ORIGINAL PAPER

Identifying the groundwater potential zones in Jamsholaghat sub-basin by considering GIS and multi-criteria decision analysis

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Abstract

Groundwater resource is a crucial asset that makes a considerable contribution to the overall annual water resources toward industrial, domestic and agriculture purposes. However, overexploitation has resulted in severe reductions in groundwater supply. Evaluation of the possibility of groundwater recharge area is quite useful in order to conserve the groundwater resources. In this research, fourteen thematic maps (i.e., Lithology, Slope, Land use and Land cover, Drainage Density, Rainfall, Lineament Density, Distance from river, Hydrological Soil Group, Geomorphology, Topographic Wetness Index, Profile Curvature, Topographic Position Index, Plan Curvature and Roughness) undergo multicollinearity check followed by overlaying all of the thematic maps in ArcGIS software by considering ranks assigned to each thematic map using Analytical Hierarchy Process in order to develop the Groundwater potential zone map. The present research area was divided into four zones according to the Groundwater potential zone map, i.e., very high, high, moderate and low groundwater potential zone consisting of 22%, 45%, 26% and 7% of Jamsholaghat sub-basin, respectively. Most of the eastern part of the study area was found highly suitable for groundwater potential zones. This was due to favorable conditions such as lithology (laterite and quartz), geomorphology (flood plain/water bodies), slope (very gentle/gentle), high/moderate rainfall of the present research area. Nevertheless, the present study advises the adoption of sustainable aquifer recharge methods to enhance the groundwater resources of the deficit regions. These methods include rainwater harvesting and irrigation methods like micro as well as drip irrigation and sprinkler.

Keywords Groundwater potential zone · Multicollinearity · Analytical hierarchy process · Sensitivity analysis · Receiver operating characteristic

Introduction

Water is critical to human life; but, due to diminishing of water resource available on the surface, groundwater is now the primary source of fresh available water for home, agricultural and other purposes. The utilization of subsurface water has increased due to the ever-increasing need for water (Das et al. 2018; Das 2019; Ajay Kumar et al. 2020). Groundwater (especially from both tube and dug wells) serves as primary origin of water for irrigation, commercial enterprise, and domestic needs, particularly in the arid zone where yearly rainfall is minimal. Agricultural uses account for 42% of total groundwater worldwide. Both environments of the villages as well as in cities, groundwater acts as crucial sustainable sources for dependable growth of the economy and water availability for drinking (Kaliraj et al. 2014; Andualem and Demeke 2019; Kumar et al. 2020). Groundwater is a dynamic and renewable natural resource, although its availability is limited in hard rock landscapes such as red and lateritic zones. Water resource enhancement is required in India since it is critical to the country's agro-economy development. In addition to that, above 90% of people living in the rural areas and approximately 30% of the people living in the urban areas uses groundwater as the main source of household and drinking requirements (Ghosh et al. 2016; Abrams et al. 2018).

Groundwater is retained in the pore of rock and soil under the water table. This is a valuable as well as essential

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elements of the natural hydrological cycle. Its accessibility makes it a great asset for residential, agricultural, and social development projects (Agarwal et. al., 2013; Choubin et. al., 2019). Water scarcity has become a problem in densely populated, urbanized areas around the countries throughout the globe, including India, Africa, and China, as the requirement of domestic, Industrial, and agricultural purposes has increased (Arshad et. al., 2020). Several researchers from around the world have used techniques like frequency ratio, logistic regression model techniques, random forest model, decision tree model, artificial neural network, and evidential belief function to locate potential groundwater recharge zones (Hutti and Nijagunappa 2011; Fenta et. al., 2014). Thus, the remote sensing technique offers systematic, comprehensive, and quick repeating region coverage, making it an effective approach for acquiring quick spatiotemporal data from a large area (Al- Rahmati et al. 2015; Gnanachandrasamy et al. 2018; Al-Djazouli et al., 2020; Koli et al., 2020).

The Geographic Information System (GIS) provides a blueprint for dealing with massive and complicated sensing data. Satellite data is widely available and used, and it is coupled with traditional maps and consideration of topographical approaches, has made fundamental data for estimating potential groundwater locations much easier to come by (Yeh et al. 2016; Raju et al. 2019). Using the Integrated Analytical Hierarchy Process (AHP) approach in conjunction with Remote Sensing (RS) and GIS, some studies have effectively identified prospective groundwater recharge zones. Furthermore, by combining multi-criteria decision analysis (MCDA) with RS and GIS techniques, AHP has now been effectively used in several studies of watershed management and groundwater investigation (Mukherjee et al. 2012; Kumar and Krishna 2018; Arulbalaji et al. 2019; Çelik 2019).

AHP technique is recognized as a basic, easy, effective, & reliable tool for MCDA (Hussein et al. 2017; Benjmel et al. 2020; Dar et al. 2020). Due to the obvious increased exploitation of this surface water resources, researchers are concentrating their efforts on creating cost-effective approaches for detecting potential groundwater recharge regions, which could help with transforming sustainable water resource management. It's critical to locate, prepare for the greatest possible use and sustainability of Groundwater Potential Zones (GWPZ) (Magesh et. al., 2012; Yeh et. al., 2016; Patra et. al., 2018). Many geological and geophysical approaches for establishing the existence of groundwater table and aquifers are thought to be significantly more trustworthy, but they are both costly and long delayed methods for assessing the availability of groundwater resources in a given location (Pinto et al. 2017; Nasir et. al., 2018). RS combined with GIS has become a cost-effective and efficient method for exploring groundwater resources, investigation, and operating procedures (Awawdeh et. al., 2013; Fashae et. al., 2014; Maity and Mandal 2017; Kanagaraj et. al., 2019).

In 1987 for the first time in India, National Remote Sensing Agency (NRSA) used RS and GIS techniques to delineate the GWPZ. After that many researches in India used the combination of RS and GIS for delineation of GWPZ. For delineation of GWPZ, most of the researches used a maximum of 8 to 10 thematic maps. The thematic maps such as geomorphology, lithology, slope, hydrological soil group (HSG), drainage density (DD), Land use and Land cover (LULC), rainfall and lineament density (LD) were commonly used by many researchers (Fenta et al. 2014; Kaliraj et al. 2014; Rahmati et al. 2015; Jothibasu and Anbazhagam, 2016; Pinto et al. 2017; Abrams et al. 2018; Patra et al. 2018; Jahan et al. 2019; Murmu et al. 2019). Apart from these thematic maps, few researchers also used distance from river, pre-monsoon groundwater depth, post-monsoon groundwater depth and topography thematic map of the study area (Das 2019; Ajay Kumar et al. 2020; Al-Djazouli et al. 2020; Dar et al. 2020; Koli et al., 2020). After going through many studies, it was found that, most of the researchers developed the suitability map of GWPZ by considering maximum of 8 to 10 thematic maps. And none of the researchers used multicollinearity check and sensitivity analysis as shown in Table 1.

Although the delineation of GWPZ using GIS and multi-criteria analysis saves a lot of time as compared to other direct methods such as collecting the data manually from the field, survey of the area, drilling in order to collect the soil sample as well as lithology data, etc., it comes with some negative impacts due to human activities as well as other reasons like field data collection for validation, resolution of thematic maps, assigning weights to thematic maps (Abrams et al. 2018; Jahan et al. 2019; Djazouli et al., 2020). Collecting accurate field data such as well yield, coordinates, etc., for assessing the validity of suitability map plays a vital role (Hussein et al. 2017; Kanagaraj et al. 2019). GWPZ suitability map also influenced by the resolution of the thematic maps (Das et al. 2018). By considering coarser resolution thematic maps, the accuracy of the suitability maps reduces, whereas with finer resolution thematic maps, the accuracy of the suitability map increases (Shekhar and Pandey 2015; Yeh et al. 2016; Lakshmi and Reddy 2018). Weights assign to each of the thematic maps shows significant impact on the suitability map (Nasir et al. 2018; Dar et al. 2020). By considering inappropriate weights for thematic maps, it would result in changes of the sub classes (i.e., Very high, High, Moderate and Low) area of the suitability map (Arshad et al. 2020). Hence, it is necessary to assign appropriate weight to each of the thematic maps by consulting with expertise related to this field as well as based on literature review

Table 1 Details of literature review for GWPZ

| Sl no.	Literature	Multicollinearity check	Sl no.	Literature	Multicollinearity check
1	Abrams et al. (2018)	No	21	Jahan et al. (2019)	No
2	Agarwal et al. (2013)	No	22	Jothibasu and Anbazhagan (2016)	No
3	Ajay Kumar et al. (2020)	No	23	Kaliraj et al. (2014)	No
4	Al-Djazouli et al. (2020)	No	24	Kanagaraj et al. 2019	No
5	Andualem and Demeke, (2019)	No	25	Koli et al., (2020)	No
6	Arshad et al., (2020)	No	26	Kumar and Krishna, (2018	No
7	Arulbalaji et al. (2019)	No	27	kumar et al. (2014)	No
8	Awawdeh et al. (2013)	No	28	Kumar et al. (2020)	No
9	Benjmel et al. (2020)	No	29	Lakshmi and Reddy, (2018)	No
10	Çelik, (2019)	No	30	Magesh et al. (2012	No
11	Choubin et al. 2019	No	31	Maity and Mandal, (2017)	No
12	Dar et al., (2020)	No	32	Mukherjee et al. (2012)	No
13	Das et al. (2018)	No	33	Murmu et al. (2019)	No
14	Das, (2019)	No	34	Nasir et al. (2018)	No
15	Fashae et al., (2014)	No	35	Patra et al. (2018)	No
16	Fenta et al., (2014)	No	36	Pinto et al. (2017)	No
17	Ghosh et al. 2016	No	37	Rahmati et al. 2015	No
18	Gnanachandrasamy et al. (2018)	No	38	Raju et al. (2019)	No
19	Hussein et al., (2017)	No	39	Shekhar and Pandey, (2015)	No
20	Hutti and Nijagunappa, (2011)	No	40	Yeh et al. (2016)	No
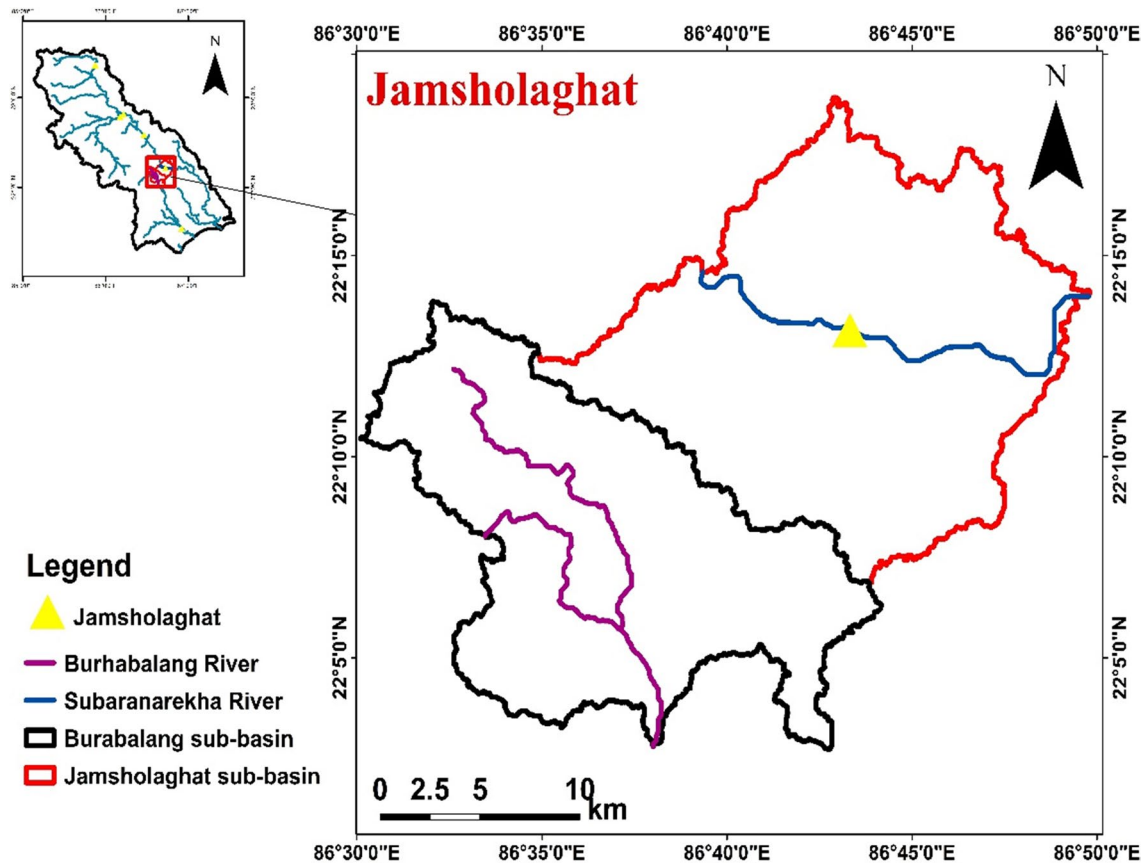
Fig.1 Delineated Jamsholaghat sub-basin in Subarnarekha Basin

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(Ghosh et al. 2016; Murmu et al. 2019; Abrams et al. 2018; Al-Djazouli et al. 2020).

The objective of the present study includes preparation of GWPZ using 14 thematic maps in ArcGIS software by considering AHP. The novelty of the study includes inclusion of maximum number of thematic maps, i.e., 14 numbers than that of previously used maximum of 10 thematic maps followed by multicollinearity check as well as sensitivity analysis. Inclusion of multicollinearity check and maximum number of thematic maps improves the accuracy of the GWPZ map. The GWPZ map offers remarkably reliable data that can aid in long-term efficient groundwater resource management in the water shortage areas.

Materials and methods

Study area

The present study area involves the Jamsholaghat sub-basin of the Subarnarekha Basin. Study area extends over provinces of West Bengal and Odisha having total catchment area of 552 km^2. Extends of its longitude and latitudes are 86°30′ to 86°50′ E and 22°04′ to 22°32′ N, respectively. Delineated Jamsholaghat sub-basin in Subarnarekha Basin is shown in Fig. 1.

Data procurement

Digital elevation model (DEM) data were procured from Alaska search facility, Earth data which is available online at https://search.asf.alaska.edu/#/, having resolution of 12.5 m. Landsat 8 data were procured from Bhuvan, National Remote Sensing Centre (NRSC) which is available freely at http://bhuvan.nrsc.gov.in. Rainfall data were acquired from Center for Hydrometeorology & Remote Sensing (CHRS) available at https://chrsdata.eng.uci.edu/. Lithology data having scale of 1:50,000 were obtained from the Geological Survey of India (GSI) available at https://bhukosh.gsi.gov.in/Bhukosh/Public. The soil type and soil depth map having scale of 1:50,000 was procured from the National Atlas and Thematic Mapping Organization's district planning map series.
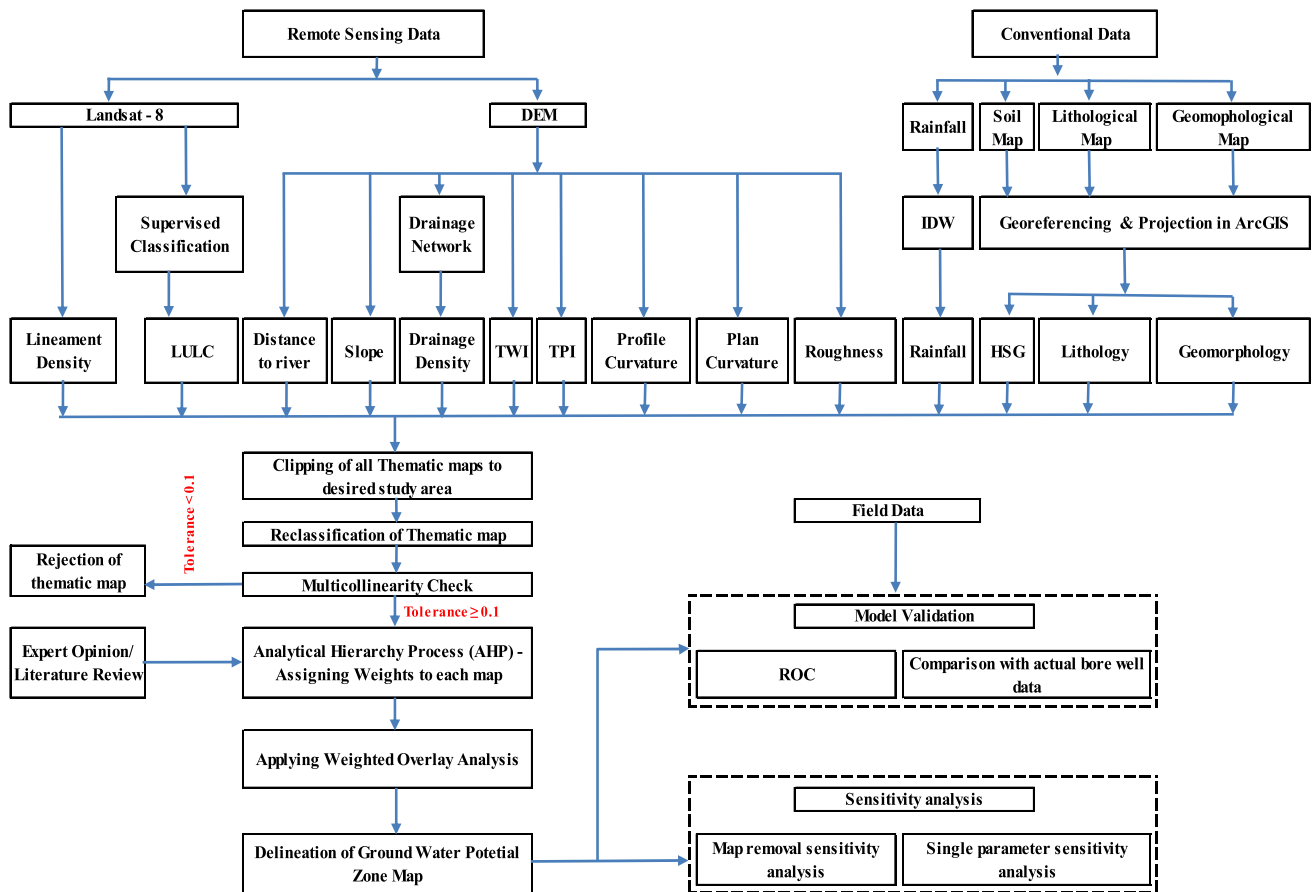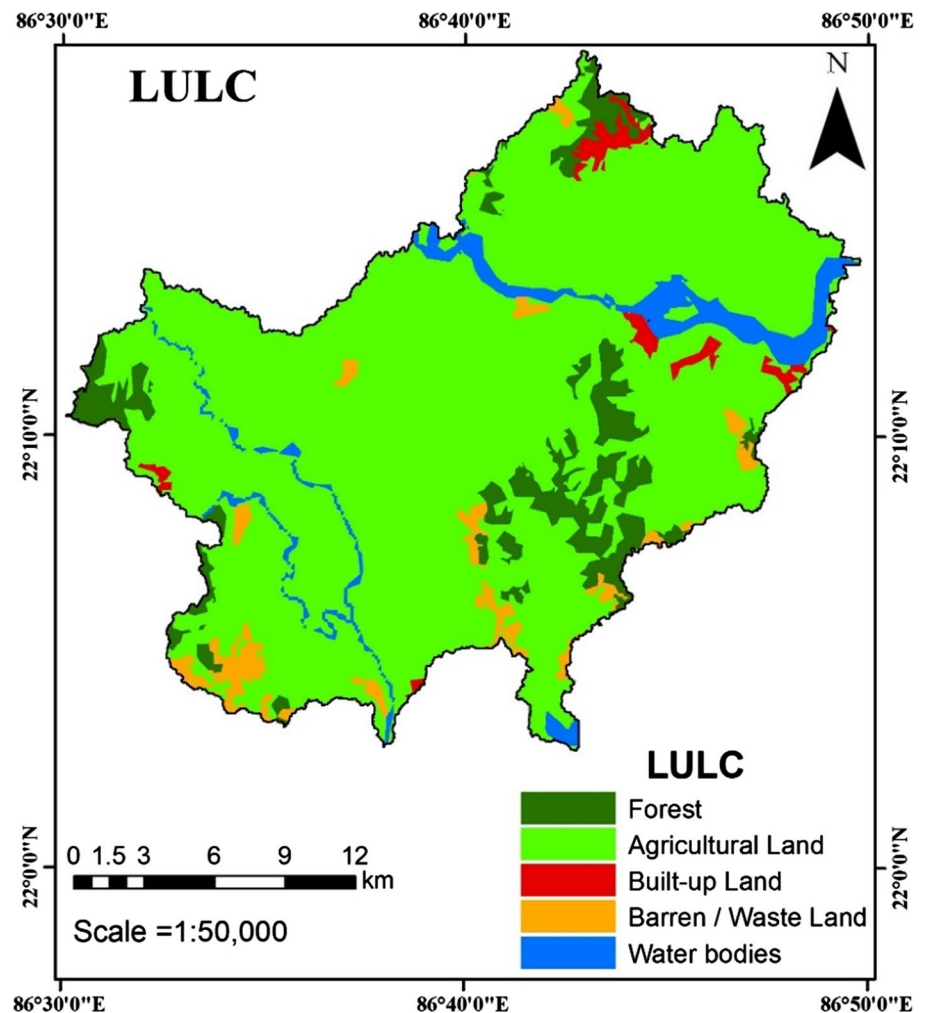

Fig. 2 Flowchart for delineating the groundwater potential zones

Fig. 3 LULC map of the study area


Methodology

It is crucial to identify the GWPZ in order to install the relief well for a particular basin. In the present study, fourteen thematic maps (i.e., Lithology, Slope, LULC, DD, LD, Distance from river, Rainfall, HSG, Geomorphology, Topographic Wetness Index (TWI), Topographic Position Index (TPI), Profile Curvature, Plan Curvature and Roughness) were prepared using ArcGIS software. Then, the multicollinearity check of 14 thematic maps were carried out followed by overlaying of thematic maps in ArcGIS after assigning weights and ranks using AHP, then followed by sensitivity analysis and validation of GWPZ map by considering the Receiver Operating characteristic Curve (ROC). The flowchart for developing the GWPZ is shown in Fig. 2.

LULC map shows the pictorial representation of the study area having agricultural land, forests, water bodies, wetlands, built up area, etc. (Jahan et al. 2019). Landsat 8 map was downloaded from Earthexplorer website. Using supervised classification in ArcGIS software, land use map

was generated. At first, the band numbers of the red, green and blue color were changed from high to low followed by classification of image based on land types using image classification tools. Accuracy of LULC map increases by increasing the number of training sample for each category of land forms. After saving the training samples, maximum likelihood classification was used in order to produce the LULC map in ArcGIS software. The present study area was broadly classified into five categories, i.e., Forest, Agricultural, Built-up, Barren/Waste and Water Bodies, consisting of 15%, 66%, 10%, 4% and 5% of the study area, respectively.

The rate of infiltration and percolation through the surface to the subsurface and its aquifers is mostly affected by particles of soil (Murmu et al. 2019). According to the United States Department of Agriculture (USDA), HSG was classified into four groups, i.e., A, B, C, and D. At first a new shapefile was created followed by drawing the polylines based on soil groups in the shapefile by using editor tool in ArcGIS software. Then, soil groups were

Fig. 4 HSG map of the study area
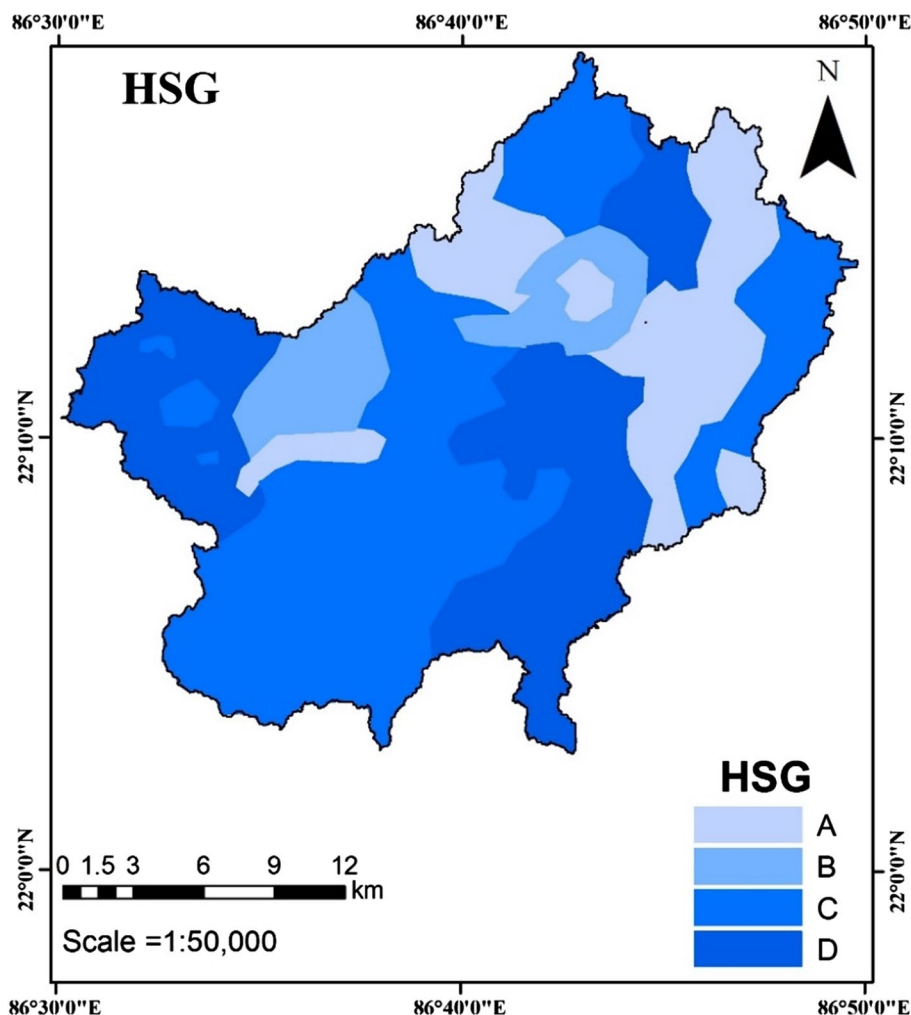
entered in the attribute table for different polygons those were being generated by joining the polylines for respective soil groups. After merging the polygons of same soil groups in attribute table using editor tool, Soil map was developed. Study area consists of mainly four types of soil group, i.e., A, B, C and D, consisting of 19%, 9%, 42% and 30% of the Jamsholaghat sub-basin, respectively.

The slope is quite important in recharging the groundwater as it controls the surface runoff (Lakshmi and Reddy 2018). Using the DEM, Slope map was generated for the study area. This was done by choosing the Surface option from Spatial Analyst Tools. The developed slope map was divided into five categories based on slope in degrees, i.e., Very Gentle, Gentle, Moderate, Moderate Steep, and Steep, accounting for 40%, 49%, 9%, 1%, and 1% of Jamsholaghat sub-basin, respectively.

The density of drainage shows the contiguousness of channel spacing as well as the composition of the surface material, providing a quantitative estimate of average stream channel length for the entire basin (Jothibasu and Anbazhagan 2016). DD map was generated from DEM of the study area. It was done by selecting "Hydrology" option from "Spatial Analyst Tools". The DEM was first geo-referenced and converted to a projected coordinate system, followed by generating the flow direction map. It was then followed by generating the flow accumulation map that was generated by eliminating the values which were below 500 in the flow accumulation map. Then stream network of the study area was generated by using flow direction and flow accumulation maps. Using this stream network, stream order of the sub-basin was developed followed by use of line density option so as to prepare the DD map in ArcGIS software. DD map of the study area consists of six ranges, i.e., < 0.9, 0.91–1.76, 1.76–2.61, 2.62–3.45, 3.46–4.30 and 4.31–5.15, consisting of 1%, 11%, 40%, 40%, 7% and 1% of Jamsholaghat sub-basin, respectively.

Fig. 5 Slope map of the study area
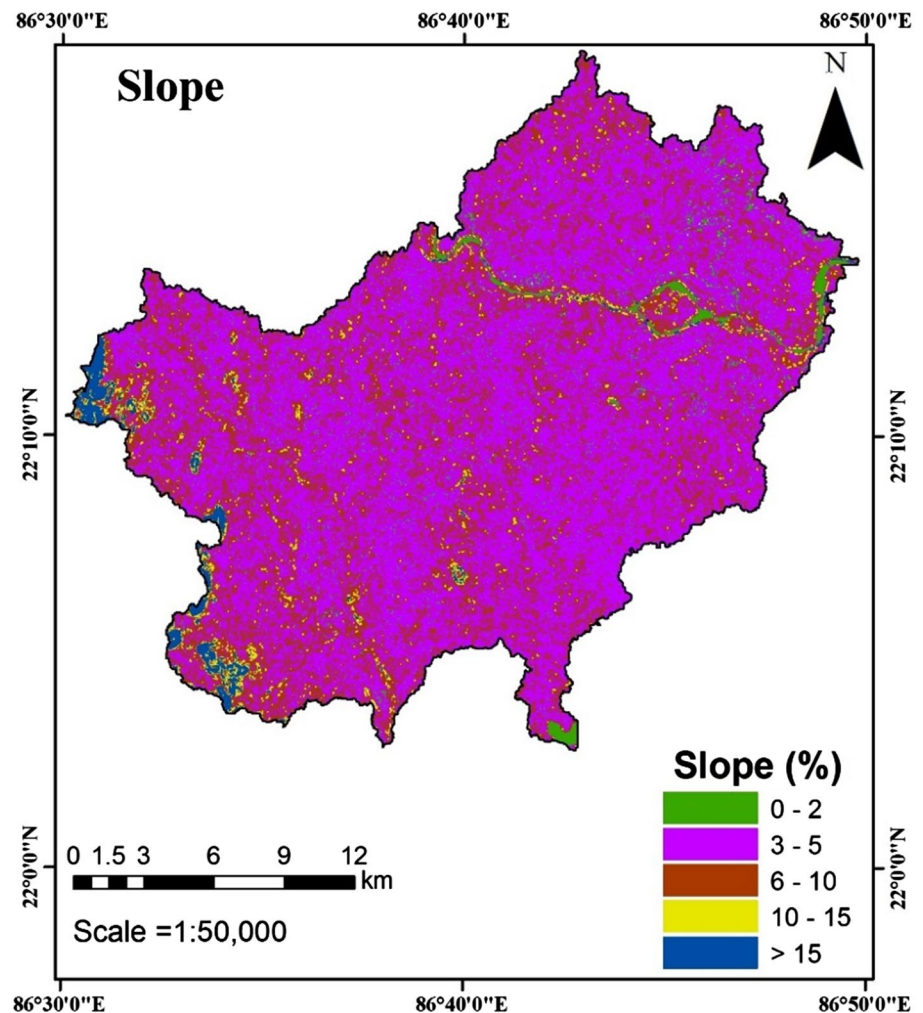
A lithology map of a research area depicts the features of several types of rocks found in the Earth's subsurface (Kumar et al. 2014). Lithology map of the present study area was downloaded from GSI by considering the latitude and longitude extend of the study area. Clip function was used in ArcGIS software in order to extract the required study area. In terms of improving the map's accuracy, lithology data was collected from Central Ground Water Board (CGWB), Bhubaneswar and verified with lithology map downloaded from GSI. Based on field data, lithology map was rectified and redeveloped. Study area consists of mainly five types of rock formations, i.e., Granite, Gravel, Laterite, Quartz and Schist, consisting of 36%, 1%, 20%, 2% and 41% of the study area, respectively.

The primary structural elements such as cleavages, fractures, discontinuity surfaces, and faults are expressed by the lineaments having the property of linearity (Shekhar and Pandey 2015). Landsat 8 map was downloaded from Earthexplorer website. The image was enhanced in PCI

Geomatica using the "Enhancements" tool. The Librarian Algorithm was then used to extract Lineament (Çelik 2019). The line density function in the spatial analyst tool was selected in order to prepare the LD map in Arc-GIS software. The study area's LD map was categorized into five groups, i.e., 0.5, 0.5–1.1, 1.2–1.6, 1.7–2.2, and 2.3–2.8 km/km^2, with 76%, 12%, 6%, 4%, and 2% of Jamsholaghat sub-basin, respectively.

Geomorphology is the study of the earth's form (landform), as well as its characterization and origins. Geomorphology map of the Jamsholaghat sub-basin was downloaded from GSI by considering the latitude and longitude extend of the study area (Hussein et al. 2017; Patra et al. 2018). Clip function was used in ArcGIS software so as to extract the required study area. In terms of improving the map's accuracy, lithology data was collected from CGWB, Bhubaneswar and verified with geomorphology map downloaded from GSI. Based on field data, geomorphology map was rectified and redeveloped. The study

Fig. 6 DD map of the study area
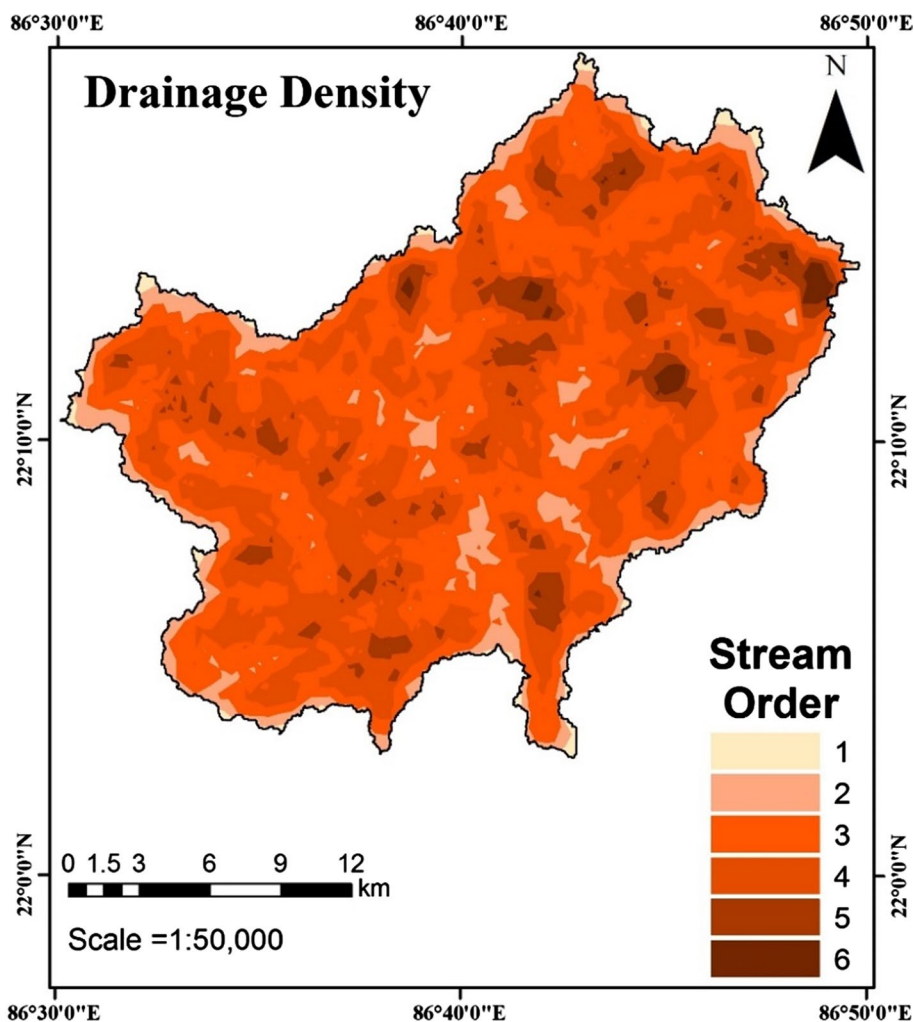
area was mainly categorized into five groups, i.e., Hills and Valleys, Alluvial Plain, Pediment Pediplain complex, Flood plain and water bodies, accounting for 4%, 1%, 82%, 10% and 3% of Jamsholaghat sub-basin, respectively.

Distance from river map was developed in ArcGIS software. At first, flow accumulation was set greater than 1000 using map algebra function in spatial analyst tool followed by generating the stream network. Based on distance, multiple ring buffer function was used in order to develop the distance from river map. Study area was categorized into six groups, i.e., < 300, 301–600, 601–900, 901–1200, 1201–1500 and > 1500 m, consisting of 5%, 9%, 13%, 17%, 21% and 35% of Jamsholaghat sub-basin, respectively.

Rainfall recharges groundwater, making it an active natural resource (Arulbalaji et al. 2019). Rainfall data from the different rain gauges of Indian Meteorological Department (IMD) situated inside the buffer zone and its nearby

regions of the research area was collected for 30 years (i.e., 1987–2016). Rainfall map was developed in ArcGIS software. At first, annual average rainfall data was estimated in excel for all the rain gauges followed by adding those data to ArcGIS based on latitude and longitude of rain gauges. In ArcGIS software, the spatial distribution map of rainfall was created using the Inverse Distance Weight (IDW) interpolation technique. The rainfall map of the present research area was classified into five groups, i.e., 1420–1471, 1472–1523, 1524–1575, 1576–1626 and 1627–1678 mm, consisting of 6%, 15%, 32%, 40% and 7% of Jamsholaghat sub-basin, respectively.

TWI map was developed in ArcGIS software. At first, slope map was generated using spatial analyst tool. Equation 1 was used in raster calculator function available in map algebra in order to prepare the TWI map (Magesh et al. 2012; Raju et al. 2019).

Fig. 7 Lithology map of the study area
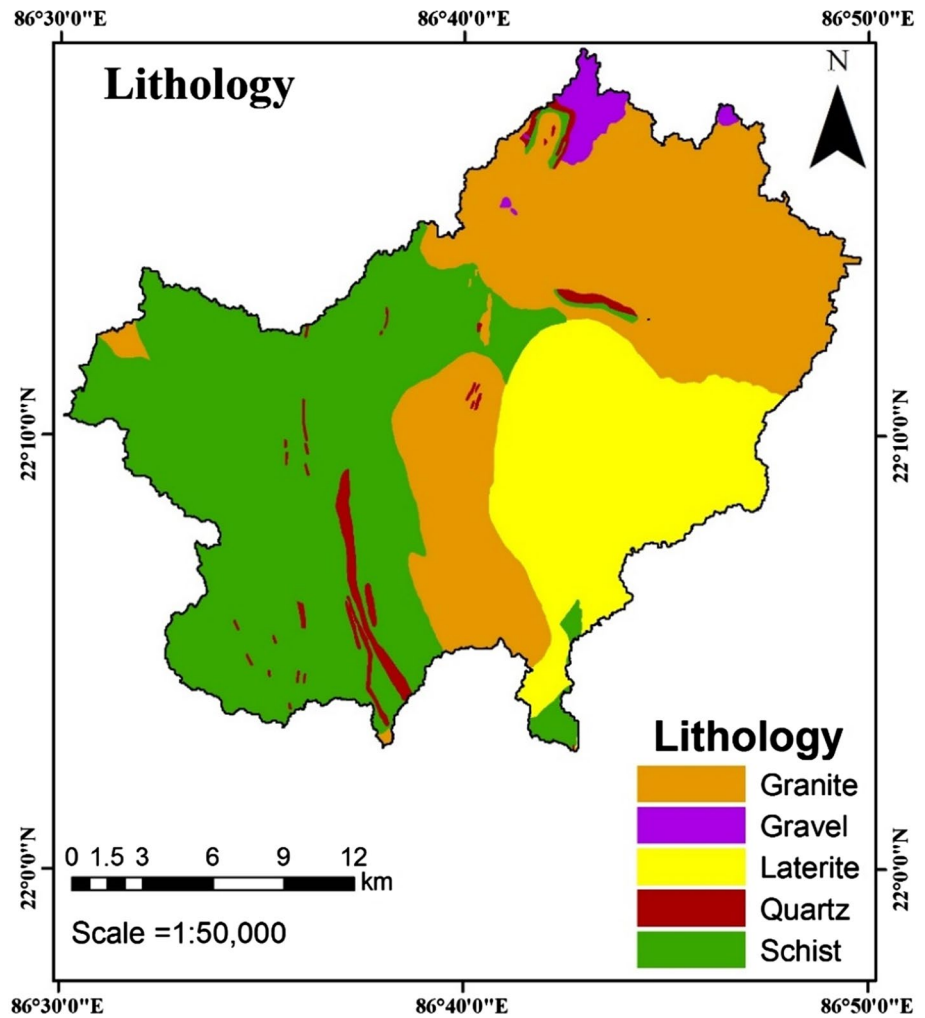
TWI $= \ln \dfrac{\alpha}{\tan \beta}$ (1)

where α is upslope and β is topographic gradient. TWI map of the present research area was categorized into four groups, i.e., very low, low, moderate and high, consisting of 52%, 25%, 15% and 8% of Jamsholaghat sub-basin, respectively.

Using the Jenness method and the Topography tools extension, the TPI thematic map was created in ArcGIS software. TPI map of the present research area was categorized into five groups, i.e., [−9]–[−1.1], [−1]–[−0.29], [−0.28]–[0.3], [0.3]–[1.1] and [1.2]–[1.3] consisting of 5%, 29%, 34%, 28% and 4% of Jamsholaghat sub-basin, respectively.

The roughness index measures the variation in elevation among neighboring cells in a DEM. Roughness was calculated using Eq. 2 (Ajay Kumar et al. 2020; Dar et al. 2020).

Roughness $= \dfrac{FS_{mean} - FS_{min}}{FS_{max} - FS_{min}}$ (2)

where FS_{min} is minimum focal statistic, FS_{max} is maximum focal statistic and FS_{mean} is mean focal statistic. Using the Neighborhood tool, minimum (FSmin), mean (FSmean) and maximum (FSmax) focal statistical thematic layers were created followed by creating the FS_{min}, FS_{max} and FS_{mean} using Raster Calculator function in Map Algebra tool then using Eq. 2 (Kanagaraj et al. 2019), Roughness map was developed. Roughness of the present research area was categorized into five groups, i.e., < 0.31, 0.32–0.44, 0.45–0.56, 0.57 – 0.68 and 0.69–0.89, accounting for 6%, 21%, 49%, 19% and 5% of Jamsholaghat sub-basin, respectively.

The maximum slope's direction is parallel to the profile curvature. Profile curvature map of the present research area was developed in ArcGIS by using curvature function in 3D analyst tool (Nasir et al. 2018; Patra et al. 2018). Profile curvature map was categorized into three groups, i.e., convex, flat and concave, consisting of 34%, 54% and 15% of Jamsholaghat sub-basin, respectively.

Fig. 8 LD map of the study area
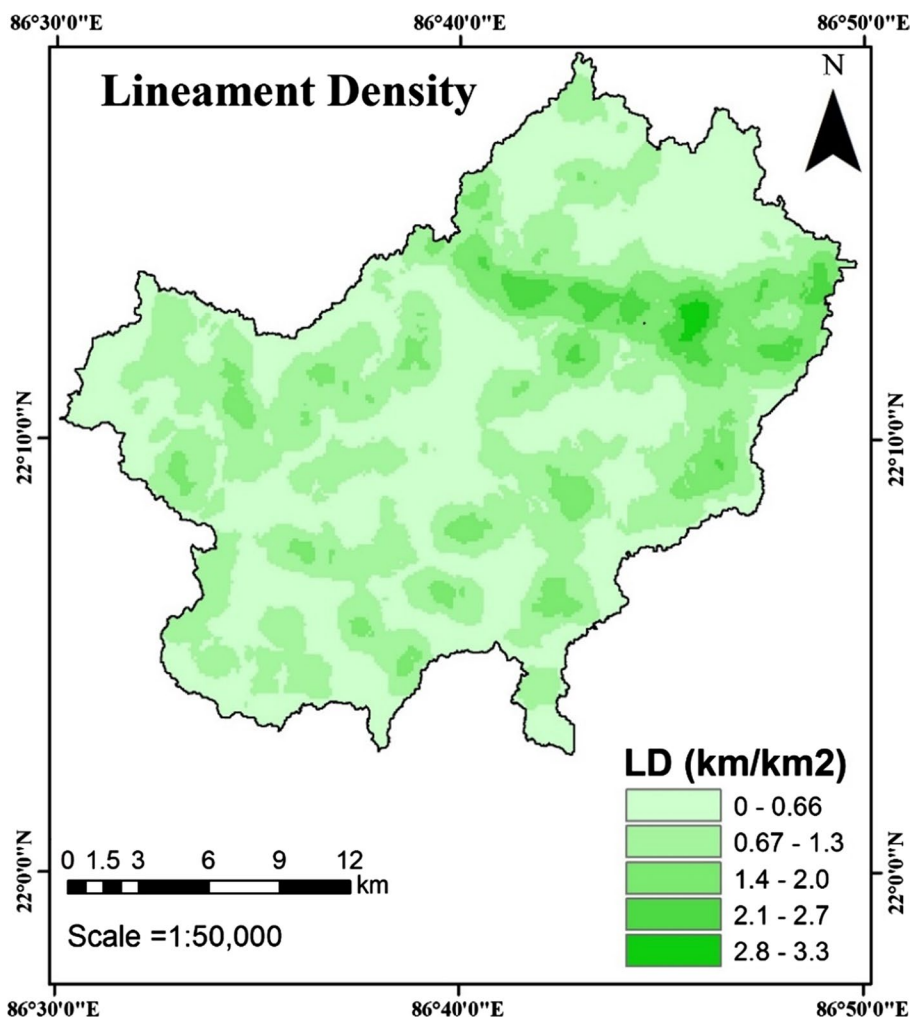
Plan curvature is perpendicular to the maximum slope direction (Murmu et al. 2019; Al-Djazouli et al. 2020). Plan curvature map of the present research area was developed in ArcGIS by using curvature function in 3D analyst tool. Profile curvature map was categorized into three groups, i.e., convex, flat and concave consisting of 24%, 55% and 21% of Jamsholaghat sub-basin, respectively.

Multicollinearity checks for GWPZ

Multicollinearity is a type of problem related to statistics where at the minimum one input variable is highly correlated with other input variables of the model. It will result in a substantial level of precision in the output of the model. As a result, check for multicollinearity among the input variables before proceeding with the regression model is crucial (Montgomery et al. 2013). The parameters of multicollinearity (i.e., variance inflation factor (VIF) and tolerance) were estimated using Eqs. 3 and 4.

$$\text{Tolerance of the ith predictor variable} \left(T_i\right) = 1 - R_i^2 \quad (3)$$

$$\text{VIF of the ith predictor variable} \left(\text{VIF}_i\right) = \frac{1}{T_i} \quad (4)$$

Multicollinearity problems exist if the tolerance value is less than 0.10 or the VIF is greater than equal to 10 (Montgomery et al. 2013). To survey the multicollinearity problem between all the thematic maps, 500 points ($N = 500$) were chosen randomly from the Jamsholaghat sub-basin and data was extracted from ArcGIS. Statistical Package for Social Science (SPSS) (v26) was used in order to check the multicollinearity problem.

AHP for GWPZ

AHP is a specific methodologies for determining the suitability of structures for their intended locations, and it is based on Prof. Saaty's MCDA (1987). Within a collection of

Fig. 9 Geomorphology map of the study area
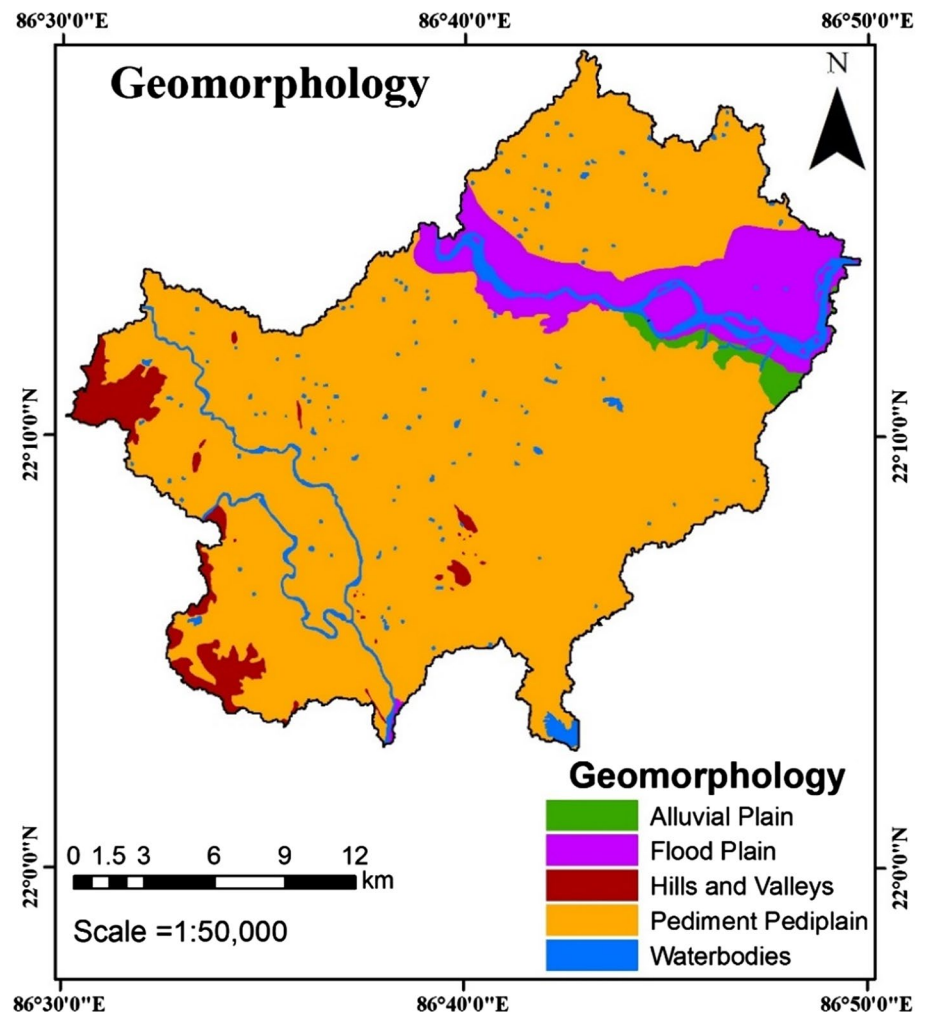
reciprocal matrices, the AHP approach performs a comparison of different variables. The significance of GWPZ was used to assign a ranking from 1 to 9. In this ranking, a '1' denotes a limited region where no building is recommended, while a '9' indicates an outstanding zone for GWPZ (Saaty 1987). The 'Consistency Ratio (CR),' as advocated by Saaty (1990), was computed by using Eq. 5 to assess the consistency of rankings and weights allocated to distinct thematic maps and their sub-classes. A CR of less than equal to 0.1, according to Saaty (1990), suggests an acceptable decision to proceed with the AHP assessment.

$$\text{Consistency Ratio (CR)} = \frac{\text{CI}}{\text{RCI}} \tag{5}$$

$$\text{Consistency Index, CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

where n is the number of thematic maps, RCI is random consistency index and $\lambda_{\max}$ is principal eigen value.

Overlay analysis for GWPZ

After allocating weights and ranks to all the thematic map as well as its sub-classes, the GWPZ map was created by considering the weighted overlay analysis in ArcGIS software thereby using Spatial analyst tool. Equation 7 shows the formula of overlay analysis.
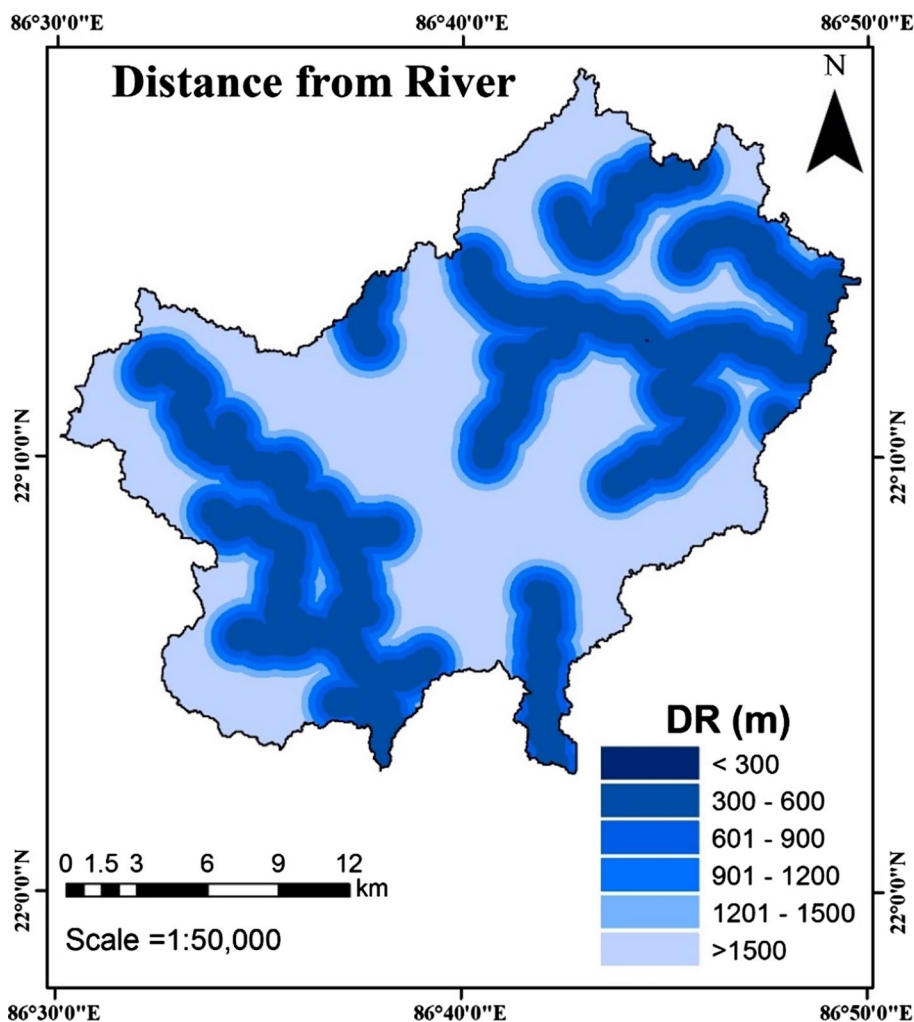
$$\text{GWPZ} = \sum_{i=1}^{n} (W_i \times R_i) \tag{7}$$

where W_i is thematic map weight and R_i is sub-classes rank.

Sensitivity analysis for GWPZ

The sensitivity analysis shows the impact of each input maps over output map. For the present study, two sensitivity analyses (i.e., map removal and single parameter) were used.

Fig. 10 Distance from river map of the study area

Sensitivity index (SI) of map removal sensitivity analysis was estimated using Eq. 8 (Arshad et al. 2020).

$$\text{SI} = \frac{\left| \left(\frac{\text{GWPZ}}{N} \right) - \left(\frac{\text{GWPZ}'}{n} \right) \right|}{\text{GWPZ}} \times 100 \tag{8}$$

where GWPZ′ is GWPZ developed by rejecting one of the thematic map at a time, n is the total number of thematic maps considered in order to develop the GWPZ′ and N is the total number of thematic maps considered in order to generate the GWPZ. Weight factor (W) of single parameter sensitivity analysis was estimated using Eq. 9 (Kumar et al. 2020).

$$W = \frac{P_r P_w}{\text{GWPZI}} \times 100 \tag{9}$$

where P_r is ranks of each thematic map, P_w is Weights of thematic map and GWPZI is groundwater potential zone index estimated by considering all of the thematic maps.

Results and discussion

Lithology, Slope, LULC, DD, LD, Distance from stream, Rainfall, HSG, Geomorphology, TWI, TPI, Profile Curvature, Plan Curvature and Roughness maps of the Jamsholaghat sub-basin are shown in Figs 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16. In order to identify the suitable locations for relief well, GWPZ map was delineated.

Multicollinearity checks for GWPZ

Table 2 shows the parameters of the multicollinearity investigation. The findings shows that for all the thematic maps, the values of VIF were below the upper limit, i.e., 10 and the values of tolerance value were above the lower limit, i.e., 0.1. Hence, from the above results it was clear that there was no multicollinearity problem exists between all of the thematic maps.

Fig. 11 Rainfall map of the study area
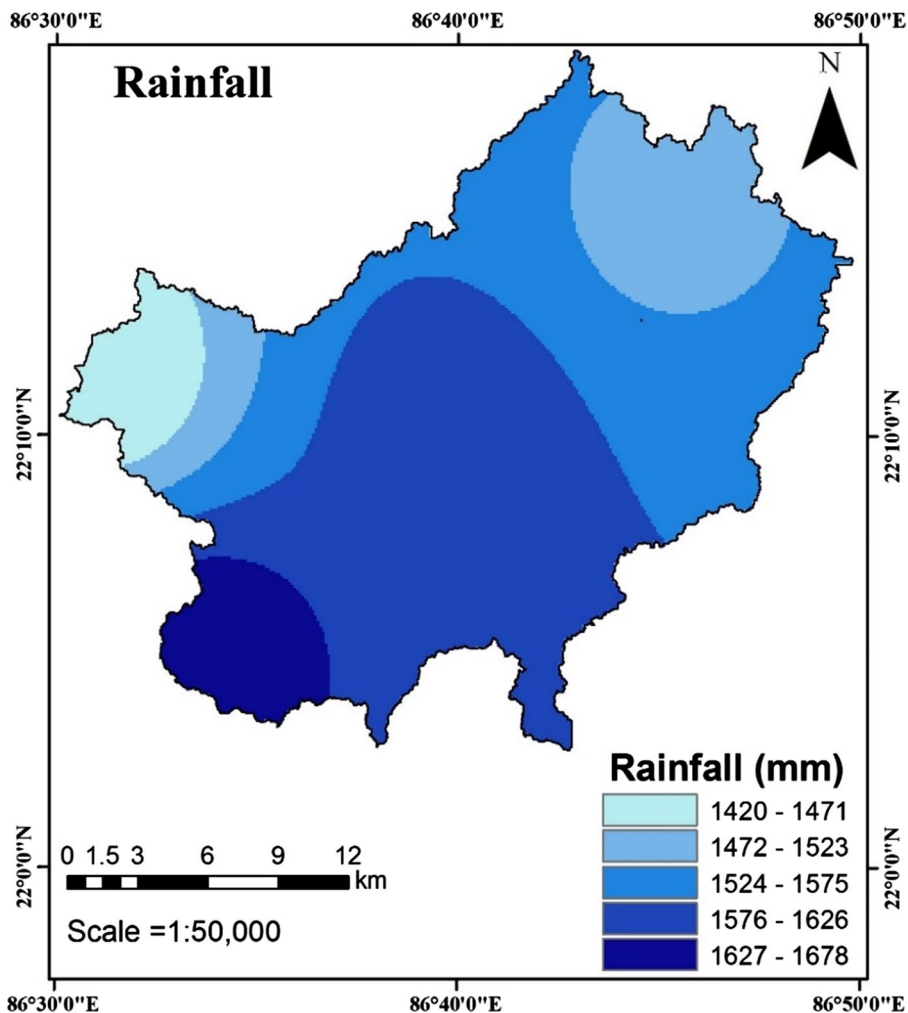
AHP for GWPZ

AHP method was used in order to assign the weightage to each thematic map as well as their sub-classes. Pairwise comparison matrix and normalized pairwise comparison matrix for Jamsholaghat sub-basin are shown in Tables 3 and 4, respectively. Normalized pairwaise comparison matrix values were estimated by dividing value of each cell to that of column total value. Criteria weights were estimated by taking the average of row values. Computation of consistency for Pairwise comparison matrix was done by using Eqs. 7 and 8. Consistency index was estimated as 0.02 and consistency ratio was 0.01. As consistency ratio is 0.01 which is less than 0.1, hence, it can be concluded that, Pairwise comparison matrix is consistence and the weights estimated through Table 4 can be used in order to assign the weights to all the thematic maps. Weight and rank value for all the thematic maps are shown in Table 5. So as to increase the accuracy, each of the theme maps' sub-classes was allocated ranks according to their priority level by considering expert opinion/literature review.

LULC map for GWPZ

LULC map was assigned 8.1% weight according to AHP. In the LULC map, each sub-class, i.e., Forest, Agricultural, Built-up, Barren/Waste and Water bodies, was assigned ranks (i.e., from 1 to 9) as 8, 7, 2, 3 and 9, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. Water bodies were assigned highest rank due to highest infiltration followed by forest and agricultural land due to little bit less infiltration than water bodies.

Fig. 12 TPI map of the study area
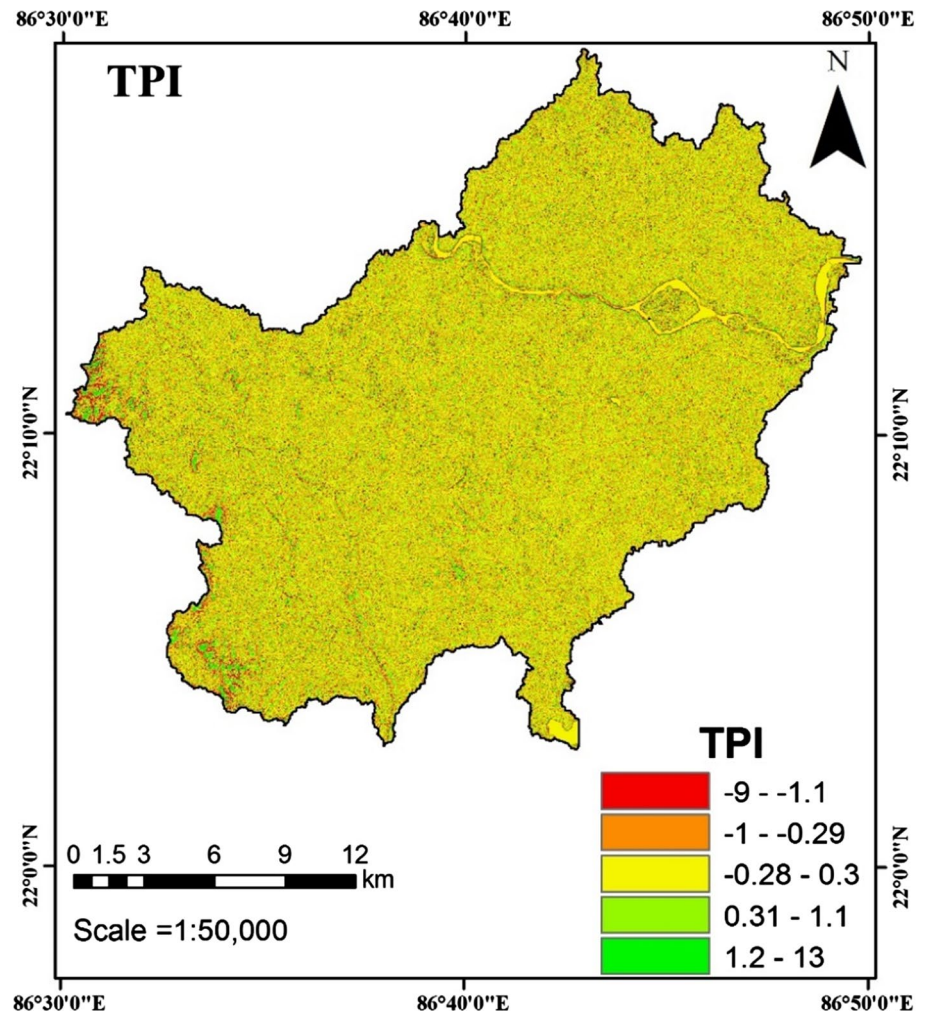
Built-up lands were assigned lowest rank as it has highly impermeable layer and least infiltration.
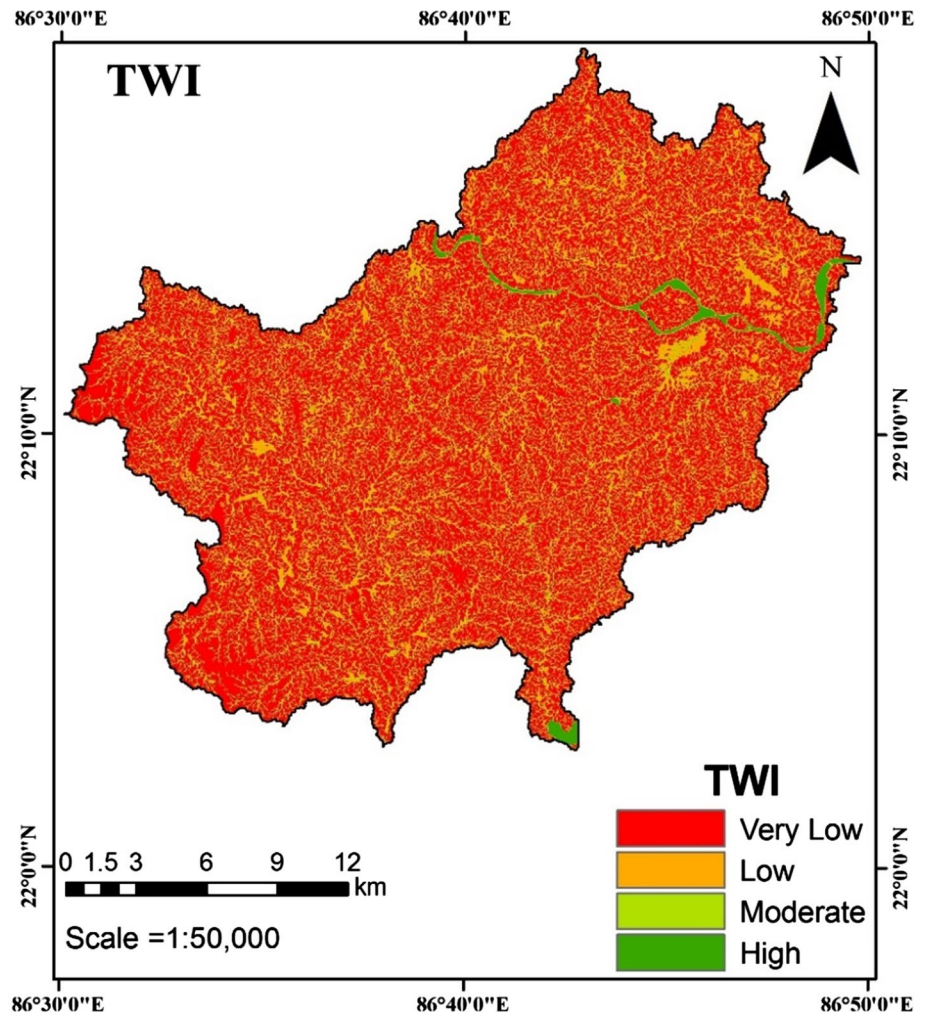
HSG map for GWPZ

HSG map was assigned 8.1% weight according to AHP. In the HSG map, each sub-class, i.e., A, B, C and D, was assigned ranks (i.e., from 1 to 9) as 9, 7, 5 and 3, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. Group A soil was assigned highest rank due to high infiltration rate, followed by Group B due to moderate infiltration, followed by Group C due to low infiltration. Group D was assigned lowest rank due to very low infiltration.

Slope map for GWPZ

Slope map was assigned 5.9% weight according to AHP. In the slope map, each sub-class, i.e., Very Gentle, Gentle, Moderate, Moderate Steep and Steep, was assigned ranks (i.e., from 1 to 9) as 9, 7, 5, 2 and 1, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS. The slope of the surface has a significant impact on surface runoff and infiltration rates. Higher slope produces low recharge, this is due to water flows with high velocity over steep slope and has less infiltration time through the surface toward subsurface. Flat and mild slopes receive the highest ranking. The low rank was given to slopes that are moderately steep and steep.

Fig. 13 TWI map of the study area

DD map for GWPZ

DD map was assigned 6% weight according to AHP. In the DD map, each sub-class, i.e., < 0.9, 0.91–1.76, 1.76–2.61, 2.62–3.45, 3.46–4.30 and 4.31–5.15, was assigned ranks (i.e., from 1 to 9) as 9, 7, 5, 3, 2 and 1, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. Permeability and DD are inversely related to each other. It means if DD is high, then it would result in high permeability and vice versa. Hence, it plays a vital role in obtaining the GWPZ map. As a result, a low DD was attributed to a high rank, and a high rank was allocated to a low rank.

Lithology map for GWPZ

Lithology map was assigned 16.9% weight according to AHP. In the lithology map, each sub-class, i.e., Granite, Gravel, Laterite, Quartz and Schist, was assigned ranks (i.e., from 1 to 9) as 5, 9, 7, 1 and 3, respectively. This is done by reclassify function in spatial analyst tool using ArcGIS software. Hydraulic conductivity is a key aquifer property that determines a lithology's groundwater recharge and storage potential. Higher the hydraulic conductivity higher the permeability and higher the infiltration. Based on this fact, highest rank was assigned to Gravel bed followed by Laterite, Granite, Schist and Quartz.

Fig. 14 Roughness map of the study area
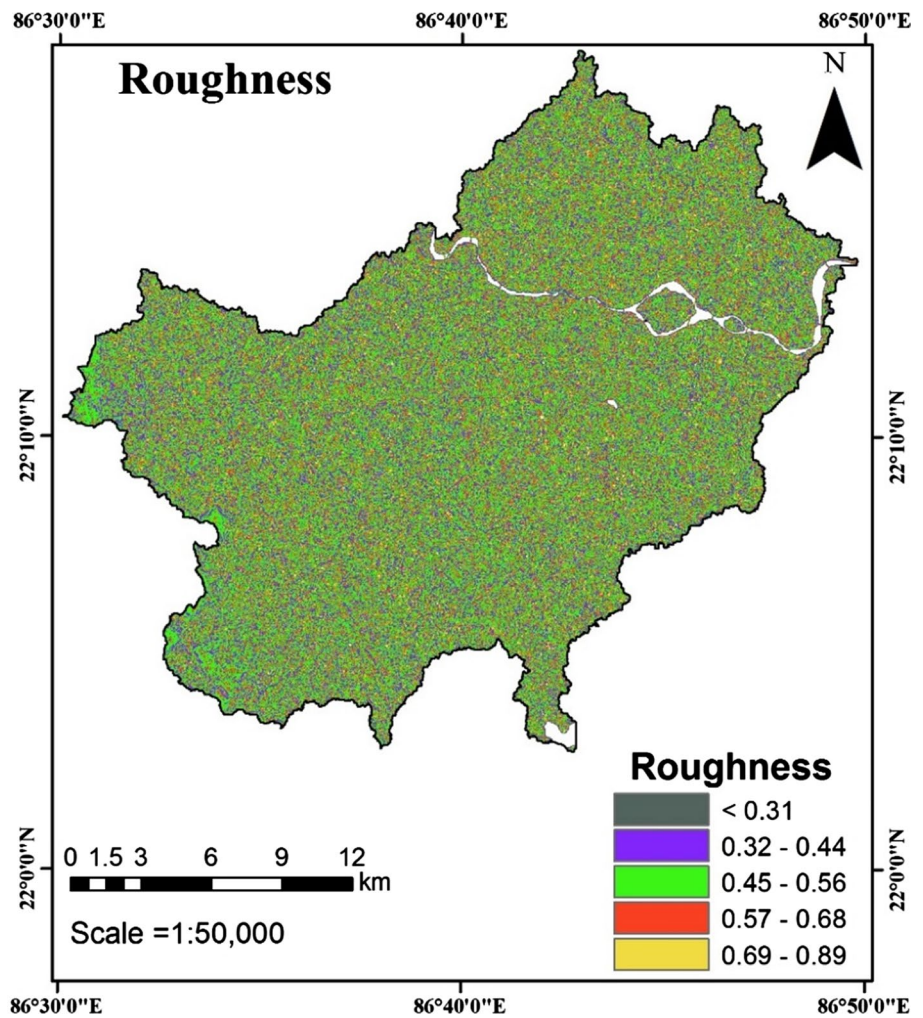
LD map for GWPZ

LD map was assigned 8.1% weight according to AHP. Each sub-class of the LD map, i.e., < 0.5, 0.5–1.1, 1.2–1.6, 1.7–2.2 and 2.3–2.8 km/km², was assigned ranks (i.e., from 1 to 9) as 2, 4, 7, 8 and 9, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS. The density of lineaments was ranked according to their proximity. It was discovered that as one moves away from the lineaments, the level of groundwater potential reduces. High rank was assigned for high density due to high porosity and infiltration, whereas low rank was assigned for low density classes due to low porosity and infiltration.

Geomorphology map for GWPZ

Geomorphology map was assigned 10.7% weight according to AHP. In the geomorphology map, each sub-class, i.e., Hills and Valleys, Alluvial Plain, Pediment Pediplain complex, Flood plain and water bodies, was assigned ranks (i.e., from 1 to 9) as 2, 7, 6, 8 and 9, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. Water bodies were assigned highest rank due to high infiltration. Low rank was assigned to Hills and valleys due to less infiltration and steep slope.

Distance from river map for GWPZ

Distance from river map was assigned 13.6% weight according to AHP. In the distance from river map, each sub-class,

Fig. 15 Profile curvature map of the study area
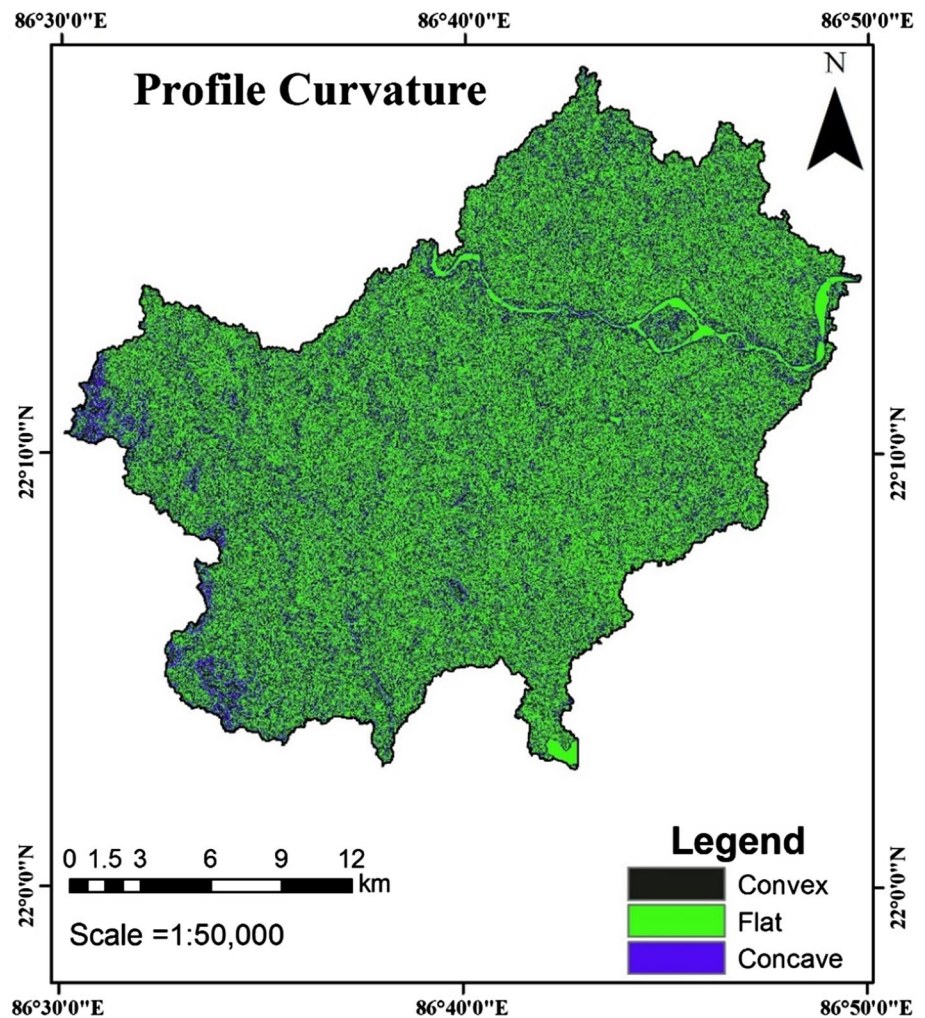
i.e., < 300, 301–600, 601–900, 901–1200, 1201–1500 and > 1500 m, was assigned ranks (i.e., from 1 to 9) as 9, 8, 7, 6, 5 and 4, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. Closer the distance from river, higher the groundwater recharge and higher the infiltration whereas away from the river results in decrease in groundwater recharge and infiltration. Therefore, high rank was assigned to closer distance areas and lower rank was assigned to far away areas.

Rainfall map for GWPZ

Rainfall map was assigned 4.5% weight according to AHP. In the rainfall map, each sub-class, i.e., 1420–1471, 1472–1523, 1524–1575, 1576–1626 and 1627–1678 mm, was assigned ranks (i.e., from 1 to 9) as 5, 6, 7, 8 and 9, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. Infiltration is mainly influenced by two factors, i.e., intensity and rainfall

duration. If the intensity of rainfall is high and duration of rainfall is short then it would result in high runoff whereas if the intensity of rainfall is low and duration of rainfall is long then it would result in low runoff. There were strong linear positive connections between groundwater recharge and rainfall. High rank was allocated to the regions with high rainfall, while low rank was allocated to the regions with low rainfall.

TWI map for GWPZ

TWI map was assigned 4.4% weight according to AHP. Each sub-class of the TWI map, i.e., high, moderate, low and very low, was assigned ranks (i.e., from 1 to 9) as 9, 7, 5 and 3, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. In general, low TWI area consist of hill and mountains having steep slope results in high runoff. However, high TWI

Fig. 16 Plan curvature map of the study area
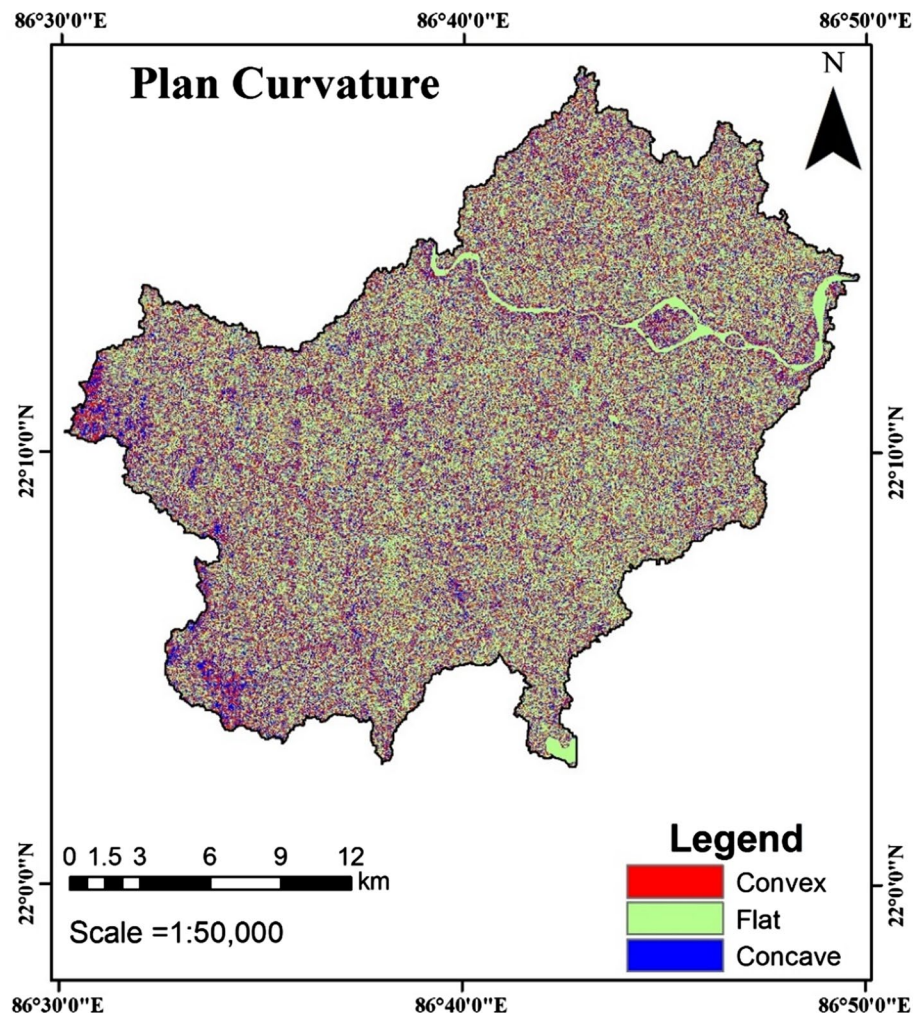
Table 2 Collinearity statistics for all the parameters of GWPZ

Sl.	Thematic Map	Tolerance	VIF
1	Lithology	0.582	1.72
2	Distance from River	0.608	1.64
3	Geomorphology	0.574	1.74
4	HSG	0.621	1.61
5	LULC	0.946	1.06
6	LD	0.916	1.09
7	DD	0.853	1.17
8	Slope	0.974	1.03
9	R/f	0.941	1.06
10	TWI	0.911	1.10
11	TPI	0.746	1.34
12	Roughness	0.921	1.09
13	Profile Curvature	0.727	1.38
14	Plan Curvature	0.716	1.40

area consist of flat regions with flat slope results in low runoff. Hence, High rank was given to higher TWI and low rank was given to lower TWI.

TPI map for GWPZ

TPI map was assigned 3.4% weight according to AHP. Each sub-class of the TPI map, i.e., $[-9]–[-1.1]$, $[-1]–[-0.29]$, $[-0.28]–[0.3]$, $[0.3]–[1.1]$ and $[1.2]–[1.3]$, was assigned ranks (i.e., from 1 to 9) as 9, 7, 5, 3 and 2, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. TPI differentiate the elevation of a cell to that of average elevation of the cell's surrounding neighborhood in the DEM. It determines the position of the topographic slope. Positive numbers show that a cell is higher than its neighbors, while negative values show that it is lower. It shows an inverse relationship with groundwater

Table 3 Pairwise comparison matrix for GWPZ

P/P	Li	DR	Gm	HSG	LULC	LD	DD	Sl	R/f	TWI	TPI	R	Prc	Plc
Li	1.0	1.5	2.0	2.5	2.5	2.5	3.0	3.0	3.5	3.5	4.0	4.0	4.0	4.0
DR	0.7	1.0	1.5	2.0	2.0	2.0	2.5	2.5	3.0	3.0	3.5	3.5	3.5	3.5
Gm	0.5	0.7	1.0	1.5	1.5	1.5	2.0	2.0	2.5	2.5	3.0	3.0	3.0	3.0
HSG	0.4	0.5	0.7	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	2.5	2.5
LULC	0.4	0.5	0.7	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	2.5	2.5
LD	0.4	0.5	0.7	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	2.5	2.5
DD	0.3	0.4	0.5	0.7	0.7	0.7	1.0	1.0	1.5	1.5	2.0	2.0	2.0	2.0
Sl	0.3	0.4	0.5	0.7	0.7	0.5	1.0	1.0	1.5	1.5	2.0	2.0	2.0	2.0
R/f	0.3	0.3	0.4	0.5	0.5	0.5	0.7	0.7	1.0	1.0	1.5	1.5	1.5	1.5
TWI	0.3	0.3	0.4	0.5	0.5	0.4	0.7	0.7	1.0	1.0	1.5	1.5	1.5	1.5
TPI	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.7	1.0	1.0	1.0	1.0	1.0
R	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.7	1.0	1.0	1.0	1.0	1.0
Prc	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.7	1.0	1.0	1.0	1.0	1.0
Plc	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.7	0.7	1.0	1.0	1.0	1.0	1.0
CT	5.6	7.3	9.6	12.9	12.9	12.7	17.3	17.5	22.7	24.0	29.0	29.0	29.0	29.0

P/P: is Parameters/ Parameters, *Li*: is Lithology, *DR*: is Distance from river, *Gm*: is Geomorphology, *HSG*: is Hydrological soil group, *LULC*: is Land use and land cover, *LD*: is Lineament density, *DD*: is Drainage density, *Sl*: is Slope, *R/f*: is Rainfall, *TWI*: is Topographic wetness index, *TPI*: is Topographic position index, *R*: is Roughness, *Prc*: is Profile curvature and *Plc*: is Plan curvature, *CT*: is Column total

Table 4 Normalized pairwise comparison matrix for GWPZ

P/P	Li	DR	Gm	HSG	LULC	LD	DD	Sl	R/f	TWI	TPI	R	Prc	Plc	Criteria weights (%)
Li	0.18	0.21	0.21	0.19	0.19	0.20	0.17	0.17	0.15	0.15	0.14	0.14	0.14	0.14	16.90
DR	0.12	0.14	0.16	0.15	0.15	0.16	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.12	13.60
Gm	0.09	0.09	0.10	0.12	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.10	0.10	10.70
HSG	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.08	0.09	0.09	0.09	0.09	8.10
LULC	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.08	0.09	0.09	0.09	0.09	8.10
LD	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.08	0.09	0.09	0.09	0.09	8.10
DD	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.07	0.06	0.07	0.07	0.07	0.07	6.00
Sl	0.06	0.05	0.05	0.05	0.05	0.04	0.06	0.06	0.07	0.06	0.07	0.07	0.07	0.07	5.90
R/f	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	4.50
TWI	0.05	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	4.40
TPI	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	3.40
R	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	3.40
Prc	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	3.40
Plc	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.03	0.03	3.50

recharge. Therefore, high rank was given to lower TPI value and low rank was given to higher TPI values.

Roughness map for GWPZ

Roughness map was assigned 3.4% weight according to AHP. In the roughness map, each sub-class, i.e., < 0.31, 0.32–0.44, 0.45—0.56, 0.57–0.68 and 0.69–0.89, was assigned ranks (i.e., from 1 to 9) as 9, 7, 5, 3 and 2, respectively. This was done by reclassify function in spatial analyst tool using ArcGIS software. The topography's undulation is often expressed by the roughness index. Roughness shows the linear relationship with undulation. Therefore, higher roughness implies higher surface runoff and low groundwater recharge. Roughness shows an inverse relationship with the recharge of groundwater. Hence, high rank was allocated

Table 5 Weight and rank of all thematic maps for GWPZ

Thematic map	% Weight	Feature classes	Sub-class rank	Normalized weight (%)	λ_{max}	CR
Lithology	16.9	Gravel Bed	9	50.3	5.2	0.05
		Laterite	7	26.0		
		Granite	5	13.4		
		Schist	3	6.8		
		Quartz	1	3.5		
Distance from river (m)	13.6	< 300	9	37.9	6.1	0.02
		301–600	8	24.9		
		601–900	7	16.0		
		901–1200	6	10.2		
		1201–1500	5	6.5		
		> 1500	4	4.3		
Geomorphology	10.7	Water Bodies	9	42.5	5.1	0.02
		Flood Plain	8	26.2		
		Alluvial Plain	7	16.3		
		Pediment Pediplain Complex	6	10.3		
		Hills and Valleys	2	4.7		
Hydrological soil group (HSG)	8.1	HSG A	9	55.8	4.1	0.04
		HSG B	7	26.3		
		HSG C	5	12.2		
		HSG D	3	5.7		
LULC	8.1	Wetlands / Water bodies	9	42.9	5.2	0.04
		Forests	8	27.9		
		Agricultural Land	7	18.6		
		Barren / Waste land	3	7.0		
		Built Up	2	3.6		
LD (km/km^2)	8.1	2.3–2.8	9	42.9	5.2	0.04
		1.7–2.2	8	27.9		
		1.2–1.6	7	18.6		
		0.51–1.1	4	7.0		
		< 0.5	2	3.6		
Drainage density (km/km^2)	6	< 0.9	9	45.9	6.3	0.04
		0.91–1.76	7	26.4		
		1.77–2.61	5	13.5		
		2.62–3.45	3	6.8		
		3.46–4.30	2	4.4		
		4.31–5.15	1	3.0		
Slope	5.9	Very Gently	9	50.5	5.2	0.05
		Gently	7	26.4		
		Moderately	5	14.1		
		Moderately Steep	2	5.4		
		Steep	1	3.6		
Rainfall (mm)	4.5	1627–1678	9	41.6	5.1	0.02
		1576–1626	8	26.2		
		1524–1575	7	16.1		
		1472–1523	6	9.9		
		1420–1471	5	6.2		
TWI	4.4	High	9	55.8	4.1	0.04
		Moderate	7	26.3		
		Low	5	12.2		
		Very low	3	5.7		

Table 5 (continued)

Thematic map	% Weight	Feature classes	Sub-class rank	Normalized weight (%)	λ_{max}	CR
TPI	3.4	(−9)–(−1.1)	9	50.4	5.2	0.04
		(−1)–(−0.29)	7	26.0		
		(−0.28)–(0.3)	5	13.2		
		(0.31)–(1.1)	3	6.2		
		(1.2)–(1.3)	2	4.2		
Roughness	3.4	<0.31	9	50.4	5.2	0.04
		0.32–0.44	7	26.0		
		0.45–0.56	5	13.2		
		0.57–0.68	3	6.2		
		0.69–0.89	2	4.2		
Profile curvature	3.4	Concave	7	63.3	3.0	0.03
		Flat	5	26.0		
		Convex	3	10.6		
Plan curvature	3.5	Concave	7	63.3	3.0	0.03
		Flat	5	26.0		
		Convex	3	10.6		

Fig. 17 Suitability map of GWPZ for Jamsholaghat

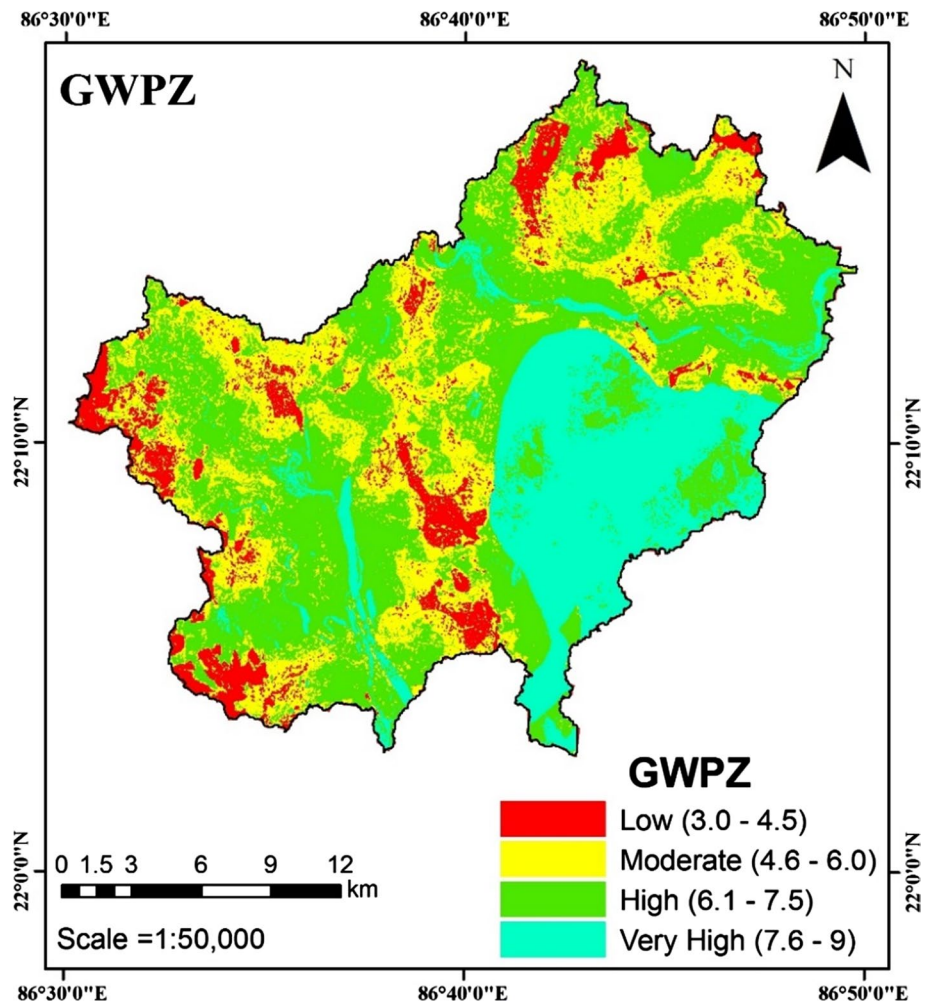**Table 6** Statistical analysis of map removal sensitivity analysis for GWPZ

Thematic map removed	Variation index (%)			
	Min	Max	Mean	SD
Lithology	0.38	5.63	3.22	0.86
Distance from River	0.24	5.38	3.02	0.81
Geomorphology	0.28	5.02	2.86	0.76
HSG	0.31	4.88	2.71	0.62
LULC	0.45	4.72	2.53	0.55
LD	0.68	4.21	2.34	0.51
DD	0.56	4.08	2.11	0.46
Slope	0.79	3.84	1.91	0.57
R/f	0.86	3.53	1.78	0.46
TWI	0.34	3.12	1.45	0.47
TPI	0.26	2.89	1.15	0.42
Roughness	0.77	2.61	0.92	0.31
Profile curvature	0.33	2.42	0.74	0.33
Plan curvature	0.39	2.36	0.62	0.29

Table 7 Statistical analysis of single parameter sensitivity analysis for GWPZ

Thematic map	Empirical Weight (%)	Effective weight (%)			
		Min	Max	Mean	SD
Lithology	16.9	6.8	56.9	25.1	10.9
Distance from River	13.6	5.5	43.1	19.6	8.4
Geomorphology	10.7	4.1	31.3	13.7	6.0
HSG	8.1	3.4	20.3	8.8	3.9
LULC	8.1	3.4	20.3	8.8	3.9
LD	8.1	3.4	20.3	8.8	3.9
DD	6.0	2.6	12.6	5.4	2.4
Slope	5.9	2.4	12.4	5.3	2.3
R/f	4.5	1.6	7.5	3.2	1.4
TWI	4.4	1.4	7.4	3.1	1.3
TPI	3.4	0.8	4.3	1.8	0.8
Roughness	3.4	0.8	4.3	1.8	0.8
Profile Curvature	3.4	0.8	4.3	1.8	0.8
Plan Curvature	3.5	0.9	4.4	1.8	0.9

to low roughness whereas low rank was allocated to high roughness.

Profile and plan curvature map for GWPZ

Profile and plan curvature map were assigned 3.4% and 3.5% weights according to AHP, respectively. For both profile and plan curvature maps, each sub-class, i.e., convex, flat and concave, was assigned ranks (i.e., from 1 to 9) as 3, 5 and 7, respectively. This was done by reclassify function in spatial

Table 8 Changes of the GWPZ with removal of the thematic map

Thematic Map	GWPZ (%)			
	Low	Moderate	High	Very High
Lithology	+42.2	−33.1	−16.6	−7.8
Distance from River	+30.5	+23.6	−13.4	−5.6
Geomorphology	+21.3	−15.7	−10.2	−3.7
HSG	+14.1	−9.8	−6.2	−0.9
LULC	+8.3	−7.6	−3.8	−0.7
LD	+18.0	−12.7	−9.3	−2.9
DD	−7.4	+1.9	+3.7	−1.5
Slope	+2.4	−2.3	−0.9	+2.0
R/f	+11.6	−9.0	−7.0	−2.3
TWI	+1.0	+2.0	−0.7	−1.5
TPI	−1.2	+2.8	+1.6	+3.0
Roughness	+3.0	−2.1	−1.3	−0.8
Profile Curvature	+1.5	−3.8	−1.7	−0.9
Plan Curvature	+1.6	−3.7	−1.5	−0.9

'+' indicates increased in area and '−' indicates decreased in area

analyst tool using ArcGIS software. In general, Water shows the deceleration trend toward the surface that is convex and accumulation trend toward the surface that is concave. Convex surface shows an inverse relationship with groundwater recharge whereas concave surface shows direct relationship with the recharge of groundwater. Therefore, higher rank was allocated to concave surface and lower rank was allocated to convex surface.

Suitability map of GWPZ

GWPZ map of the study area was prepared by overlaying Lithology, Slope, LULC, DD, LD, Distance from stream, Rainfall, HSG, Geomorphology, TWI, TPI, Profile/Plan Curvature, and Roughness maps in ArcGIS software by considering the weights as well as ranks given to all the 14 thematic maps and its sub-classes according to AHP. For weighted overlay method in ArcGIS, Eq. 10 was used.

$$
\begin{aligned}
GWPZ = &\ 0.169 \times \text{Lithology} + 0.136 \times \text{Distance from river} \\
&+ 0.107 \times \text{Geomorphology} + 0.081 \times \text{HSG} \\
&+ 0.081 \times \text{LULC} + 0.081 \times \text{LD} + 0.06 \times \text{DD} \\
&+ 0.059 \times \text{Slope} + 0.045 \times \text{Rainfall} \\
&+ 0.044 \times \text{TWI} + 0.034 \times \text{TPI} \\
&+ 0.034 \times \text{Roughness} + 0.034 \\
&\times \text{Profile Curvature} + 0.035 \\
&\times \text{Plan Curvature}
\end{aligned}
\tag{10}
$$

Fig. 18 Existing well over GWPZ for Jamsholaghat

ROC Curve
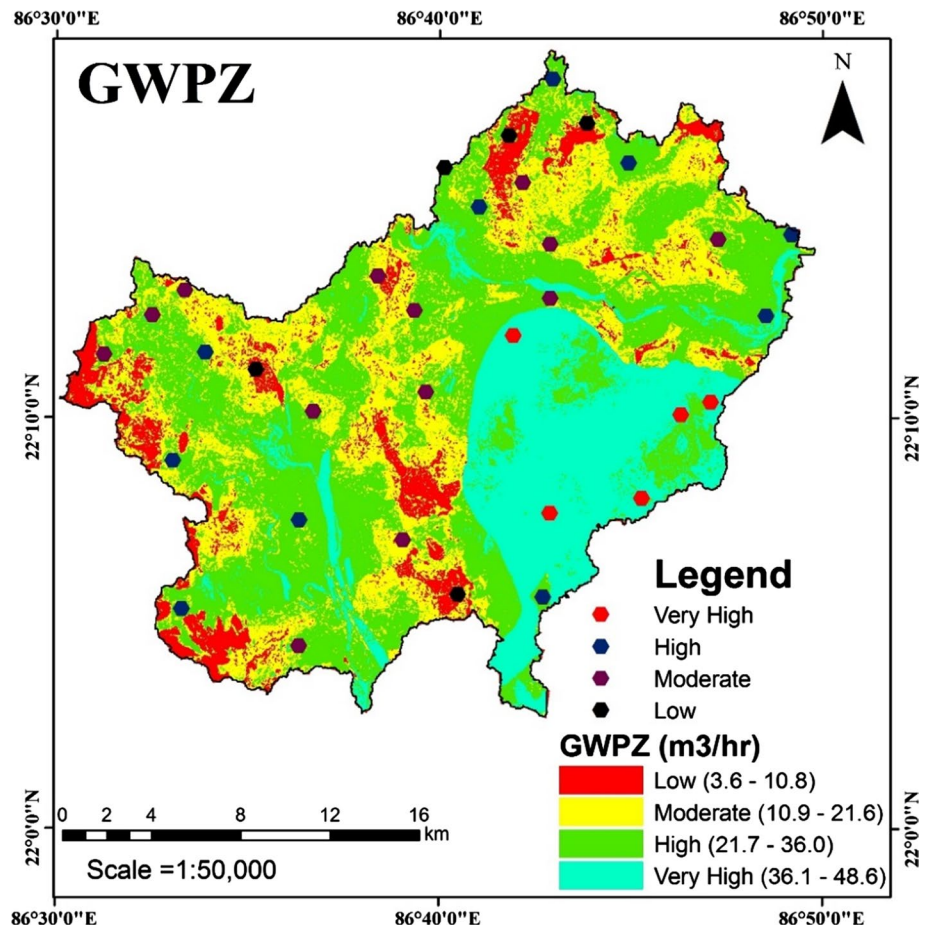
Fig. 19 Cross-validation of the GWPZ map using ROC Curve
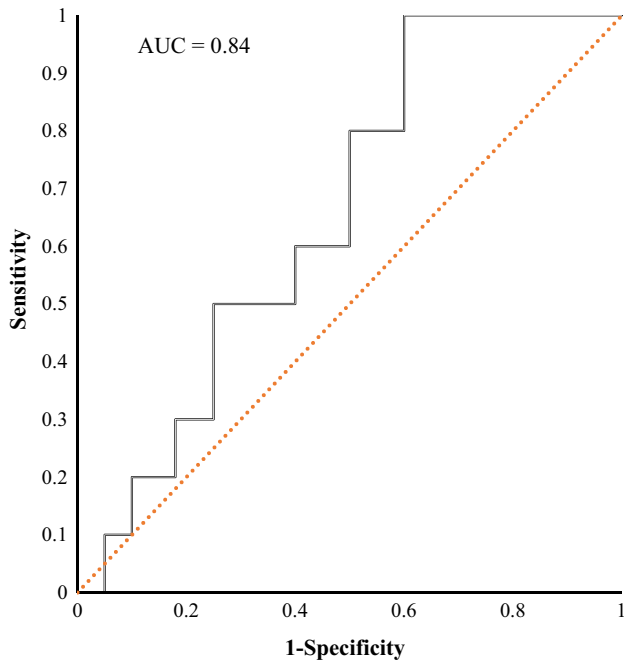
According to the GWPZ map, the Jamsholaghat sub-basin was categorized into four zones, i.e., very high, high, moderate and low GWPZ consisting of 22%, 45%, 26% and 7% of the Jamsholaghat sub-basin, respectively. Figure 17 shows the GWPZ prepared using all thematic maps.

From the Fig. 17, it was clear that 67% of the area consist of very high and high GWPZ categories. This was due to favorable conditions such as lithology (laterite and quartz), geomorphology (flood plain and water bodies), slope (very gentle and gentle), high/moderate rainfall, LULC (agricultural and forest) and high LD of the present research area, i.e., Jamsholaghat sub-basin. However, 33% of the area consist of moderate and low GWPZ categories. This was due to unfavorable conditions such as hills and valley, steep slope, low LD, and low rainfall.

Sensitivity analysis of GWPZ

Table 6 shows the estimation of map removal sensitivity analysis, whereas Table 7 shows the estimation of single parameter sensitivity analysis. From the Table 6, it was

clear that Lithology and distance from river maps have great impact followed by Geomorphology, HSG, LULC, LD and DD have moderate impact and Roughness and Curvature maps have lowest impact in GWPZ computation. The values of variation index were high upon elimination of lithology map after that distance from the river map, geomorphology map. It reveals that the lithology map has a significant impact on GWPZ of the present research area. Table 7 reveals the effective weight in percentage of all the thematic maps. The result shows that, higher the empirical weight higher the effective weight.

Table 8 reveals the changes in percentage of areas for different groups (i.e., Very high, high, moderate and low) of GWPZ after removing one thematic map at a time. The result reveals that exclusion of lithology map and distance from river map influences the GWPZ highly by increasing the low suitability area 42.5% and 30.5%, respectively. However, exclusion of TWI, TPI, Roughness and Curvature maps shows lower impact to GWPZ.

Validation of GWPZ

A total of 33 well yield data were collect in order to validate the GWPZ using ROC. Out of 33 wells, only 3 wells were shown disagreement to the GWPZ map generated using ArcGIS software. The existing well over GWPZ map is shown in Fig. 18. The well yield data was compared to the produced GWPZ map using SPSS software for the validation process. The cross-validation of GWPZ map using ROC curve is shown in Fig. 19. The Area Under the Curve (AUC) is a statistic that measures how effectively a parameter can differentiate among two groups. The AUC of the GWPZ map is 0.84, indicating that the AHP approach produced very accurate predictions.

Conclusion

In Jamsholaghat sub-basin flood and drought situation occurs often during monsoon and non-monsoon season due to heavy rainfall, high runoff, low infiltration and also due to lack of proper storage facility. In this study, an attempt was made in order to locate the GWPZ by considering combination of AHP, GIS approach and remote sensing. Important part of GWPZ was to locate the most suitable location thereby increasing water storage capacity in aquifer, improving the groundwater table and reducing the impact to environment due to drought during non-monsoon period. Numerous procedures exist, some were insufficient for a particular zones due to provincial conditions, time-consuming and others because of social and political problems.

However, use of GIS and remote sensing along with multi-collinearity check and AHP methods improves the accuracy of the output as well saves a lot of time.

Previously attempts were made in order to develop the GWPZ map (Agarwal et al. 2013; Abrams et al. 2018; Andualem and Demeke 2019; Çelik 2019; Murmu et al. 2019 and Kumar et al. 2020) but maximum of 10 number of thematic maps were used (Awawdeh et al. 2013; Fashae et al. 2014; Maity and Mandal 2017; Pinto et al. 2017; Gnanachandrasamy et al. 2018; Choubin et al. 2019; Raju et al. 2019; Al-Djazouli et al. 2020 and Koli et al., 2020). Final accuracy of the GWPZ map lies between 0.7 and 0.78 (Nijagunappa, 2011; Magesh et al. 2012; Fenta et al. 2014; Kaliraj et al. 2014; Yeh et al. 2016; Das et al. 2018; Kumar and Krishna 2018; Lakshmi and Reddy 2018; Nasir et al. 2018; Patra et al. 2018; Arulbalaji et al. 2019; Hutti and Jahan et al. 2019; Raju et al. 2019; Arshad et al. 2020; Benjmel et al. 2020) without considering the multicollinearity check and sensitivity analysis. However, inclusion of multicollinearity check as well as sensitivity analysis improves the accuracy of the thematic map up to 0.84.

The novelty of the present study was to consider multi-collinearity check and sensitivity analysis for GWPZ map. Furthermore, 14 thematic maps were being consider in order to delineate the GWPZ map. It was found that multicollinearity checks plays crucial role in selecting suitable locations as it checks uncertainty among the data hence, it increases the accuracy of the result. Sensitivity analysis shows the importance of each thematic map over others thereby validating the weights assigned using AHP to each thematic map.

Declarations

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