ORIGINAL ARTICLE

Groundwater potential zones delineation using GIS and AHP techniques in upper parts of Chemoga watershed, Ethiopia

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Abstract

Water is one of the most imperative needs and used for innumerable purpose. The needs of groundwater exploration have being increased due to the radical climatic changes, for continually increased population growth and a change of human lifestyle. GIS and AHP of multicriteria decision making are the most effective, applicable and logical approaches to delineate the groundwater potential zones in upper parts of Chemoga watershed. GIS and AHP are a 7 computer-based systems used to handle, store, manipulate, analyze and present geospatial data to resolve several complicated problems in the environment. Hence, the groundwater potential zone is delineated by overlaying the weights of ten influencing factors (lineament density, rainfall, geomorphology, Lithology, slope, drainage density, roughness, land use/land cover, depth to groundwater level and elevation) in ArcGIS platform under spatial analysis tool. All those influencing factors are selected on the bases of their contribution for the ground water recharge. Based on the findings of weighted overlay analysis, 11.1, 18.2, 47.1, 15.4 and 8.2% of the region depicted very good, good, moderately good, poor, very poor groundwater potential zones, respectively. The investigated groundwater potential sites have validated by seven existed borehole data and hence the study verified their close relationships. Out of seven boreholes, about 7–4 and 3–1 were found under very good to good and poor to very poor groundwater potential zones, respectively.

Keywords AHP · Influencing factors · Weighted overlay analysis · Groundwater potential zone · Borehole · Chemoga watershed · Ethiopia

Introduction

Water is one of the most vital naturally gifted resources to survive. Beside to the elixir of life, the day-to-day activities and the economic development of any country are absolutely depends on existence of water resource. However, about 71% of the planet Earth is occupied by Water body, 96.5% is saline water (ocean, seas and bays). The freshwater used for domestic purpose is accounted only 3.5 and 68% of it is presented on the surface in the form of ice and glaciers while the 30% is confined below the surface or found in aquifer materials in the form of groundwater and the remaining 2% is found in lake, ponds, stream and in the atmosphere (Shiklomanov 1993). Recently, almost all studies justified that surface freshwater scarcity is the most critical problem for most countries in the world. This is because of the number of complicated environmental problems such as the everlasting deforestation that has posed a serious climate change and drought; Surface water pollution by the wastes released and discharged from the rapidly expanded industries and urbanization; and the increased demand for the radically increased urbanization and industries. Therefore, all these factors strongly pushed to explore the other alternative groundwater resource for their demand and supply. So, currently it is the main source of water for domestic uses for most people in the world (Africa groundwater Atlas 2019) and is the most invaluable natural resources that support human health, economic development and ecological diversity (Sewnet et al. 2016).

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However, the groundwater occurrence and distribution are controlled by complicated observable and obscure/incomprehensible surface and subsurface influencing factors; most scholars (Oikonomidis et al. 2015; Senanayake et al. 2016, Anteneh et al. 2022, Melese and Belay 2022) are recommended to use advanced technologies in groundwater potential (GWP) zones mapping for an area of interest. So, the science of groundwater needs detailed understanding of the aquifer system, hydrology, ecology and physiographic conditions, surface and deep sited geological features (dykes, folds and their type, fault) using direct and indirect investigation and the integrated approaches geographic information system (GIS), remote sensing (RS) and analytical hierarchy processes (AHP) of multicriteria decision making (MCDM). In most parts of the country and specifically in the present study area, considerable numbers of boreholes drilled by the federal and regional government are poor well yield. This is because the boreholes were drilled without detailed investigation of surface and subsurface factors that controlled the occurrence of groundwater potential such as the climate, geology, hydrology, ecology and physiographical set up of the environment.

Therefore, for the needs of rapidly increasing population and urbanization, assessing potentially available groundwater resources by conducting effective technologies should be the core strategic policy for most countries in the world. Geological and geophysical techniques of GWP zone investigation were time consuming and costly. AHP with MCDM technique has become popular all over the world and applied in several fields of sciences to simplify complex/multifaceted problems, both concrete and abstract (Zewdie and Yeshanew 2023). Using integrated approaches of RS, GIS and AHP with MCDM are widely accepted and well suited for GWP zone demarcation. By its quality for producing repetitive, cost effective, comprehensive, feasible spatiotemporal and spectral data of extensive area quickly, it becomes an invaluable technique in delivering vital information regarding the different variables controlling groundwater occurrence (Aluko and Igwe 2017). It is powerful and effective method used by several scholars such as Anteneh et al. 2022; Arulbalaji et al. 2019; Patra et al. 2018; Singh et al. 2017; Panahi et al. 2017. The AHP of MCDM reduces ambiguities caused by broken down the complicated features of groundwater controlling factors, and the decision making elements had hieratically structured and the normalized weights of each element was determined to obtain a complete and clear picture of the objectives of this work with high confidence and certainty. In AHP the existed problems were defined, the pairwise comparison matrix was constructed, the Pairwise matrix normalized and gaining general priority (Asmare et al. 2023). For this study integrated approaches of RS, GIS and AHP of MCDM the AHP method of MCDM analysis of

10 thematic layers were used to map the GWP zone in the upper parts of Chemoga watershed.

Study area

The study is conducted at upper part of Chemoga watershed in Blue Nile basin, Northwestern part of Ethiopia. More specifically, it is bounded by UTM reading of 342,000–377,000 m E and 1,128,000–1,168,000 mN and covers an area of 1400 km^2. The study area is defined by multi spectral land features of plane land, mountainous, steep to gentle slope, ragged topography, dome and conical ridges are prominently observed surface land features. The topographic elevation ranges from 1509 to 3732 m a m s l (Fig. 1).

In multispectral land features of the highly elevated and steep catchment, gravity has assisted water to descent toward the river channel; conversely, in gently, sloping watersheds water has been trapped for prolonged lag times and increase infiltration rate to recharge the groundwater (Zewdie and Tesfa 2023).

The drainage structure of the study area shows dendritic pattern and the main river Chemoga has being derived from Choke mountain and has drained toward the south to feed the great Abay river. The climate condition of the study area varies from warm temperature to cool temperature, but generally gain better precipitation in the summer with an average annual rainfall and temperature of 1264 mm and 22 °C, respectively. In dry season (January–April) most of the water bodies such as streams, rivers and pond are dried due the combined impact/influences of drought (absence of rain fall), prolonged and uncontrolled motor pumps for domestic use, irrigation and construction purposes. Hence, in this season, the community is highly stressed for water resources.

Since agriculture is the primarily economic activity in the area, most parts of the catchment are intensively farmed/ploughed and cropland, grasslands, and shrubs are the prominent land use and land covers in the catchment. The economic activity is absolutely depends on mixed agricultural system. And hence, groundwater is highly required for domestic uses and irrigation purposes in the watershed.

Methods and materials

Due to the inconsistent nature of groundwater occurrences, briefly characterization of groundwater influencing factors and potential zones delineation using GIS and AHP is cost effective and significantly important to determine the appropriate locations of boreholes for the most feasible groundwater potential. This study intended to delineate GWP zone

Fig. 1 Location map
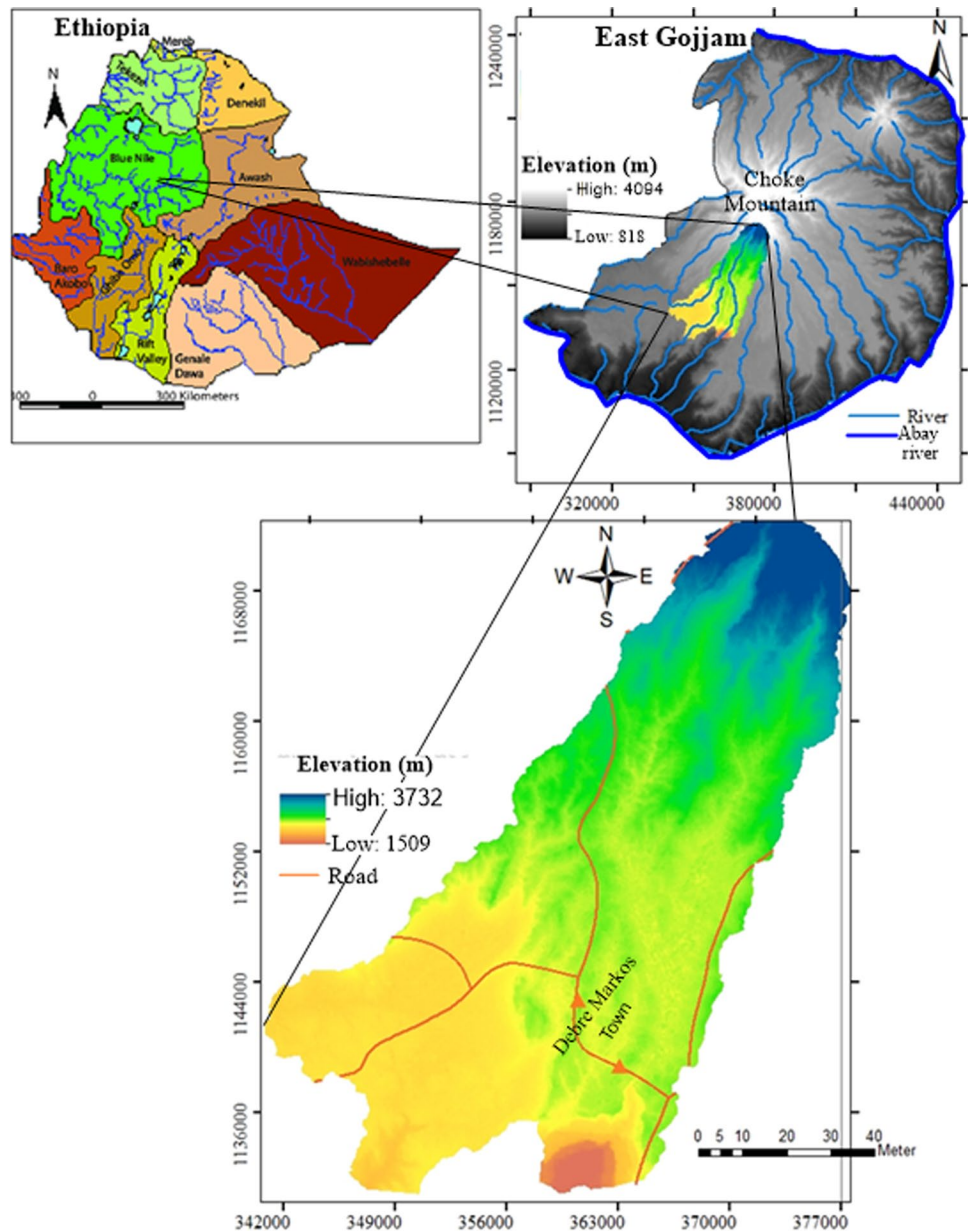
in the upper part of Chemoga River watershed using RS, GIS-based AHP of MCDM techniques by weighted overlay analysis of ten influencing factors for the occurrence and distribution of groundwater. The groundwater modeling map was created using a weighted index overlay analysis by adding the weighted values of each thematic layer and. it was validated by adding seven productive boreholes in ArcGIS plat form. The general procedures followed in this work were clearly illustrated as follow.

GIS-based AHP

The AHP of MCDM technique was initially developed by Saaty (1980) and has been used and provides a new scientific analysis in several field of sciences such as for suitable dam site and waste disposal site selection, natural hazard prediction, in marketing decision making process to simplify the multifaceted problems and make decisions in complex environments by properly organizing, structuring and evaluating the different thematic layers. MCDA has gotten its worldwide acceptance as effective technique because of its role in dealing with complicated decision problems (Agarwal and Garg 2016). AHP is a powerful and flexible tool for the quantitative and qualitative studies of multi-criteria challenges (Lyu et al. 2018). This technique is very important to extract critical data and to have deep insights for the subject matter and greatly helps to have better understanding for the existed research problem (Zewdie and Yeshanew 2023).

Presently RS and GIS-based AHP of MCDM is a new technology to delineate GWP zone across the world, and this is an effective and invaluable technique in delivering vital information concerning to the various controlling factors of groundwater occurrence and distribution. Currently, several scholars (Arulbalaji et al. 2019; Stanley Ikenna Ifediegwu 2021; Melese and Belay 2022; Anteneh et al. 2022) have being applied this method to minimize the problems raised by commonly used conventional groundwater exploration techniques of geological, hydrogeological and geophysical investigation in multifaceted aquifer system.

In this work, multi-criteria modeling were applied to investigation the GWP zone the upper parts of Chemoga watershed. Initially, the main controlling thematic layers (lineament density, rainfall, geomorphology, Lithology, slope, soil, drainage density, elevation, roughness, land use/land cover and depth to groundwater level) for the groundwater recharge were clearly understood, defined and structured based on the researchers' knowledge and previous studies. For the hierarchically formulated subjective parameters, numerical values were assigned for each thematic layer and to prioritize each environment, the relative impotency of each factor was calculated using pairwise comparison matrix. The weights were normalized to compute the eigenvectors, maximum Eigen values and consistency index (CI) and consistency ratios (CR) using (Eq. 1–5). This greatly helps to assess and understand for identification of complicated research problem. For the validation of the pairwise comparisons, the consistency index of each layer was checked. Then, the weight of the relative importance of each layer was overlaid, and the overall groundwater recharge zone map was produced using 10.5 version of ArcGIS software from 30 m DEM. The general flowchart of the study followed to achieve the proposed objectives was stipulated below (Fig. 2).

To obtain the layers and sub-layers of the governing factors for the groundwater occurrences and distribution, the values of each column in the pairwise matrix were added (Eq. 1)

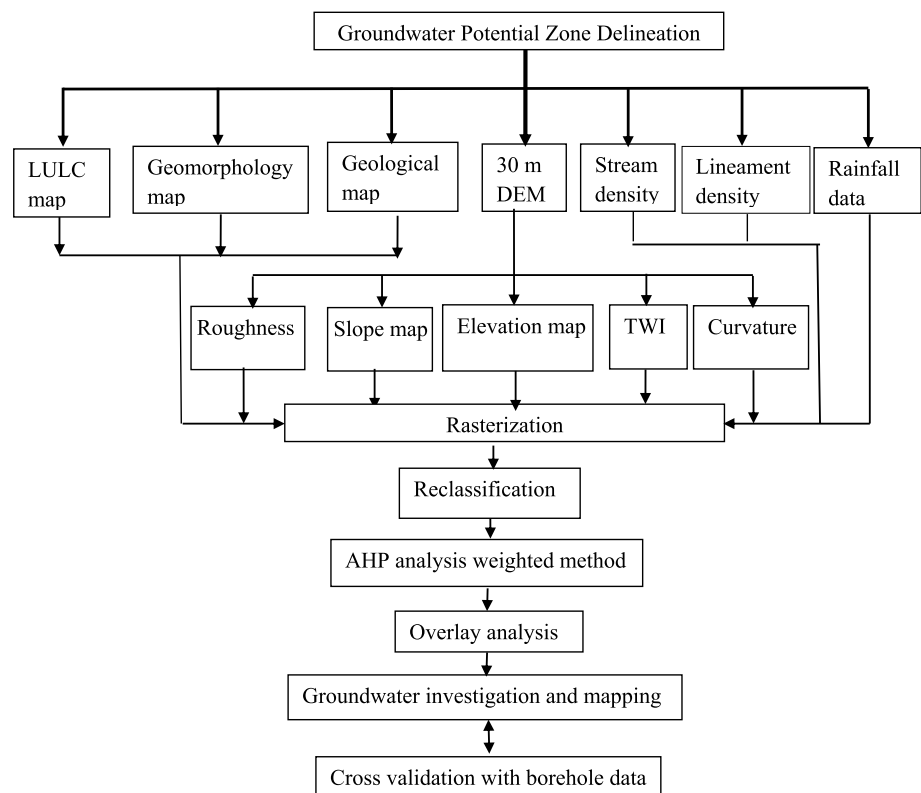$$L_{ij} = \sum_{j=1}^{n} a_{ij} \tag{1}$$

where a_{ij} = factor layer.

To produce the normalized pairwise matrix, each element in the row was divided by the sum of each column in the matrix (Eq. 2).

$$X_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

The standard/mean final weights of the factor layers were determined by dividing the sum of the normalized row of the matrix by the number of factor layers (N) using (Eq. 3).

Fig. 2 Flow chart

$$W_{ij} = \frac{\sum_{i=1}^{n} X_{ij}}{N} \tag{3}$$

CI also calculated using equation (Eq. 4):

$$CI = \frac{\lambda \max - n}{n - 1} \tag{4}$$

where λ max is the largest Eigen value and is calculated from the matrix, and n is the total number of thematic layers (Jazouli et al. 2019).

For each parameter, the degree of consistency/the coherence of this approach was checked and verified. This greatly helps to reconsider or revise the judgment to be consistent with the allowable degree (CR ≤ 10%) and never be a negative number, but for CR > 10% is inconsistent and needs further amendment of subjective judgment for consistency (Eq. 5):

$$CR = \frac{CI}{RI} \tag{5}$$

where CI and RI are the consistency and random consistency indexes that depends on the size of pairwise comparison matrix (number of elements being compared) and determined from (Saaty, 1977) standard using the table below (Table 1).

All the factors that control the groundwater occurrences and distribution were compared with one another in relation to their relative importance for selecting the best mode using the standard scales of Saaty 1980 with 9 levels of intensity (Table 2).

Most of the maps were extracted from a spatial resolution of 30 m a DEM and was obtained from Ethiopian Geological Survey. To prepare the GWP map, the calculated weights of each thematic layer were multiplied by the rates of classes. The influencing factors/thematic layers were added and

overlaid with weighted linear combination (WLC) techniques. The mathematical equation formulated by (Musa et al. 2000; Sener et al. 2005; Anteneh 2022) was used to compute GWP using WLC technique Eq. 6.

$$GWP = \sum_{i=1}^{n} W_i R_i \tag{6}$$

where GWP is groundwater potential, W_i is weight for each thematic layer, and R_i rates for the classes within a thematic layer derived from AHP.

Moreover, the secondary collected data from seven existed boreholes and hand dug wells were used to determine depth to groundwater level of the study area. To prepare the groundwater level thematic layer, the spatially referenced groundwater level data were imported and interpolated using IDW technique.

Sensitivity analysis

For this analysis, the techniques used by (Lodwick et al. 1990, and Fabbri 1996) were applied to generate permissible GWP map and this analysis computes the degree of variation and effectiveness of the influencing factors to the generated GWP map. The technique was performed by removing one or more input data (groundwater influencing factors) and creates a new GWP map by overlaying the remaining thematic layers in each time and provides essential evidence on the influences of weights assigned to each thematic layer. The technique is mainly concerned in validating the importance of the parameters in appraising the GWP condition and greatly helped to recognize the most/least important thematic layer (s) in the execution of GWP map. It was carried out to determine the impacts of each thematic layer on the GWP map of an analytical modeling. The map removal

Table 1 Random index values (Saaty 1977)

Matrix size (n)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 2 Fundamental scales of AHP Saaty 1980

Intensity of importance	Definition	Expression
1	Equally importance	Two activities equally contributed to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgment	When compromise is needed

sensitivity analysis was performed using sensitivity index equation applied by Gogu et al. (2000); Anteneh et al. (2022) Eq. 7:

$$Si = \frac{GWP - GWP'}{GWP} \times 100 \qquad (7)$$

where S is sensitivity analysis index due to removal of one map; GWP is the original GWP index obtained by computing all the thematic layers; GWP′ is the GWP index found by excluding one thematic layer at a time; N and n are the respective number of thematic layers used to calculate GWP and GWP′. Sensitivity analysis of a single parameter was realized to examine the impact of each parameter on the GWP value. In this technique, the actual weight of each factor was compared with theoretical or assigned weight. The effective weight of each parameter was computed using e the equation given below (Napolitano and Fabbri 1996):

$$W = \frac{RW}{GWP} \qquad (8)$$

where W, R, W and GWP are the effective weight of each influencing factor, rates, weights of the parameters and groundwater potential index, respectively.

Data sources

A number of various formats of important primary and subordinate data were collected from various sources (Table 3) and were imported, processed and analyzed in ArcGIS software to produce different maps of the influencing factors for groundwater occurrences and distribution in the catchment.

Result and discussion

All the relevant data to delineate groundwater potential zone were added, processed, rasterized and resembled into 30 m pixel size to create the overlay analysis of each model in ArcGIS platform. Applying the integrated approaches of RS, GIS-based AHP with MCDA of the thematic layers and weight determinations and provides composite GWP model

map. On the bases of researchers' expert, judgment and previous studies, the subjectively and obviously set controlling parameters for the GWP zone mapping were hierarchically formulated in the matrix and changed into numerical values to obtain the relative impotency (rating) of each thematic layer for the generation of the suitability modeling map of GWP zone in the area (Table 4). The pairwise comparison matrix of the ten influencing factors for the GWP zone mapping and their corresponding weights were determined and vary from 41.6 (highest) to 3.2 (lowest). Weights of the remaining parameters were set between these weighted values as shown below in (Table 4). The weight of each parameter was given on the bases of their relative importance for groundwater occurrence and the number of feature in each thematic layer. Accordingly Saaty (1980), the CR values were checked for the acceptance of their pairwise comparison matrix of the thematic layers.

Each governing factor for the GWP zone mapping was discussed in detail as follow.

Rainfall

Rainfall is the most important water source in the hydrological cycle and the primarily leading factor in the groundwater of an area (Arulbalaji et al. 2019). It is one of the essential hydrologic variables to recharge the groundwater (Murmu et al. 2019; Kotchoni et al. 2019; Kaur et al. 2020), and the amount of groundwater recharge is deeply depending on the intensity and duration of the rainfall in the catchment. The amount of precipitation is generally controlled by the combined factors of elevation, aspect, land use and other climatic variables of the area and hence, northern parts of the area is characterized by high elevation, afforested and gain better precipitation.

For this study, from 2011 to 2020, rainfall recorded data was used. To produce the precipitation map of the watershed, the inverse distance weight was interpolated in ArcGIS platform under spatial analysis tool and the annual rainfall which varies from 275 to 300 mm per year was reclassified into six classes (Fig. 3). Rainfall has direct relationship to GWP. The more rainfall in the area is the more percolation and infiltration to recharge the ground water zone. Hence, in

Table 3 Data types and their sources

Data type	Original format sources	Spatial resolution	Source of data
Borehole data	–	–	Amhara water and energy bureau
LULC	Vector	10 m	Karra Kontgis et al. (2021)
DEM	Raster	30 m	Ethiopian geological survey
Geological map	Vector	1:250,000	Ethiopian geological survey
Rainfall data	Point	–	From the free download through the link given https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.06/

Table 4 Pairwise comparison matrix of 10 thematic layers and their local and average weight

Factors	Features	Local weight	Average weight
Rainfall	3000–2935	41.6	20
	2935–2892	26.2	
	2892–2853	16.1	
	2853–2813	9.9	
	2813–2757	6.2	
Land use	Open water	35	14.3
	Forest	23.7	
	Shrub	15.9	
	Cropland	10.6	
	Grassland	7	
	Bare area	4.6	
	Built area	3.2	
Drainage density (km^{-1})	Dd < 0.92	41.6	20
	0.92–1.88	26.2	
	1.88–2.92	16.1	
	2.92–4.34	9.9	
	Dd > 4.34	6.2	
Lithology	Alluvium soil	35	14.3
	Eluvium soil	23.7	
	Sandstone	15.9	
	Pyroclastic rock	10.6	
	Upper basalt	7	
	Middle basalt	4.6	
	Lower basalt	3.2	
Slope (%)	S < 5	41.6	20
	5–12	26.2	
	12–20	16.1	
	20–34	9.9	
	$S > 34$	6.2	
Water level (m)	$d < 12$	37.9	16.6
	12–21	24.9	
	21–30	16	
	30–40	10.2	
	40–49	6.5	
	49–58	4.3	
TPI	TPI < −27	41.6	20
	−27–(−7)	26.2	
	−7–7	16.1	
	7–27	9.9	
	27–134	6.2	
Lineament density (km^{-1})	1.82–1.46	41.6	20
	1.46–1.09	26.2	
	1.09–0.73	16.1	
	0.73–0.36	9.9	
	Ld < 0.36	6.2	
Curvature	$C > 25$	41.6	20
	25–7	26.2	
	7–(−8)	16.1	
	−8–(−26)	9.9	
	C < −26	6.2	

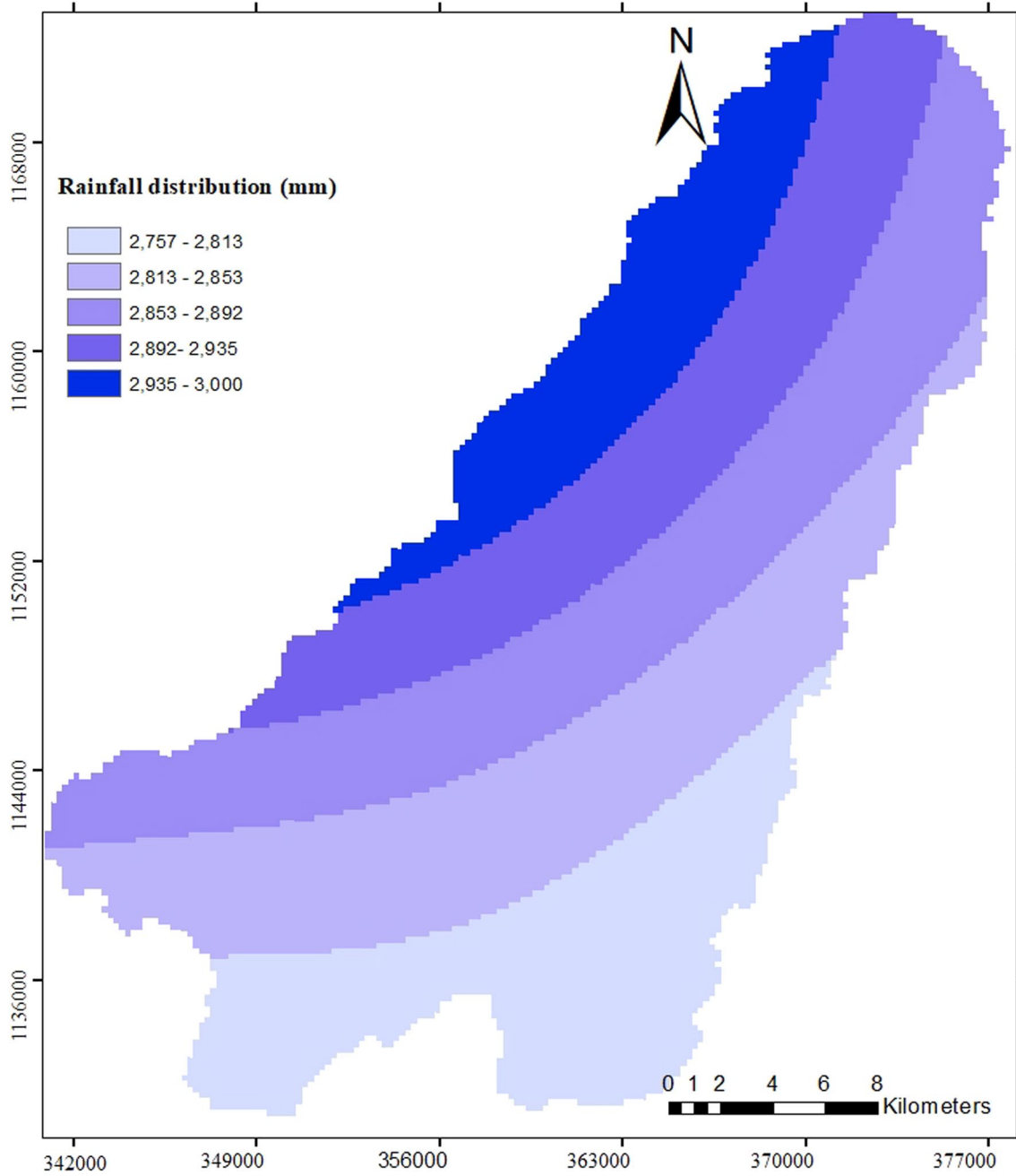| Table 4 (continued)	Factors	Features	Local weight	Average weight
	Geomorphology	Lowland	41.6	20
		Plane land	26.2	
		Plateau	16.1	
		Linear ridge	9.9	
		Hills	6.2	

Fig. 3 Rainfall distribution map

the pairwise comparison matrix analysis, the highest weight is given to the highest rainfall value and vice versa (Table 5).

Geology

The spatial distribution, occurrence and quality of groundwater is greatly influenced by the characteristics of the prominent lithological formation in the area of interest. The rate of percolation is greatly influenced by the size of pore space, the interconnectedness and porosity of the lithological or soil units. The precipitated water is infiltrated and percolated down through the pore spaces of porous and pervious geological materials, and along joints and bedding planes within the rock. In the area of such lithologic formations, lack of surface drainage and high rates of infiltration are common conditions. Moreover, the quality of groundwater is highly affected by the soil and rock composition through which groundwater has circulated.

The groundwater occurrence and quality was governed by the interconnected interaction of lithology characteristics, land use, topography, and climate conditions of the catchment. The plane lands captured and retained the runoff water and flood from poorly cultivated and sloppy surface and enhance rate of water infiltration. As briefly explained by some scholars (Naghibi et al. (2017) Koïta et al. (2018), Yohannes Mesele and Abraham Mechal 2020) due to deep occurrence and purifying nature of the overlying geological material, groundwater is less susceptible to contamination than surface water and is considered the safest and reliable water resource for domestic, irrigation, and industrial uses.

From the Ethiopian geological Survey data, in the watershed, seven units of lithological features have identified (alluvium soil, Eluvium soil, pyroclastic rock, upper basalt, middle basalt, lower basalt and Sandstone (Fig. 4a and b).

Due to its recent deposits, the quaternary alluvium has good potential, and has better permeability and productivity (Kebede 2013). Similarly, highly fractured rocks could yield a good amount of water. Conversely, massive and fresh lithological units have low hydraulic transmissivity, conductivity, storativity and yields. To each lithologic unit, Weights were given on the basis of importance for groundwater occurrence and hydraulic properties such

as hydraulic transmissivity, conductivity, storativity and yields observed from pumping test (Table 6). So, from field observation, researchers' expert, previously published papers and general understanding of the properties of the lithologic units, the higher and lower rank is provided for the Alluvium soil and lower basalt, respectively.

LU/LC

Surface and subsurface conditions (soil erosion, soil moisture, soil fertility, surface run off, infiltration, interception, evapotranspiration and other entities) are intensively affected by the land use and cover of the area. A number of scholars such as Berhanu and Hatiye (2020), Kaur et al. (2020), Ibrahim Bathis and Ahmed (2016), Jasrotia et al. (2016) verified that land use and cover plays a significant role for the groundwater occurrences in a certain area. The land use and land cover map of the present study area was extracted from Ethiopia sentinel 2 with 10 m resolution from the free download link https://livingatlas.arcgis.com/landcover/uploaded by (Karra Kontgis et al. 2021). The tiff data were clipped based on area of interest and processed in Arc GIS software to determine the area or percentage coverage of each land use using ArcGIS platform Hence, six land use types have identified in the area and their spatial extent is clearly determined as cultivated land (80.9%), forest (9.1%), grassland (9.1%), built up (0.43%), shrubs (0.4%), open water and bare areas accounted (0.08%) (Fig. 5). The highest proportion (80.9%) of the catchment is comprised by cultivated land and the intensive agriculture impact lead to soil erosion, moisture release, and less infiltration rates. The relative weight of pairwise comparison matrix was given accordingly their order of importance for the occurrence of groundwater (Table 7). Properly managed and cultivated lands, forest and vegetated lands greatly reduce run off. Water is retained for a long time and enhance rate of infiltration in those areas. Hence, high rate of weights is assigned for them. Conversely, bare area, poorly managed and cultivated lands enhance runoff in the catchment, and hence, low rate of weights is assigned for them.

Table 5 Normalized weight and comparison matrix of rainfall

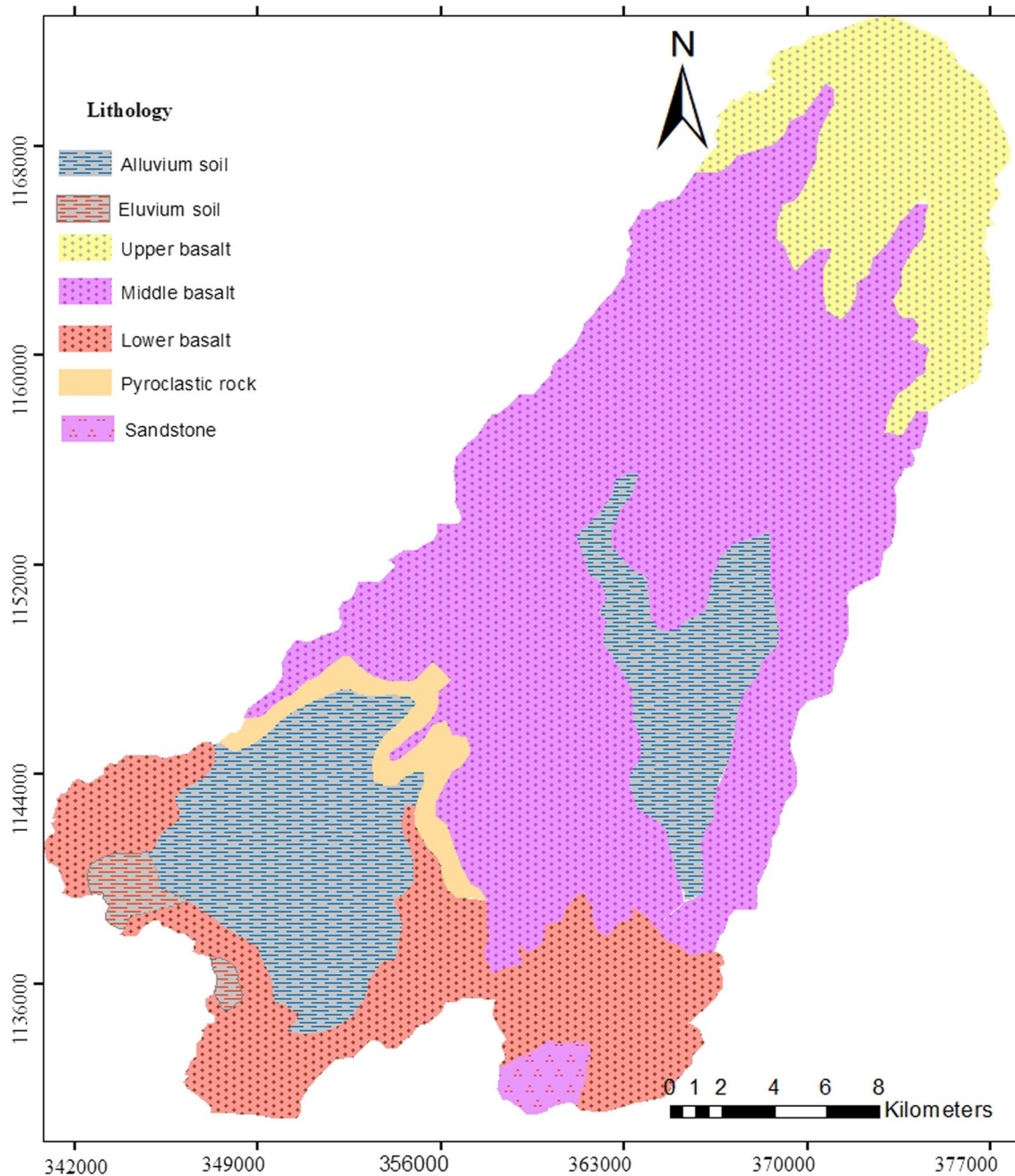| Rainfall (mm)	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] 3000–2935	1	2	3	4	5	41.62	1
[2] 2935–2892	0.5	1	2	3	4	26.18	2
[3] 2892–2853	0.33	0.50	1.00	2	3	16.11	3
[4] 2853–2813	0.25	0.33	0.50	1	2	9.86	4
[5] 2813–2757	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is			
5	1.12	0.023	0.02	acceptable			

Fig. 4 Lithological map

Stream density

The drainage pattern is governed by the geological landforms and geological structures of the catchment. The dendritic and parallel drainage patterns that are developed in the area are the effects of the existence of weak geologic formations, the parallelly aligned ridges and geologic structures.

Drainage density is inversely related to permeability and indirect indicator for GWP (Agarwal and Garg 2016; Rajaveni et al. 2017; Patra et al. 2018). The higher drainage

density value, the lower the infiltration rate and hence, the groundwater is not much predicted in the area conversely low drainage density represents high infiltration and hence contributes more to the groundwater potential (Arulbalaji et al. 2019). After the stream networked data were clipped based on area of interest, the drainage density map was prepared using line density at spatial analysis tool under arc toolbox in ArcGIS platform. The drainage density map was generated dividing the sum of total stream length by the area of the catchment in km^2 in the software. Based on the

Table 6 Normalized weight and comparison matrix of lithologic formation

Lithology	[1]	[2]	[3]	[4]	[5]	[6]	[7]	Rate	Rank
[1] Alluvium soil	1	2	3	4	5	6	7	35.04	1
[2] Eluvium soil	0.5	1	2	3	4	5	6	23.75	2
[3] Sandstone	0.33	0.5	1	2	3	4	5	15.90	3
[4] Pyroclastic rock	0.25	0.33	0.5	1	2	3	4	10.56	4
[5] Upper basalt	0.20	0.25	0.33	0.5	1	2	3	6.96	5
[6] Middle basalt	0.17	0.20	0.25	0.33	0.5	1	2	4.62	6
[7] Lower basalt	0.14	0.17	0.2	0.25	0.33	0.5	1	3.18	7
N	RI	CI	CR	CR < 0.1, therefore, it is acceptable					
7	1.32	0.046	0.035						

findings, high drainage density is recorded in the lower parts of some selected areas and in this area the infiltration capacity of the soil formation is low and groundwater depletion is highly expected. The drainage density was grouped into five classes. Accordingly, the importance drainage density for the groundwater occurrence and distribution, the higher and the lower weights (41.62 and 6.24) were given for the lower and higher drainage density value (Dd < 0.92 and 4.34) (Table 8 and Fig. 6).

Lineament density (Ld)

Largely extended faults and joint systems are responsible for the occurrence of GW and very important for local (perched) aquifer system recharge. Lineaments are structurally controlled linear or curvilinear geological features that represent faulting and fracturing zone developed when the geologic formation is subjected for external pressure and in increased secondary porosity and permeability. They have a significant role for groundwater occurrence and circulation. The water movement between surface and subsurface is controlled by dykes and faults (Ahmed and Sajjad 2018). Hammouri et al. (2012); Fashae et al. (2014) and Bhuvaneswaran et al. (2015) certified that an increasing in lineament density enhance the groundwater potential zone. The lineament density of the present study area was varied from 0.00 to 1.82 and classified into 5 classes. The relative weights of pairwise comparison matrix were given accordingly their order of importance for the occurrence and movement of groundwater and hence, the higher and the lower weights (41.62 and 6.24) were given for the values of Ld 1.09–1.82 and Ld < 0.22, respectively (Table 9 and Fig. 7). High lineament density is commonly observed in the upper parts of the catchment, and it is determined as a recharge zone for the groundwater zone.

Slope

Slope is a crucial factor in controlling groundwater recharge in an area of interest. Steep slope results in high runoff and erosion of surface soil and significantly reduces the groundwater recharge potential. Conversely gentle surface slope allows water to flow very slowly and provide adequate time to infiltrate into the soil and significantly increases the groundwater recharge potential (Ibrahim Bathis 2016; Rajaveni et al. 2017) and high weights are assigned to gentle to nearly level slope (Table 10). Hence, as clearly underlined by a number of scholars such as Oikonomidis et al. (2015), Patra et al. (2018) and Kaur et al. (2020), slope has inverse relationship to the GWP. In ArcGIS platform, slope map could be prepared from DEM data by percent or degree. For the present study area, the slope map was produced by percent using slope icon at surface tool under the spatial analysis tool in the Arc toolbox using 30 m resolution. The classification and their extent are clearly depicted as shown below (Fig. 8). By considering only this parameter, the most upper parts of the catchment posses steep slope, and hence, in the area, high runoff is highly expected, Based on the previous studies and researcher judgments, the weights and rank of the pairwise comparison matrix each slope class was ordered accordingly their importance for the occurrence of groundwater (Table 10).

Depth to groundwater level

Generally the groundwater level is governed by the spatiotemporal variations. For the existed boreholes and hand dug well continuous measurement data, the groundwater level is highly dynamic for both unconfined and confined aquifer. For unconfined aquifer, the depth to water table is very close to the surface during heavy rainfall season (June–November) and relatively deep in the dry season (December–May). The depth to groundwater level map was produced by interpolating 7 groundwater level data using IDW interpolation techniques in ArcGIS platform under spatial analysis tool, and it varies from 3 to 58 m below the surface. The relative weights and rank of the pairwise comparison matrix were given accordingly their order of importance for the occurrence of groundwater (Table 11). Hence, the lowest depth to
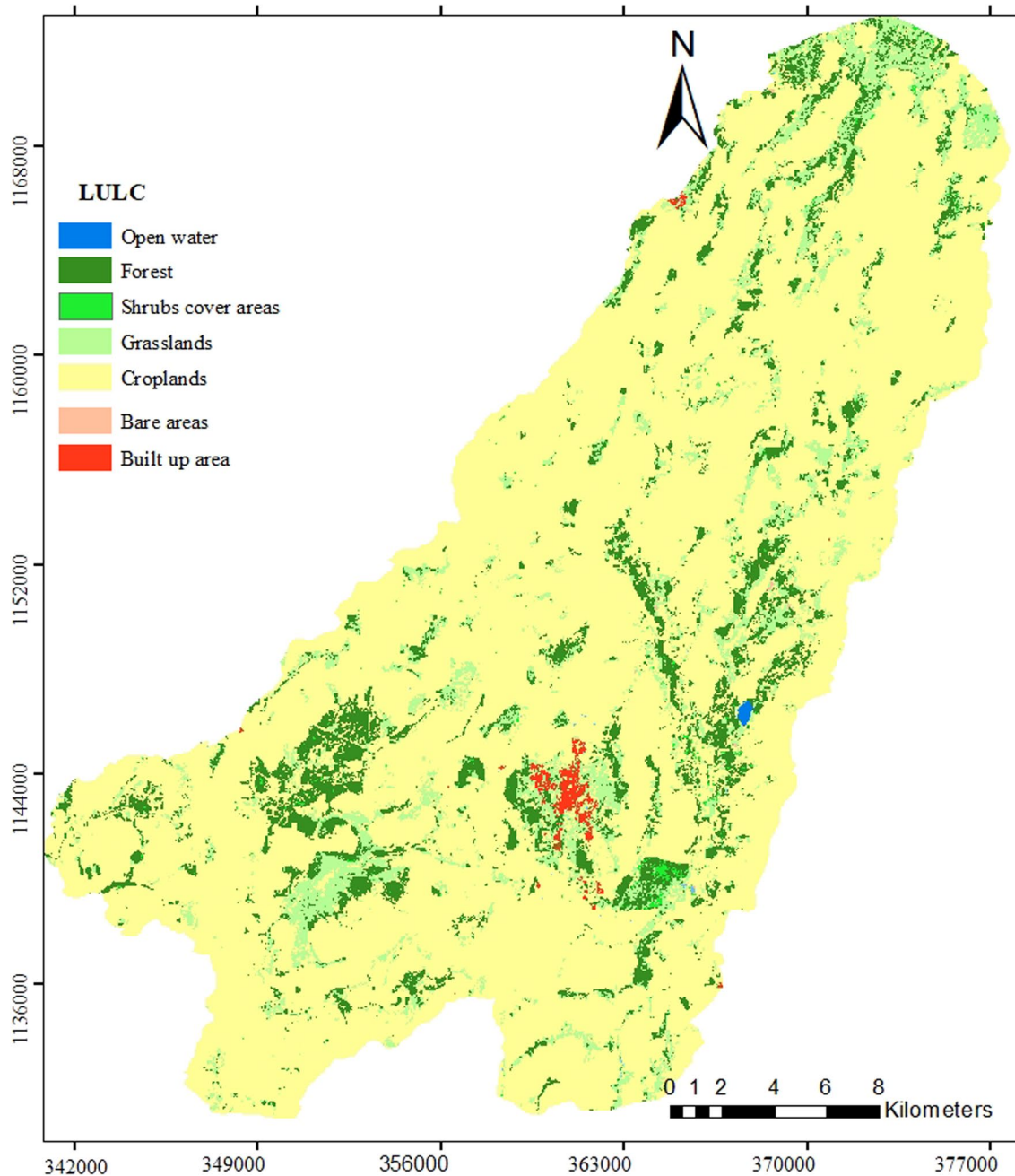
Fig. 5 LULC map

groundwater level (d < 12 m) refers to high GWP and vice versa (Fig. 9.)

Geomorphology

The study area is characterized by multi spectral land features developed by intensive and complex interactions among different geologic and tectonic events. The geomorphologic set up of an area plays a significant role for the occurrence, distribution and movement of groundwater (Patra et al. 2018).

The different geomorphological units identified in the present study area were produced in geomorphological map using Arc-GIS platform. Planes, lowlands, plateau, linear ridges and hills (steep rock faces) are the most prominent elements of geomorphological features in the area. The identified geomorphological features were properly aligned with the existing understanding of the study area's geological and tectonic history. Lowland plane land and plateau are the most prominent surface features that preserved all over the catchment while hills and linear ridges were observed in upper and lower sections

Table 7 Normalized weight and comparison matrix of LULC

Land use	[1]	[2]	[3]	[4]	[5]	[6]	[7]	Rate	Rank
[1] Open water	1	2	3	4	5	6	7	35.04	1
[2] Forest	0.5	1	2	3	4	5	6	23.75	2
[3] Shrub	0.33	0.5	1	2	3	4	5	15.90	3
[4] Cropland	0.25	0.33	0.5	1	2	3	4	10.56	4
[5] Grassland	0.20	0.25	0.33	0.5	1	2	3	6.96	5
[6] Bare area	0.17	0.20	0.25	0.33	0.5	1	2	4.62	6
[7] Built area	0.14	0.17	0.2	0.25	0.33	0.5	1	3.18	7
N	RI	CI	CR	CR < 0.1, therefore, it is acceptable					
7	1.32	0.046	0.035						

Table 8 Normalized weight and comparison matrix of stream density (Dd)

Drainage density (km^{-1})	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] Dd < 0.92	1	2	3	4	5	41.62	1
[2] 0.92–1.88	0.50	1	2	3	4	26.18	2
[3] 1.88–2.92	0.33	0.50	1	2	3	16.11	3
[4] 2.92–4.34	0.25	0.33	0.50	1	2	9.86	4
[5] Dd > 4.34	0.20	0.25	0.33	0.50	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, it is acceptable			
5	1.12	0.023	0.02				

of the proposed area (Fig. 10). In this process, those features were identified and delineated based on remote sensing data and field observations. The relative weights and rank of the pairwise comparison matrix were given accordingly their order of importance for the occurrence of groundwater. Lowlands and plane lands offer long resident time which greatly enhance rate of percolation and infiltrations and assigned high rating values (41.62–26.18) (Table 12). While hills, linear ridges and highly elevated areas posses high runoff and has no significant role for the occurrence of groundwater and hence offered by the lowest weights.

Roughness

The multispectral land features play an important role for continuous surficial processes. The topographic undulation or the amount of elevation difference between adjacent cells of the digital elevation model (DEM) of a certain area is defined by roughness. The area with high roughness promotes high flooding or runoff whereas the areas with low roughness uphold the runoff water and infiltrate or percolate to feed the groundwater.

The topographic roughness index is quantified using the formula initially developed by Guisan et al. (1999).

$$TRI = \frac{Focal\ mean - Focal\ min}{Focal\ max - Focal\ min} \tag{9}$$

The roughness map of the Chemoga catchment was varied from 0.11 to 0.89 and reclassified into 5 classes (Fig. 11)

For each roughness class, the relative weights were given based on the groundwater contribution, i.e., high weights are assigned for low roughness value and vice versa (Table 13).

Compound topographic index/topographic wetness index (TWI).

The overall hydrological processes and the water infiltration of a certain catchment are greatly affected by the topographic characteristics of the area. Hence, TWI is mostly used to compute topographic control on hydrological processes and reflects the potential groundwater infiltration caused by topographic effects (Mokarram et al. 2015). The TWI map of the present study area was prepared using TOPMODEL. The model was initially developed by Beven (1997) and stimulates the hydrologic fluxes of water throughout watershed. The TWI can be quantified applying the equation given below (Eq. 10).

DEM → Fill → Fill direction → Flow accumulation → slope in degree → Radian of slope = (slope*1.570796)/90 → Tan slope = con (slope > 0, tan (slope) 0.001) → flow accumulation scaled = (flow accumulation + 1*cell size = TWI = ln (flow accumulation scaled/tan slope)

$$TWI = \ln\left(\frac{\alpha}{\tan\beta}\right) \tag{10}$$

α = Upslope contributing area; β = Topographic gradient. The TWI values of the study area were varied from − 17 to 10 and reclassified into 5 classes. For this analysis, the
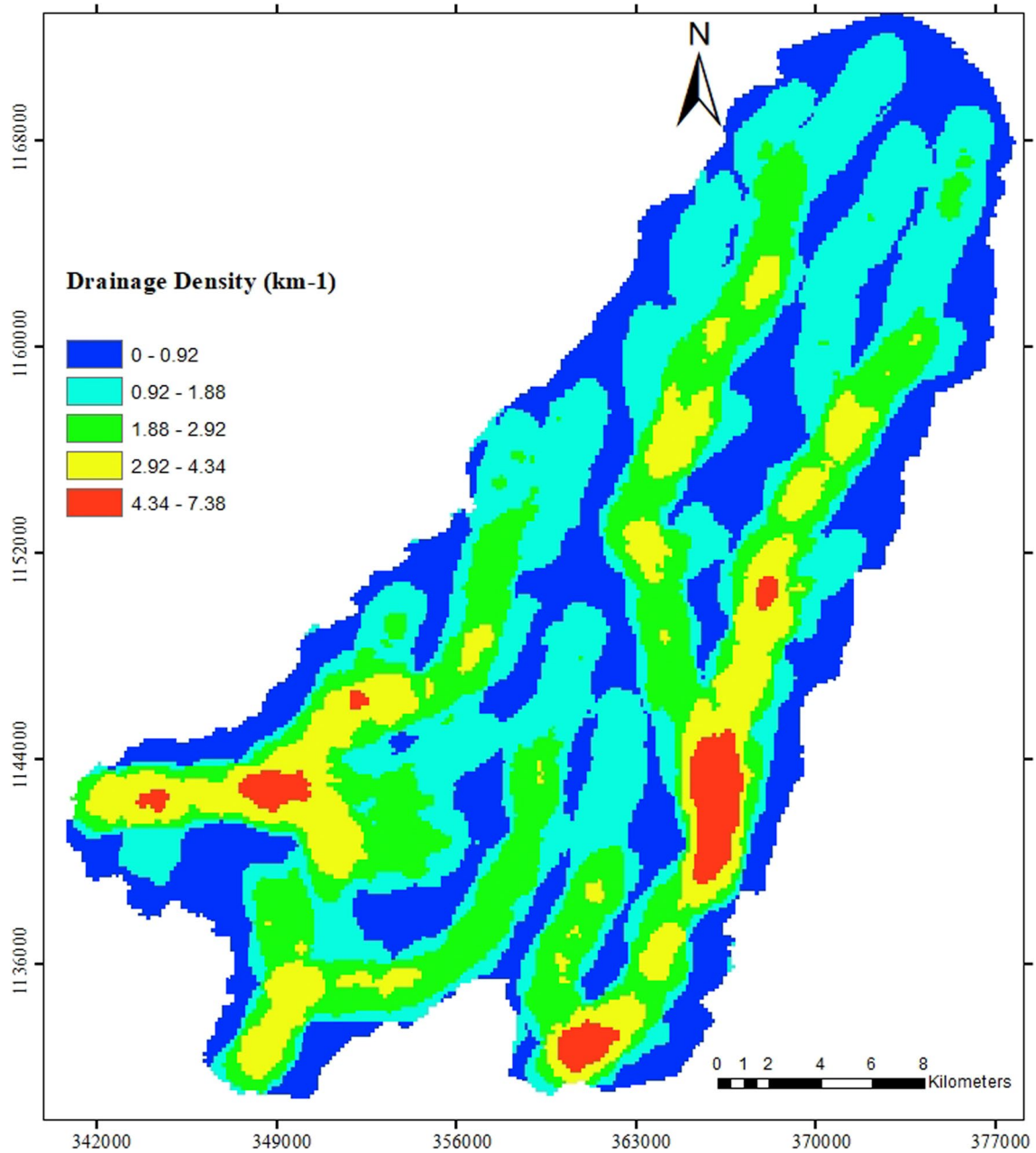
Fig. 6 Drainage density map

Table 9 Normalized weight and comparison matrix of lineament density

Lineament density (km^{-1})	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] 1.09–1.82	1	2	3	4	5	41.62	1
[2] 0.79–1.09	0.5	1	2	3	4	26.18	2
[3] 0.54–0.79	0.33	0.50	1.00	2	3	16.11	3
[4] 0.22–0.54	0.25	0.33	0.50	1	2	9.86	4
[5] Ld < 0.22	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, it is acceptable			
5	1.12	0.023	0.02				
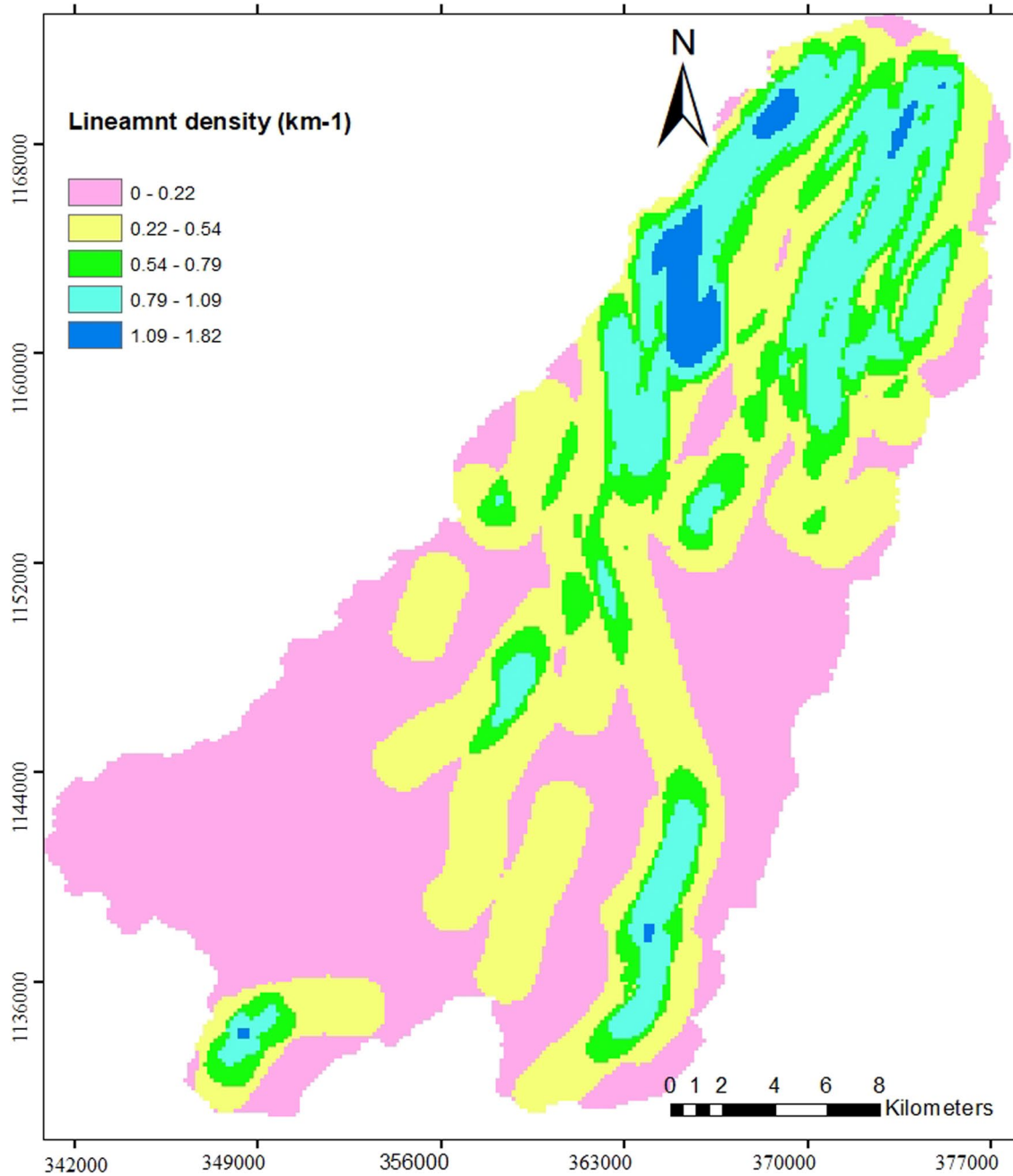
Fig. 7 Lineament density map

Table 10 Normalized weight and comparison matrix of the slope

Slope (%)	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] $S < 5$	1	2	3	4	5	41.62	1
[2] 5–12	0.5	1	2	3	4	26.18	2
[3] 12–20	0.33	0.50	1.00	2	3	16.11	3
[4] 20–34	0.25	0.33	0.50	1	2	9.86	4
[5] $S > 34$	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is acceptable			
5	1.12	0.023	0.02				
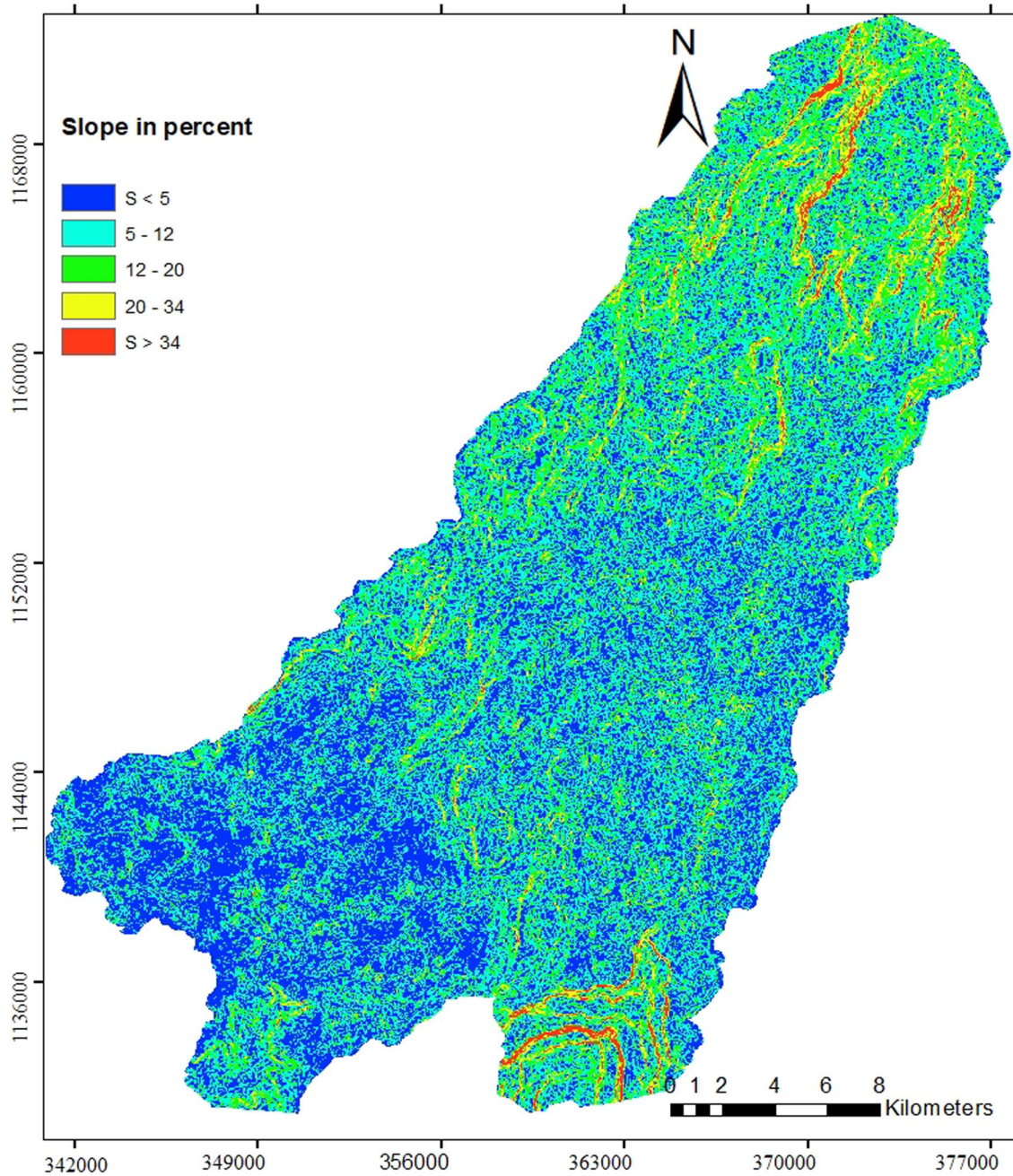
Fig. 8 Slope map

Table 11 Normalized weight and comparison matrix of the water level

water level (m)	[1]	[2]	[3]	[4]	[5]	[6]	Rate	Rank
[1] < 12	1	2	3	4	5	6	37.94	1
[2] 12–21	0.5	1	2	3	4	5	24.88	2
[3] 21–30	0.33	0.5	1	2	3	4	16.04	3
[4] 30–40	0.25	0.33	0.5	1	2	3	10.24	4
[5] 40–49	0.2	0.25	0.33	0.5	1	2	6.55	5
[6] 49–58	0.17	0.2	0.25	0.33	0.5	1	4.34	6
N	RI	CI	CR	CR < 0.1, therefore, consistency is acceptable				
6	1.24	0.034	0.027					
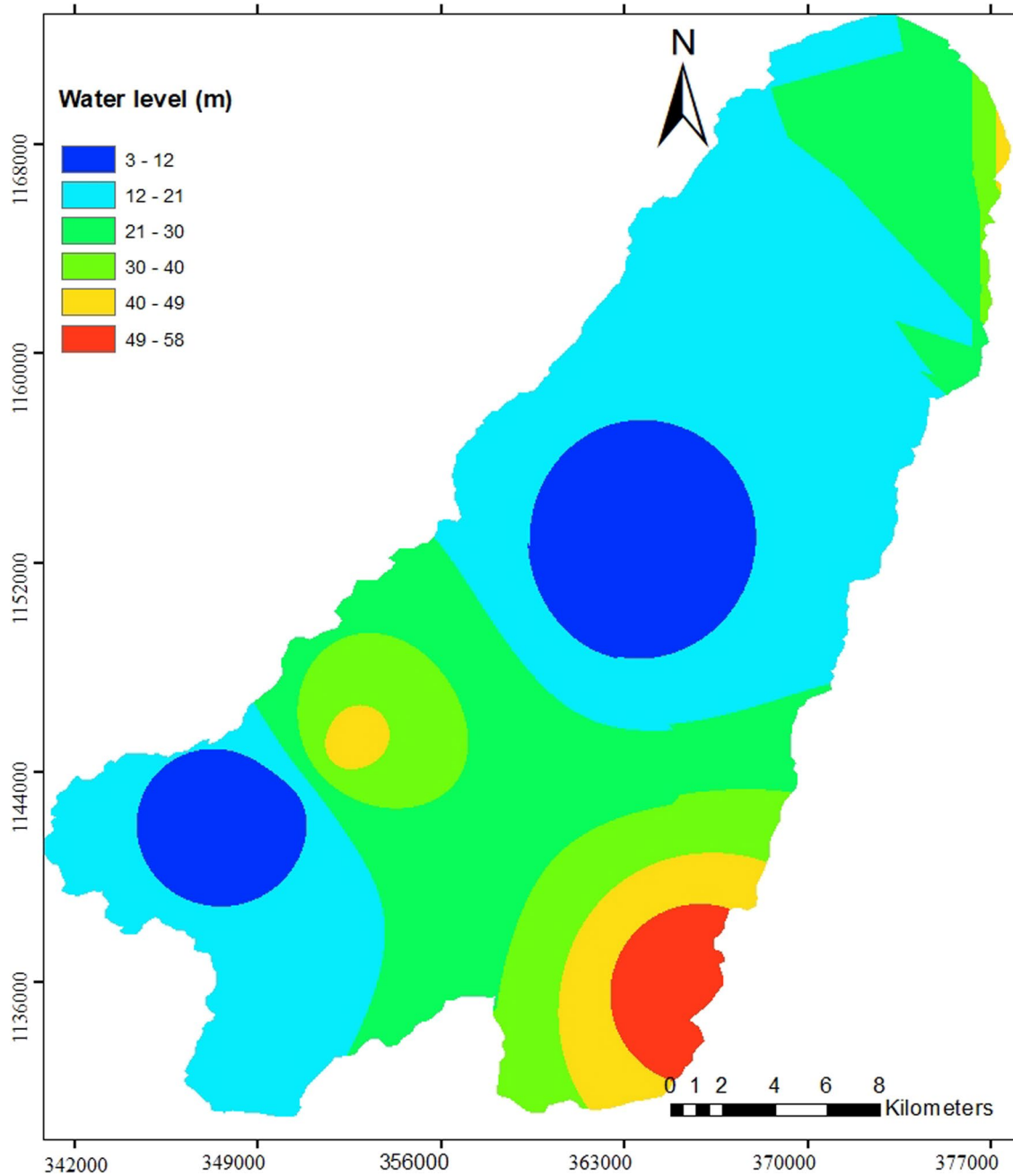
Fig. 9 Groundwater table map from borehole data

higher TWI value $(10 - (-1))$ the higher weight (41.62) has been assigned and vice versa (Table 14 and Fig. 12).

Topographic position index (TPI).

TPI is a vital factor to characterize the surface earth features which is extensively use to measure topographic slope positions and to computerize landform classifications (Reu et al. 2013). The physical earth processes such as hilltop, valley bottom, exposed ridges, flat plain, upper

and lower slope actions on landscape are correlated with TPI and the mathematical equation formulated by (Jenness 2006) was used to estimate the TPI as depicted below (Eq. 11).

$$TPI = (M_o - \sum_{n-1} M_n)/(n) \tag{11}$$

where M_o—elevation of the model point under evaluation, M_n—elevation of grid, n–the total number of surrounding
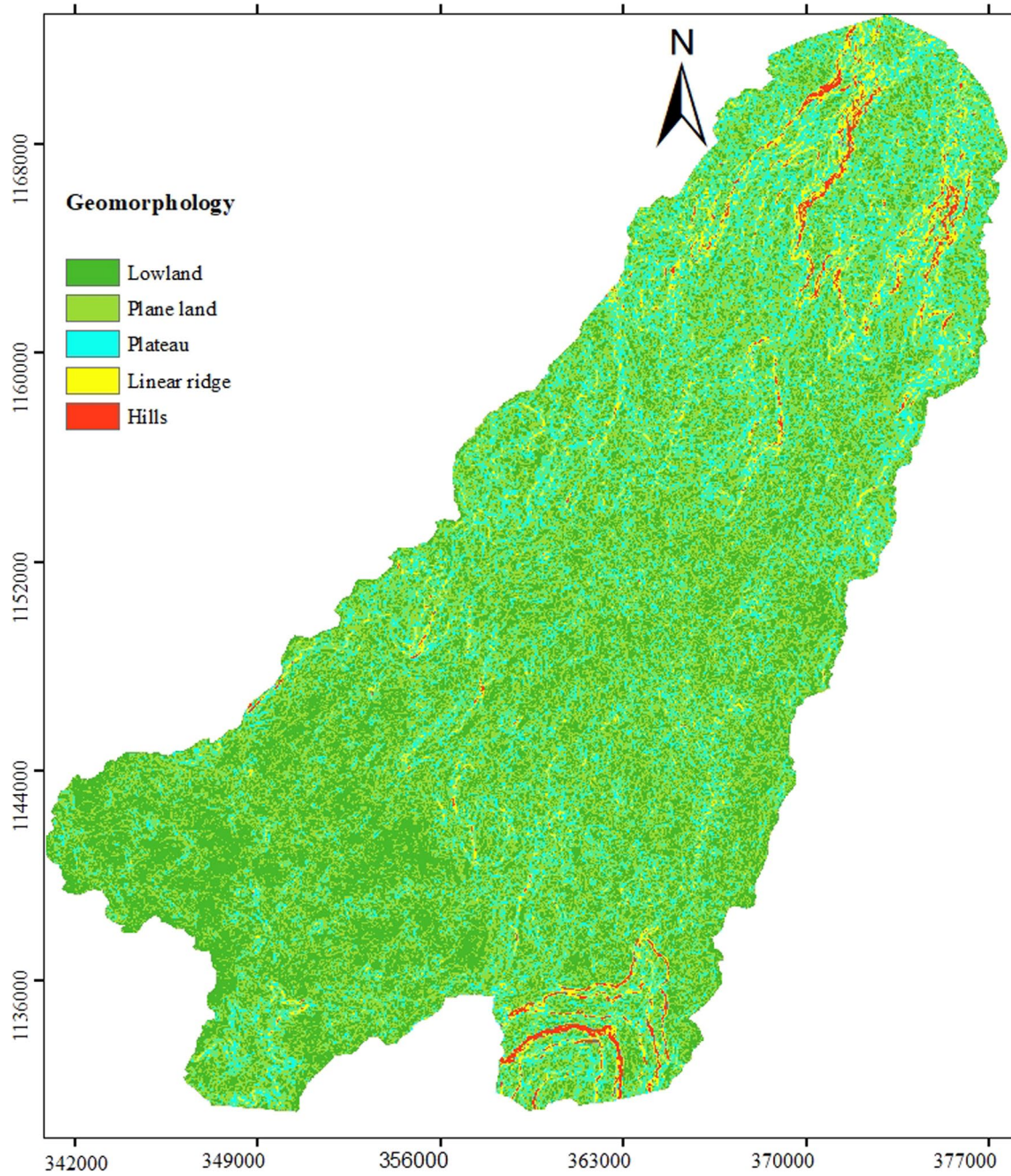
Fig. 10 Geomorphology map

Table 12 Normalized weight and comparison matrix of the landforms

Geomorphology	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] Lowland	1	2	3	4	5	41.62	1
[2] Plane land	0.5	1	2	3	4	26.18	2
[3] Plateau	0.33	0.50	1.00	2	3	16.11	3
[4] Linear ridge	0.25	0.33	0.50	1	2	9.86	4
[5] Hills	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is acceptable			
5	1.12	0.023	0.02				
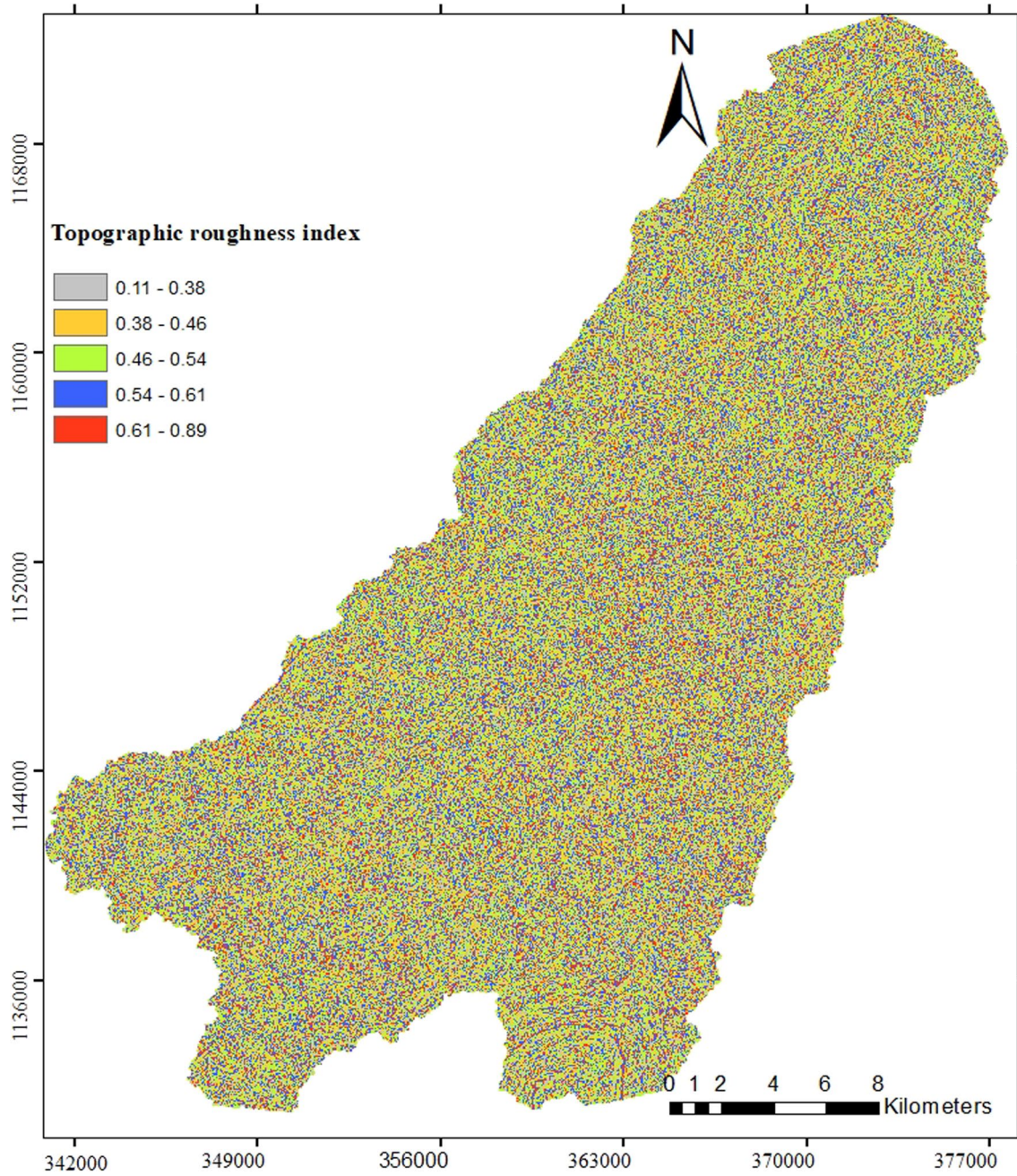
Fig. 11 Topographic roughness index map

Table 13 Normalized weight and comparison matrix of the TRI

TRI	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] 0.11–0.38	1	2	3	4	5	41.62	1
[2] 0.38–0.46	0.5	1	2	3	4	26.18	2
[3] 0.46–0.54	0.33	0.5	1	2	3	16.11	3
[4] 0.54–0.61	0.25	0.33	0.5	1	2	9.86	4
[5] 0.61–0.89	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is acceptable			
5	1.12	0.023	0.02				

Table 14 Normalized weight and comparison matrix of the TWI

TWI	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] 10–(− 1)	1	2	3	4	5	41.62	1
[2] 1–(− 5)	0.5	1	2	3	4	26.18	2
[3] −5–(− 7)	0.33	0.50	1.00	2	3	16.11	3
[4] −7–(− 9)	0.25	0.33	0.50	1	2	9.86	4
[5] −9–(− 17)	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is			
5	1.12	0.023	0.02	Acceptable			
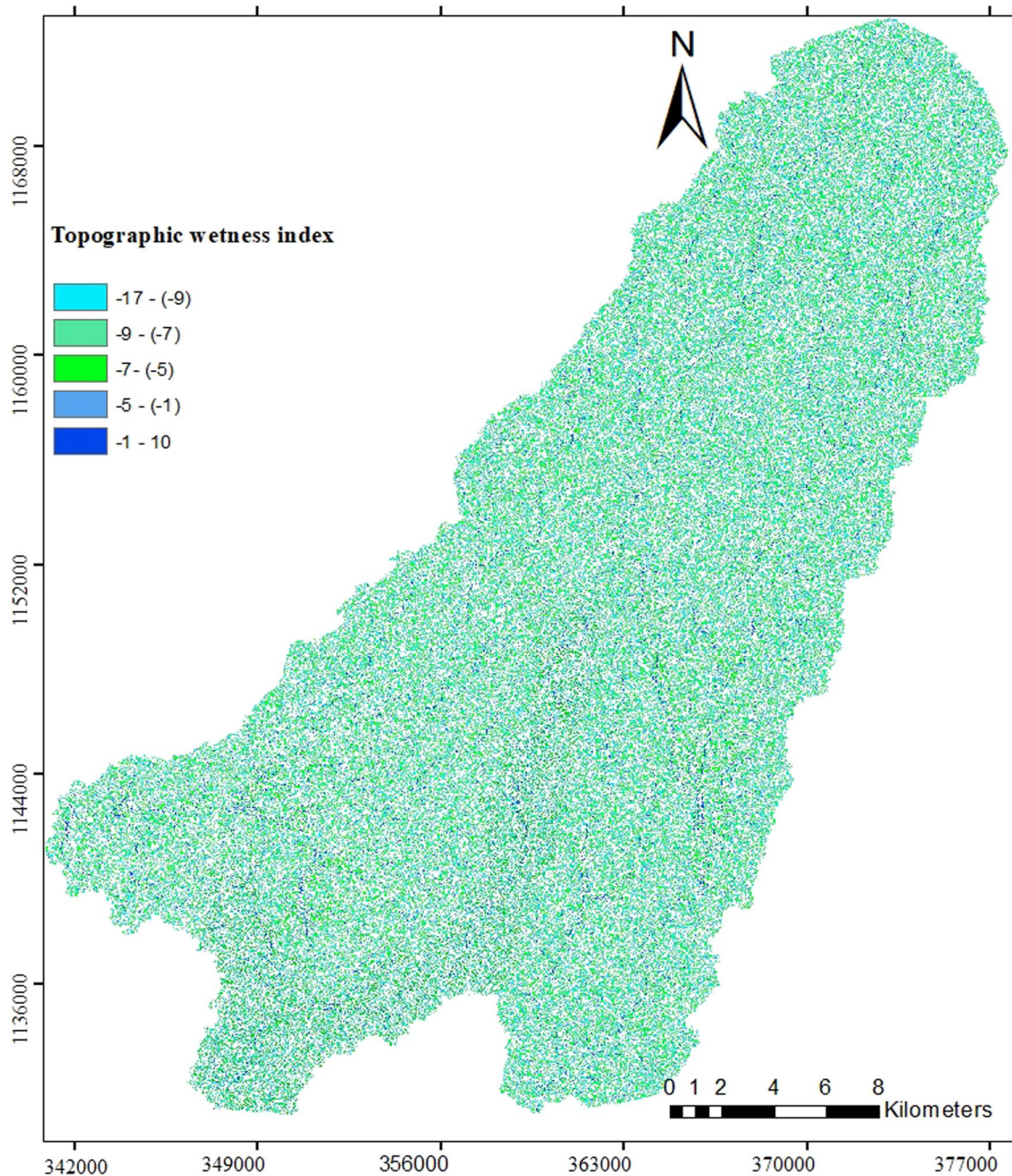
Fig.12 Topographic wetness index map

points employed in the evaluation. Hence, the TPI values of the proposed area were varied from -27 to 134. The zero values of TPI stand for flat ground surface with high rainfall infiltration and groundwater potential zone is highly expected in the areas of low TPI values (Fig. 13). Conversely, higher TPI values stand for hilltop and high ridge earth features characterized by high run off and exhibit poor groundwater zone. Hence, for groundwater potential zone demarcation, the lower TPI values ($TPI < -27$) are assigned by higher weights (41.62) and vice versa (Table 15).
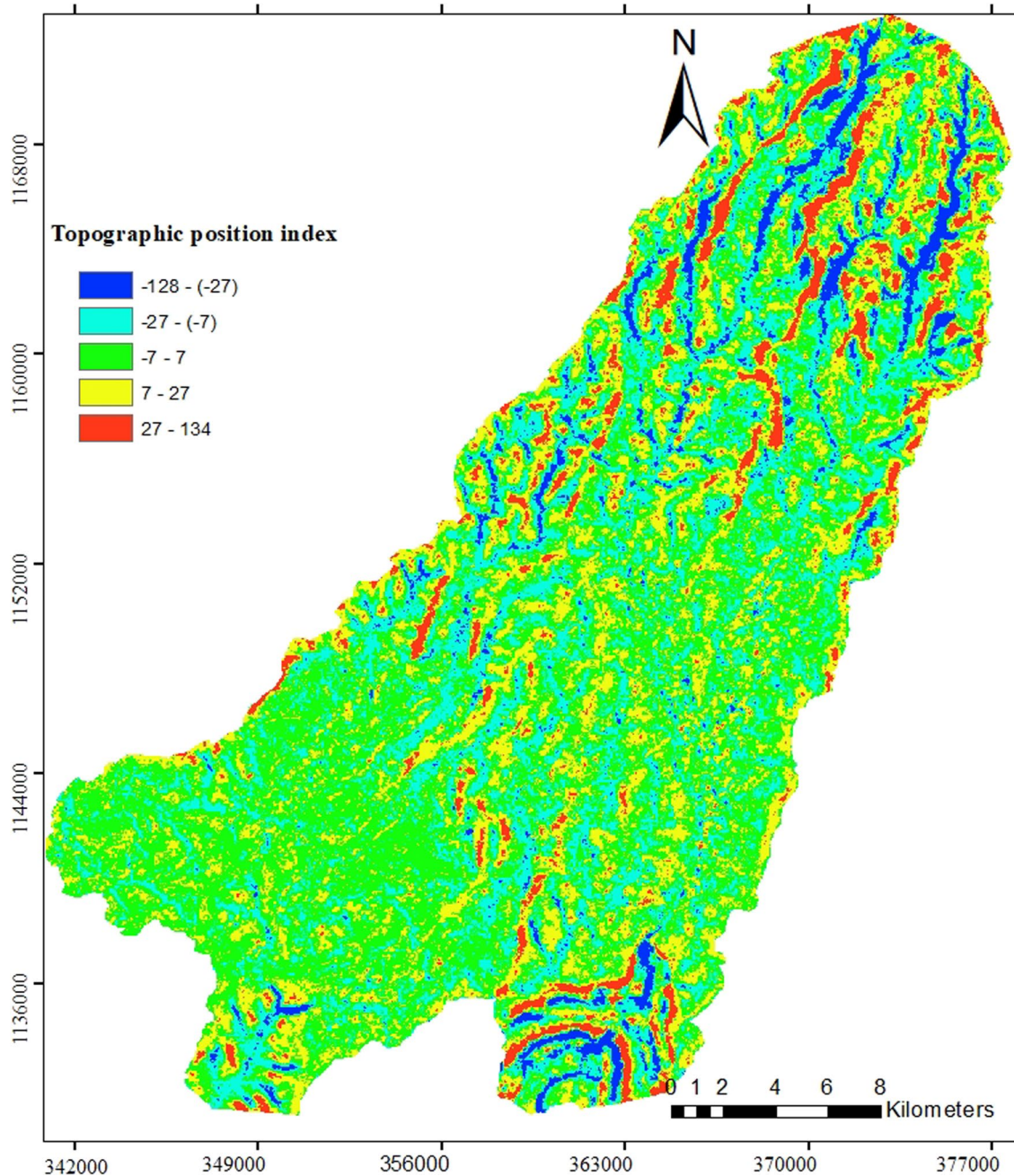
Fig. 13 Topographic position index map

Table 15 Normalized weight and comparison matrix of the topographic position index

TPI	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] < − 27	1	2	3	4	5	41.62	1
[2] − 27 to − 7	0.5	1	2	3	4	26.18	2
[3] − 7 to 7	0.33	0.50	1.00	2	3	16.11	3
[4] 7–27	0.25	0.33	0.50	1	2	9.86	4
[5] 27–134	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is acceptable			
5	1.12	0.023	0.02				
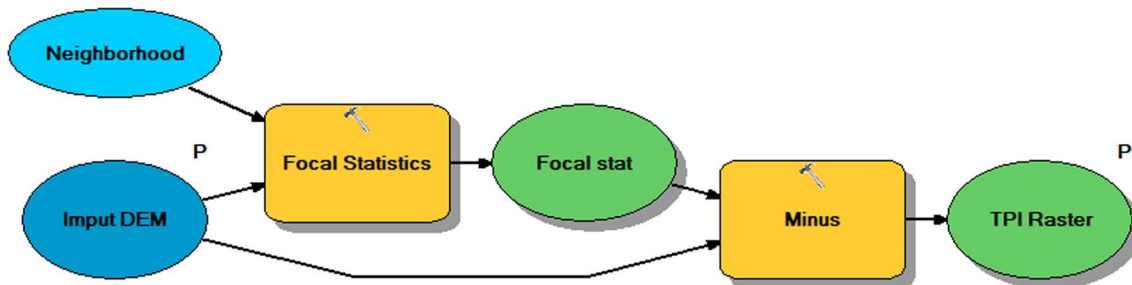
Curvature

The folded geological structures play a vital role to capture the freely flowing water. Curvature is the naturally folded surface profile, and it can be concave or convex upward profiles (Nair et al. 2017). Generally, water tends to decelerate and tends to accumulate in convex and concave profile, respectively (Arulbalaji et al. 2019). The Curvature values of the study area were varied from − 26 to 25 and reclassified into 5 classes such as C > 25, 25–7, 7–(− 8), − 8–(− 26) and C < − 26. High weight is assigned for high curvature value and vice versa (Fig. 14 and Table 16).

Groundwater potential map

For this work, the subjective groundwater controlling parameters were hierarchically formulated based on the researchers' expert and by reviewing previously published research articles and converted into their relative weights to determine the most feasible groundwater potential zones. The influencing factors of GW occurrence (Table 17) were combined based on their relative weights using WLC of GIS spatial analysis tool. The GWP map was produced by integrating the weight of all the influencing factors using the equation given below.

$$GWP = 0.29RF + 0.21Gw + 0.15Li + 0.11LU + 0.08Sl + 0.06Cu + 0.04Gm + 0.03Ld + 0.02TPI\ 0.015Dd \tag{12}$$

Where GWP = groundwater potential, RF = rainfall, GW = Depth to groundwater level, Li = lithology, LU = Land use/land cover, Sl = slope, curvature, GM = geomorphology, LD = lineament density, TPI = topographic position index, DD = drainage density. The overall weighted analysis of GWP modeling map was classified into four distinct zones using the rating values of all the influencing parameters in ArcGIS environment. The area coverage of each well-defined class of GWP zone is 0.3% (poor), 0.9% (moderate), 80.3% (good) and 18.5% (very good) (Fig. 15). Hence, most parts of study areas are demarcated as good GWP zones, and some parts of study areas are delineated as poor GWP zones. Upper part of the study area is characterized by mountains areas with medium lineament density and moderate to steep slope area which engaged high runoff while the lower parts of the catchment is characterized by gentle to moderate slope over different lithologic formations.

Validation of groundwater potential map

In this work, the GWP map was validated with 41 water point yields data (7 boreholes and 34 hand dug well) collected from field and water well drilling organizations. However, there is no standard classification for groundwater yield
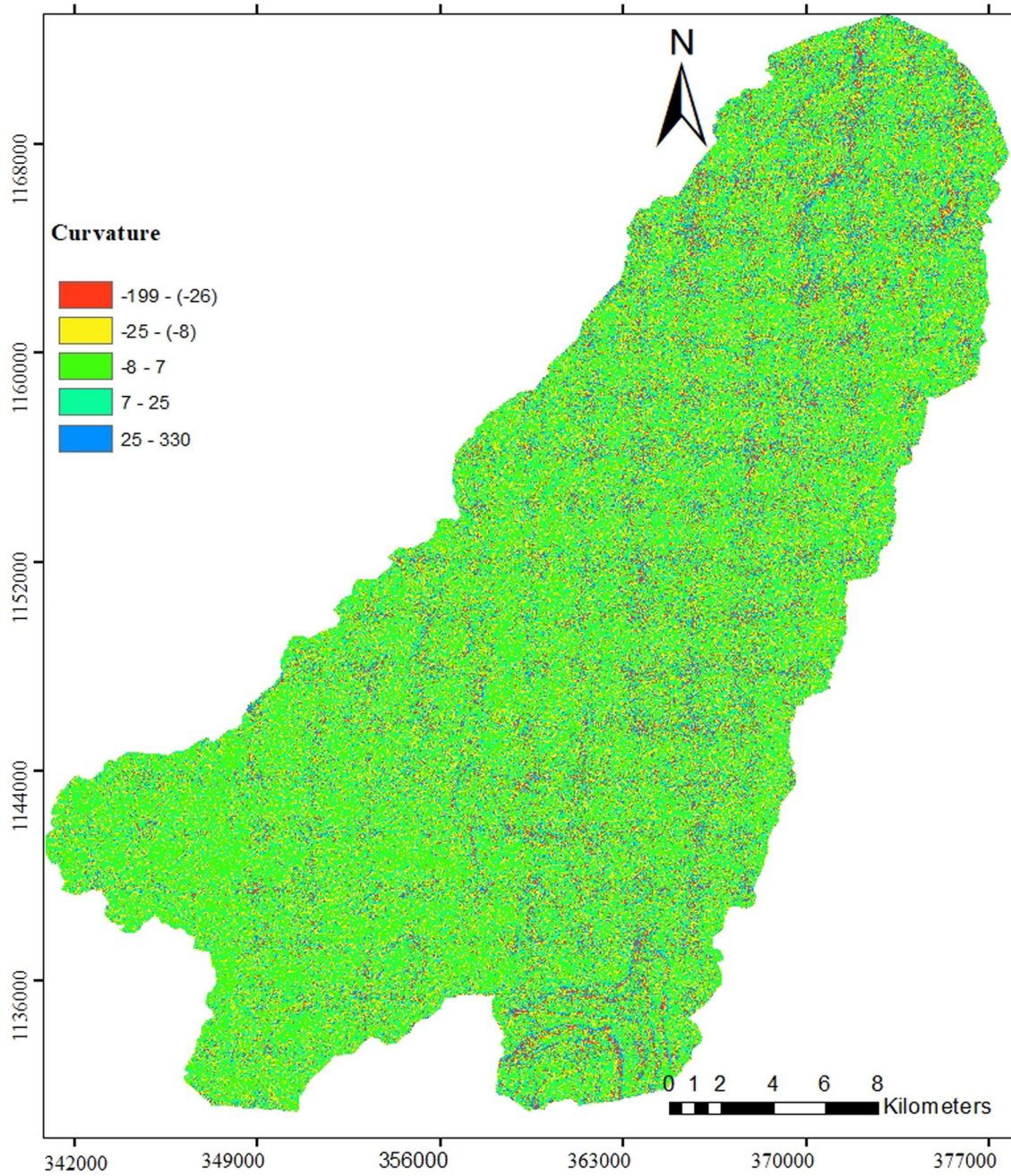
Fig. 14 Curvature map

Table 16 Normalized weight and comparison matrix of the curvature

Curvature	[1]	[2]	[3]	[4]	[5]	Rate	Rank
[1] $C > 25$	1	2	3	4	5	41.62	1
[2] 25–7	0.5	1	2	3	4	26.18	2
[3] 7–(− 8)	0.33	0.5	1	2	3	16.11	3
[4] − 8–(−26)	0.25	0.33	0.5	1	2	9.86	4
[5] $C < -26$	0.20	0.25	0.33	0.5	1	6.24	5
N	RI	CI	CR	CR < 0.1, therefore, consistency is acceptable			
5	1.12	0.023	0.02				

Table 17 determining the relative weights of each decisive factor

Factors	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	Weight (%)
[1] Rainfall	0.34	0.41	0.39	0.35	0.30	0.27	0.24	0.22	0.20	0.18	29.0
[2] Depth to GW level	0.17	0.21	0.26	0.26	0.24	0.22	0.21	0.19	0.18	0.16	21.0
[3] Lithology	0.11	0.10	0.13	0.17	0.18	0.18	0.17	0.16	0.15	0.15	15.2
[4] Land use	0.09	0.07	0.06	0.09	0.12	0.13	0.14	0.14	0.13	0.13	10.9
[5] Slope	0.07	0.05	0.04	0.04	0.06	0.09	0.10	0.11	0.11	0.11	7.9
[6] Curvature	0.06	0.04	0.03	0.03	0.03	0.04	0.07	0.08	0.09	0.09	5.6
[7] Geomorphology	0.05	0.03	0.03	0.02	0.02	0.02	0.03	0.05	0.07	0.07	4.0
[8] Lineament density	0.04	0.03	0.02	0.02	0.02	0.01	0.02	0.03	0.04	0.05	2.8
[9] TPI	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.04	2.0
[10] Drainage density	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	1.5
N	RI	CI	CR	CR < 0.1 consistency is acceptable							
10	1.49	0.092	0.061								

data with respect to site specific conditions, but most scholars (Tuinhof et al. 2011, Gilli et al. 2012, Anteneh et al. 2022) verified that very high yield zone for > 20 l/s and very low yields zone for < 0.1 l/s. Hence, for this work considering the proximity of the environment and geological settings of the watershed, the groundwater yield data were classified into 5 classes (0.095–5.69 l/s (low yield zone), 5.69–9.29 l/s (moderately low yield zone), 9.29–11.69 l/s (medium yield zone), 11.69–15.09 l/s (high yield zone) and 15.09–25.59 l/s (very high yield zone). Thus, for validation purpose, the low values of point yield data are assigned to represent very poor GWP zone and the high values of point yield data are assigned to represent very high groundwater zone (Fig. 15). The groundwater potential validation map appropriately overlapped with their respective potential zones. Hence, the applied method to investigate the GWP zone is highly consistent, accurate and legitimated. As clearly depicted in the validation map, in the very good GWP zones, very high yield water points (15.09–25.59 l/s) are recognized with Alluvium, Eluvium and pyroclastic aquifer formation in the lowest slope values. The lowest slope enhance to retained rainfall for a long time to easily infiltrated/percolated down to recharge the groundwater through those porous lithological units (Alluvium, Eluvium and pyroclastic). Conversely, low to moderately low GWP zones (0.095–9.29 l/s) are characterized by high depth to water level, high drainage density, moderate to extremely steep slopes and multispectral landforms. In sloppy areas and impermeable lithologic formations rainfall infiltration to recharge the groundwater is insignificant because the water has overflowed in the form of runoff. So, to effectively keep soil erosion, the natural environment and to enhance rate of infiltration terracing and water resource management vital for groundwater potential.

Sensitivity analysis results

Map removal sensitivity analysis result

In a MCDM, sensitivity analysis is recommended to check the stability of the outcome against the subjectivity of the expert judgments. The overall contribution of each thematic layer for the GWP zone modeling map is statically summarized in the table below (Table 18). In spite of the differences in mean variation index (MVI), eliminating a thematic layer bring on/give rise significant impact on the output map. Thus, each influencing factor used in AHP analysis plays its own specific role to delineate the GWP zone. In this analysis, the highest sensitivity index (MVI = 2.7) is found by removing rainfall layer that relatively scored the highest theoretical weights (29%). Similarly, groundwater is moderately to less sensitive to lithology, slope, land use, depth to groundwater, drainage density, curvature, lineament density, geomorphology and TPI with MVI of 3.4, 3.3, 2.7, 2.1, 1.6, 1.5, 1.1, 0.8 and 0.5, respectively (Table 18).

Single layer sensitivity analysis

The empirical and effective weights for each governing factor for GWP zone is clearly portrayed in the table below (Table 19). The empirical and effective weights of each thematic layer would have different weights for similar layer depending on the geological, hydrogeological, local and regional conditions. Some scholars (Fenta et al. 2014; Panahi et al. 2017, Anteneh et al. 2022) also confirmed that sensitivity variations greatly dependence on the various conditions and geological features of the area interested. In this study, the mean effective weights of the 1st most influencing factors of GWPZs were determined as rainfall (21.9%),
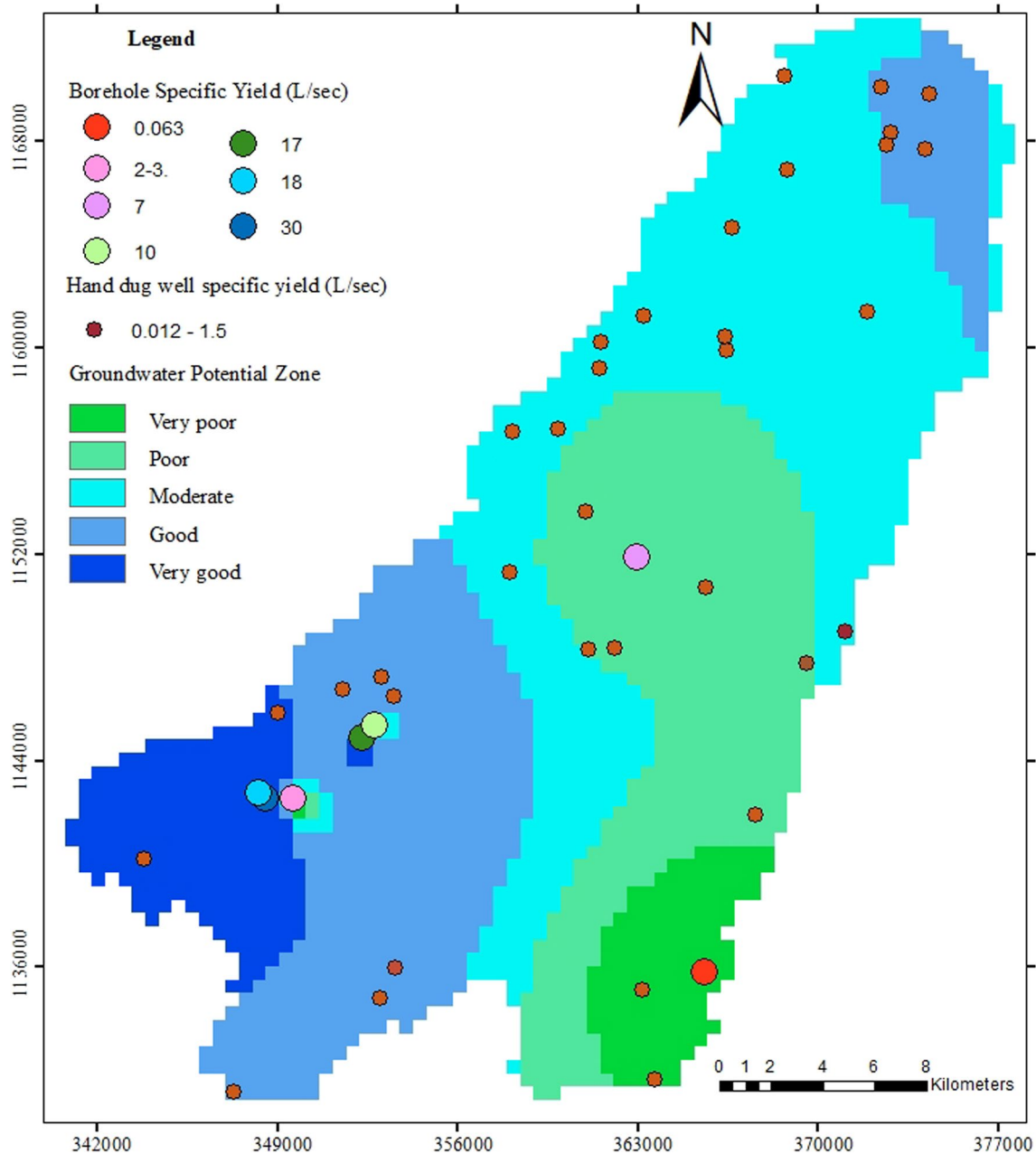
Fig. 15 Groundwater potential zone and validation map

depth to groundwater (11.2%), Lithology (13.6%), Land use and land cover (9.7%) and slope (6.5%) and show more less values compared to their empirical weights (Table 19). This reveals that these thematic layers are the most effective factors for GWP zone. While the last five thematic layers (curvature, geomorphology, lineament density, TPI and drainage density) their mean effective weights are generally greater than or close to their empirical weights (Table 19), and they have relatively less effective for GWP zone mapping. This statistical approach was obtained directly from the attribute table of the layer in ArcGIS platform. The values were

absolutely depending on the number of pixel size or area coverage of each feature, and hence, the analysis was more reliable and vital to infer GWP zone mapping.

Conclusion and recommendations

The GWP zones of the upper parts of Chemoga watershed were delineated using integrated approaches of RS- and GIS-based AHP of MCDA, and the result was validated with field observed groundwater sources such as borehole

Table 18 Statistics of map removal sensitivity analysis

Thematic layer removed	Effective/variation index (%)			
	Min	Max	Mean	SD
Rainfall	0.0	9.5	3.7	1.4
Depth to GW level	0.0	5.9	2.1	1.8
Lithology	0.1	12.2	3.4	3.3
Land use	0.2	4.2	2.7	1.8
Slope	1.1	5.8	3.3	1.5
Curvature	0.2	3.7	1.5	1.1
Geomorphology	0.1	1.9	0.8	0.6
Lineament density	0.0	2.6	1.1	0.7
TPI	0.0	1.3	0.5	0.8
Drainage density	0.3	3.1	1.6	1.5

Table 19 Statistics of single parameter sensitivity analysis

Thematic layer removed	Empirical Weight (%)	Effective/variation index (%)			
		Min	Max	Mean	SD
Rainfall	29.0	0	72.9	21.9	14.3
Depth to GW level	21.0	4	57.6	11.2	9.5
Lithology	15.2	1.3	41.2	13.6	11.4
Land use	10.9	1.8	54.2	9.7	6.8
Slope	7.9	4	39.8	6.3	5.5
Curvature	5.6	1	21.1	7.5	5.7
Geomorphology	4.0	1.5	24.9	10.8	4.9
Lineament density	2.8	0.7	22.6	9.4	3.1
TPI	2.0	0.3	21.4	8.7	6.9
Drainage density	1.5	0.3	19.7	6.7	4.3

and hand dug well yield data. MCDA is an important technique in decision making process to simplify objectively complicated problems by applying multiple subjective parameters. The findings of this study laid concrete for the detailed geophysical, geological and hydrogeological investigations. Based on the overall analysis, 11.1, 18.2, 47.1, 15.4 and 8.2% of the proposed area depicted very good, good, moderately good, poor, very poor groundwater potential zones, respectively. The findings of this work provide vital information for the governmental and nongovernmental sectors in decision making processes for the selection of borehole location for drilling. The study inspired the concerning body to develop sustainable groundwater management, to have proper administration, management, and sustainable use of groundwater resources in upper parts of Chemoga watershed.

- For groundwater and surface water development, the most effective and simple techniques (forestation, soil conservation (terracing) should be done in the bare land and sloping areas which posses high runoff.

- Surface water and rainwater harvesting practice more effective and significantly reduces the stresses of groundwater exploration in the area.
- Since the societies are totally depend on mixed agricultural activity, sustainable water resource management practices in the watershed is required for their high water demand.
- For the demand of rapidly increased population growth, it is vital to investigate and locate the GWP zones for future groundwater development and management.

Limitation

To accurately determine the groundwater potential zone, the challenges encountered for this work were lack of sufficient borehole data (only 7 borehole data). For the detailed study, integrated approaches of some indirect and direct methods such as geophysical, a continuous GW level recorded data and in situ hydrogeological recorded data are required. This study provides some important information to the ground water zone so, for the detailed study and exploration purpose some advanced technologies are required on the area of interest.

Declarations

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