no. | Block | Area of block ($km^2$) | Monsoon rainfall | Coefficient (K) | Runoff (Q = rainfall × coefficient) (mm) | Volume (Area × Runoff) (M $m^3$) | 30 % of the total runoff (M $m^3$) |
|---|---|---|---|---|---|---|---|
| 1. | Dondilohara | 954.53 | 856.00 | 0.406 | 347.53 | 331.72 | 99.52 |
| 2. | Gurur | 555.54 | 1054.40 | 0.463 | 488.18 | 270.84 | 81.25 |
| 3. | Gundardehi | 708.23 | 883.57 | 0.339 | 299.53 | 212.067 | 63.62 |
| 4. | Balod Block | 1174.07 | 1044.68 | 0.424 | 442.94 | 520.042 | 156.01 |
| | Total | 3392.38 | – | – | – | 1334.66 | 400.40 |

considered (CGWB 2002, 2007). The net amount of available source water has been calculated by considering 75 % efficiency of the artificial recharge structure (CGWB 2007). The obtained value is multiplied by 1.33 (A reciprocal of 75 % efficiency). Since surface water requirement = Storage space × 1.33, so that the volume of water required for artificial recharge is 309.43 x $10^6$ $m^3$.

Availability of source water to recharge the groundwater in the study area has been assessed in the form of non-committed surplus runoff. The normal monsoon rainfall of the area is about 1145 mm. The percentage of runoff to rainfall (Table 6) and the depth of runoff due to rainfall is 40.39 cm. The total yield of runoff generated from Balod district having 2238.36 $km^3$. Area works out to 1334.66 M $m^3$ and 30 % of the total runoff i.e. 400 M $m^3$ is considered as surplus monsoon runoff available for artificial recharge.

*Proposed suitable groundwater recharge structures and their capacity* Maximum storage capacity and gross capacity due to single and multiple fillings during rainy season, respectively, were taken into consideration for designing different groundwater recharge structures in this study. Storage distribution should be 70 % for earthen structures, percolation tank and surface spreading structures and 30 % for cement plugs and check dams. The sizes of recharge structures as per the slope were selected on the basis of information available in the CGWB (2013b) manual.

## Result and discussion

The artificial groundwater recharge zones for the Balod district were obtained using weighted overlay operation of thematic layers namely drainage, lineament, geology, geomorphology, soil texture, soil depth, land cover, rainfall, groundwater depth and slope in GIS environment. To determine artificial groundwater recharge zones, appropriate weights were allotted to these ten thematic layers and their different features. The determined artificial groundwater recharge zones of the Balod District are shown in Fig. 15. The groundwater potential zones are classified into four different categories as very good, good, moderate, poor and very poor. It is found that in these different categories about 43, 12, 14 and 31 % of the study area falls under good, very good, moderate zones, poor and very poor artificial groundwater recharge zone, respectively. It is evident from the artificial groundwater recharge zones map that eastern and north-western part of the study area are most suitable for artificial groundwater recharge (Fig. 15).

### Types and feasible numbers of recharge structures

Various groundwater recharge structures have suggested in this study by considering different geological and hydrogeological parameters and feasibility of sites in the study area. Artificial groundwater potential recharge zone determined by MCDA is used here to suggest or identify the different artificial recharge structures.

The proposed suitable artificial recharge structures to construct in the study area are mainly Continuous contour trenches (CCT)/continuous contour bund (CCB), check dams (CD), boulder check dam (BCD), gravity head recharge wells (GHRW), nala plugging (NP) and percolation tanks (PT) and their total numbers are, respectively, 18, 26, 55, 7, 29 and 43. The details of proposed suitable artificial recharge structures including the estimated 178 numbers and location of artificial recharge structures is presented in Fig. 16.

## Conclusion

In this study MCDA based methodology has been adopted to determine potential artificial recharge zones, suitable recharge structures and their sites to improve groundwater conditions of the Balod district. MCDA method supports the relative importance of different thematic layers and their sub classes which affects groundwater recharge. Results indicate that 28 % of the area was found as very good and 15 % of the area classified as good

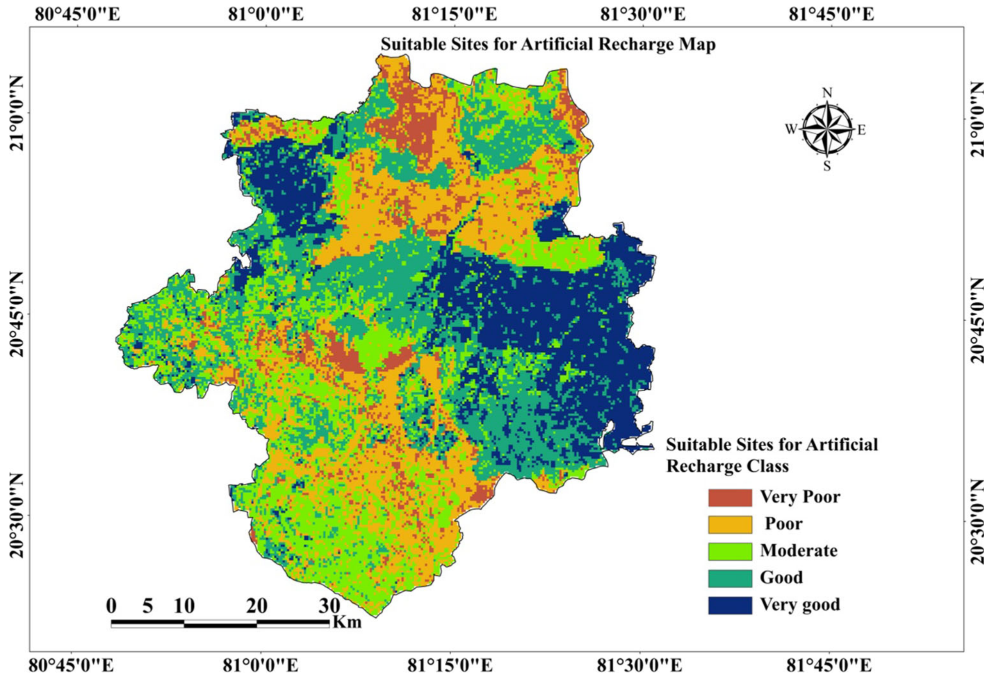


**Fig. 15** Artificial groundwater recharge zones of Balod District

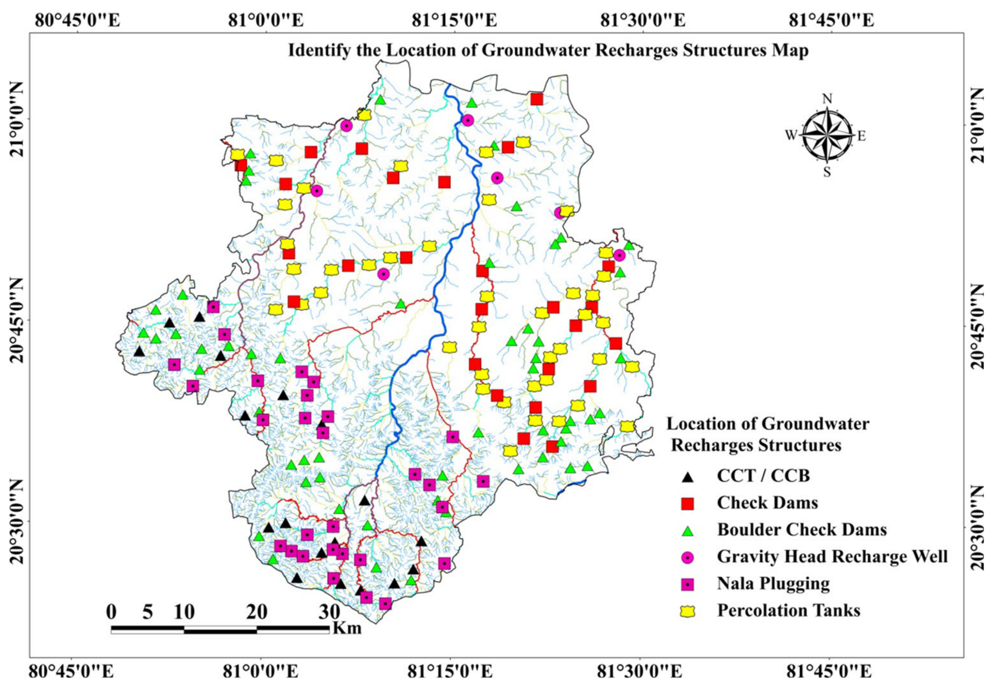


**Fig. 16** Identified location of groundwater recharges structures and their types

zone for artificial recharge of groundwater. Remaining 12, 14 and 31 % of the total area comes under respectively moderate, poor and very poor groundwater recharge zone. The GIS and MCDA techniques has proved profitable to identify suitable sites for artificial recharge of groundwater over other conventional methods. This study will facilitates proper development and management of groundwater resource of the study area.

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