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Research paper

Identification of groundwater potential zones in Kabul River Basin, Afghanistan

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ABSTRACT

Groundwater (GW) plays a vital role in the socio-economic growth of Kabul River Basin (KRB) in Afghanistan. Since the GW resources in the basin have not been properly managed, there is a need for sound strategies by first identifying the potential GW zones. This study assesses the potential groundwater zones for the KRB using the Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP). In this direction, seven different thematic maps of *rainfall, lithology, land use/land cover, slope, soil, drainage density*, and *lineament density* are first prepared using the GIS. The AHP is then employed to assess the weights of different themes. Finally, the weighted overlay option in the GIS is used to generate the map of the groundwater potential zones (GWPZ). The *Very Good* zones are mostly located in the downstream and central parts of the KRB, covering around 1543 km^2 area. The *Good* and the *Poor* zones are found to be randomly distributed, covering about 39 444 km^2 and 27 658 km^2, respectively. The *Very Poor* zones are located in the west, southwest, and in some central parts of the basin, covering about 2272 km^2. It is found that only 18% of the total average annual precipitated water of 6.88×10^9 m^3/year infiltrates into the subsurface and ultimately contributes to recharging of the groundwater.

1. Introduction

Afghanistan, located in the aridity region, has water resources mainly from the high mountain series. About 80% of the water emanates from Hindu Kush Mountains at an altitude of 2000 m (Qureshi 2002). These mountains possess inherent storage of water in the form of snow during the winter season and snowmelt during the summer season, promoting the perpetual flow of water in all rivers in all seasons. The country's climatic conditions range from arid to semi-arid, receiving irregular rainfall over the years. The rainfall ranges from 75 mm (Farah) to 1170 mm (South Slang), with heavy rainfalls during the winter months (Favre and Kamal 2004).

Of the total amount of runoff, just 15% of Afghanistan's overall precipitation contributes to the country's groundwater recharge (Aini 2007). Traditional underground systems such as the Karezes (Qanats), the springs, and the shallow wells (locally called as Arhads) have been widely used in the country for the purposes of irrigation and domestic uses. Around 15% of Afghanistan's irrigated land receives water from these underground systems. It is estimated that all the traditional groundwater irrigation schemes have been reduced or dried up entirely, with approximately 60–70% of the Karezes being unused and 85% shallow wells being dry (Qureshi 2002). People who rely on these systems have been terribly suffering from the failures or reduced discharges of these systems. The key causes of the low discharge are the low rainfall and, as a result, low groundwater recharge. In addition, the boring of deep wells near the Karezes and the shallow wells have adversely impacted the production of these conventional irrigation systems. The shallow wells are used in the most metropolitan regions to provide water for the drinking and other domestic uses. The water levels drop by around 0.5–3 m every month depending on the region (Qureshi 2002). Many of these wells are now dry and individuals (often women and children) are forced to walk miles to meet their everyday water needs.

Renewable water resources per capita of Afghanistan fell gradually from 5573 m^3/year in 1972 to 1839 m^3/year in 2017. In 1992, around 10 million people did not have access to the safe drinking water while this number increased to 15 million by 2015 (https://www.worldometers.info/water/afghanistan-water/#water-resources). Accordingly, this situation highlights the need for the major water supply and demand studies to be conducted to promote overall water management throughout the country. Based on the Food and Agriculture Organization (FAO) data, the country generates 65.3 km^3 of renewable water resources per year. Of the total renewable water resources, 10.65

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km^3 is from the groundwater and 55.5 km^3 is from the surface water. The surface water supplied from Kabul River Basin (KRB) is approximately 11.5 km^3 while total amount of groundwater provided by the basin is about 1.92 km^3 (FAO, 2016).

Kabul River Basin includes 13 provinces and the capital City of Kabul. The KRB regularly faces groundwater shortages, and most people in the area suffer from a variety of disasters caused by the unsafe drinking water. Water scarcity in the KRB is caused by numerous factors, such as the undesirable topographical conditions, fast population growth and urbanization, inadequate awareness, and lack of proper planning and management of water resources. In most parts of the KRB, especially in Kabul, people are digging deep wells to meet their daily needs without following the strategies offered by the government. As a result, without adequate guidance, drilling and construction of new bore wells have led to unaffordable utilization of water resources. Therefore, to enhance the availability of fresh water and reduce water shortages in the watershed, it is important to assess the appropriate areas for the groundwater extraction.

In several hydrogeological studies, notably those concerned with the groundwater exploration, defining the zones of different recharge potential is the initial step followed by the assessment of the subsurface flow direction and the trapping conditions. The evaluation of recharge potential often plays a role in variety of environmental and agricultural concerns. This property is very significant since it reflects the rate of water flows from the surface to the deeper aquifers. Groundwater potential zones have been depicted using different conventional approaches such as the geological, hydrogeological, geophysical, and photogeological techniques (Pinto et al., 2015). However, with the increase of computer power, the digital technology is being used to integrate different conventional methods with the satellite imagery/remote sensing (RS) and the geographic information system (GIS) technologies.

Many researchers in the field of water resources engineering have applied several methods for the determination of groundwater potential zones around the world (Dinesh Kumar et al., 2007; Swetha et al., 2017; Jesiya and Gopinath 2020, among many). Different thematic layers such as the land use/land cover, soil, lithology, slope, geology, geomorphology, elevation, etc have been applied in different studies to investigate the groundwater potential zone of a region. Patra et al. (2018) stated that choosing the required number of thematic layers and justifiable weights distribution are crucial to the advantage of the application of the RS and the GIS in evaluating the potential zones of groundwater resources. The systematic use of the Analytic Hierarchy Process (AHP) via GIS has developed accessible and effective methodologies for the spatial data management and multi-criteria decision-making evaluation. The analyses of different thematic datasets have been proven effective in delineating groundwater potential zones (Shekhar and Pandey 2014). Andualem and Demeke (2019) employed several thematic layers to delineate the potential groundwater zone of Guna Tana Landscape, Upper Blue Nile Basin, Ethiopia using the GIS with the Multi-Criteria Decision Analysis (MCDA) methodology and suggested that water resource planners could apply this methodology to identify potential regions for the development and to increase the supplement productivity of irrigation and domestic use. Rahmati et al. (2014) applied the AHP and the GIS to investigate the potential zone of groundwater in Kurdistan plain of Iran and recommended that this methodology can be applied to create a potential groundwater zone map for the future planning especially in the data-scarce areas. Many studies (Adiat et al., 2012; Hajkowicz and Higgins 2008; Machiwal et al., 2010) proposed that the accuracy of the groundwater potential prediction zones is highly dependent on the exhaustiveness of the set of criteria used and the decision options.

To the knowledge of authors, there is no study yet to analyze the groundwater potential zones in Afghanistan, including the KRB. Therefore, the present study is the first to determine the groundwater potential zones of the KRB using seven different thematic layers (*rainfall, soil, land cover, lineament density, drainage density, lithology, and slope*) in the GIS environment under the Analytic Hierarchy Process (AHP) technique. The main purpose of this study is to delineate the groundwater potential zones of the study area and to create a future groundwater exploration guide map to ensure that this essential resource is optimally and sustainably controlled and operated.

2. Study area

The KRB, located in the northeast quarter of Afghanistan, lies between latitudes 33 ßN and 37 ß N, and longitudes 67 ßE and 74 ßE (see Fig. 1), with average elevations ranging from 382 m to 6206 m above mean sea level (see Fig. 1). The total catchment area of the KRB is approximately 72 000 km^2 that covers 12% of total Afghanistan's area and the storage capacity of the basin is estimated to be around 22 billion m^3 (Qureshi 2002). The northern part of the basin contains high mountains that provide most of the flow of Kabul River. The eastern part of the KRB is mainly covered with forests, accounting for about 93% of the country's forest area (World Bank 2010). Of 1.56 million ha of irrigated area in Afghanistan, 20% of irrigated region is located in the KRB. The climate of this basin is considered as the semi-arid and continental with hot summers and cold winters. Generally, the basin receives high precipitation from November to February and the amount of precipitation falls near to zero during the hot summers. The annual average precipitation from 2009 to 2018 is recorded to be around 530 mm/year. The annual minimum and maximum temperatures in the upstream part of the basin are recorded as 6.4 °C and 20 °C respectively, wherein at the downstream part of the basin the temperature reaches to 17 °C and 28 °C, respectively.

3. Materials and methods

Various researchers in the field of water resources engineering have used several thematic layers to depict the groundwater potential zones of a region (Shaban et al., 2005; Dinesh Kumar et al., 2007; Yeh et al., 2008; Ganapuram et al., 2009; Mogaji et al., 2014; Rahmati et al., 2014; Selvam et al., 2014; Pinto et al., 2015; Jhariya et al., 2016; Swetha et al., 2017; Jesiya and Gopinath 2020). In general, the choice of these thematic maps depends on the local expert or sufficient knowledge about the properties of the study area. In the present study, seven different types of thematic maps (*Rainfall, Lineament density, Drainage density, Slope, Land use/Land cover, Soil, and Lithology*) are used to derive the groundwater potential zone map of the KRB. Annual measured rainfall data at 18 stations from 2009 to 2018 are obtained from the Ministry of Energy and Water of Afghanistan. The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Digital Elevation Model (DEM) with 30 m by 30 m spatial resolution (see Fig. 1) is downloaded from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). Referring to Fig. 1, a careful examination of DEMs reveals that the slope and the drainage network are towards the southeastern direction while the groundwater flow is from the north and west to the northeast direction. The Lineament density, the Drainage density, and the Slope maps of the KRB are generated based on the DEM using the ArcGIS spatial analyst tools. The soil map is acquired from the soil survey data collected by the United States Department of Agriculture (USDA) (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/worldsoils/?cid=nrcs142p2_054000). The land cover data of the KEB are downloaded from the Earth Explorer NASA LPDAA collections of the Moderate Resolution Imaging Spectroradiometer (MODIS) and finally, the lithology map of the study area is downloaded from the U.S Department of the Interior (https://catalog.data.gov/dataset/geologic-age-and-lithology-of-afghanistan-glgafg-shp). Fig. 2 shows the detailed Flowchart of the methodology employed in this study.

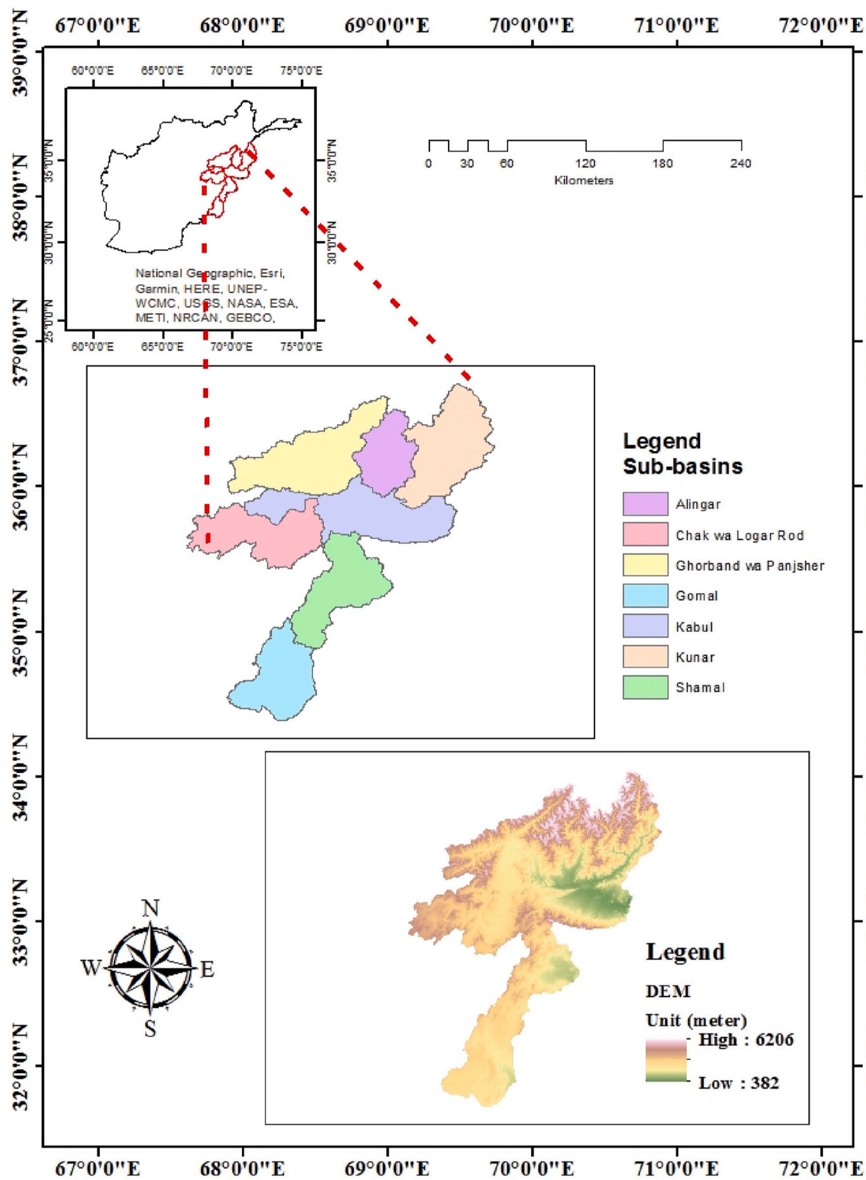

Fig. 1. Map of Afghanistan and Kabul River Basin.

3.1. Lineament and lineament density

The lineaments represent the surface topography of the underlying structural features and illustrate the fault and fracture regions. These factors are of great hydrogeological importance as they offer a route for the groundwater flows into the subsurface. Since the presence of lineaments typically implies a permeable region, the groundwater potential can be indirectly revealed by the lineament density in an area. Areas with high lineament density are ideal for good groundwater potential zones (Chepchumba 2019).

Four different combinations of the hillshade maps with azimuth and altitude of 315–45, 200–50, 100–60, and 50–90, respectively, are generated based on the DEM and analyzed by using the GIS to digitize the lineament map of the study area (KRB). The lineaments are extracted manually from each hillshade map by using GIS spatial analyst tool. To create the lineament density map, the lineaments generated from the hillshade maps are analyzed in the ArcMap10.3, and the lineament density map of the study area is created for the further analysis.

The major lineaments, exist in the NE to SW and the NW–SE, are presented in Fig. 3. Most of the lineaments are located in the north, northeastern, and southeastern parts of the study area. In the present study, the lineament length density (LD) is used to create the lineament map of the KRB. The LD is defined as the total length of lineaments in a unit area (Selvam et al., 2014) and it is expressed as:

$$\mathrm{LD} = \sum_{i=1}^{i=n} L_i / A \tag{1}$$

where, $\sum_{i=1}^{n} L_i$ indicates the total lengths of lineaments and A represents the area of the watershed. As mentioned before, the lineaments are extracted for the whole KRB (see Fig. 3) and the ArcMap is utilized to create the lineaments density map (Fig. 4).

As shown in Fig. 4, the low (0.08–0.161 km/km^2) and the very low (<0.08 km/km^2) lineament densities are located in the west, south-western, and mostly in the center parts of the region, where the medium (0.161–0.242 km/km^2) and the high lineament (0.242–0.323 km/km^2) densities are located in the northeastern, northwestern, and south-western parts of the basin, respectively. The very high lineament (>0.403 km/km^2) densities are located in the northeastern and

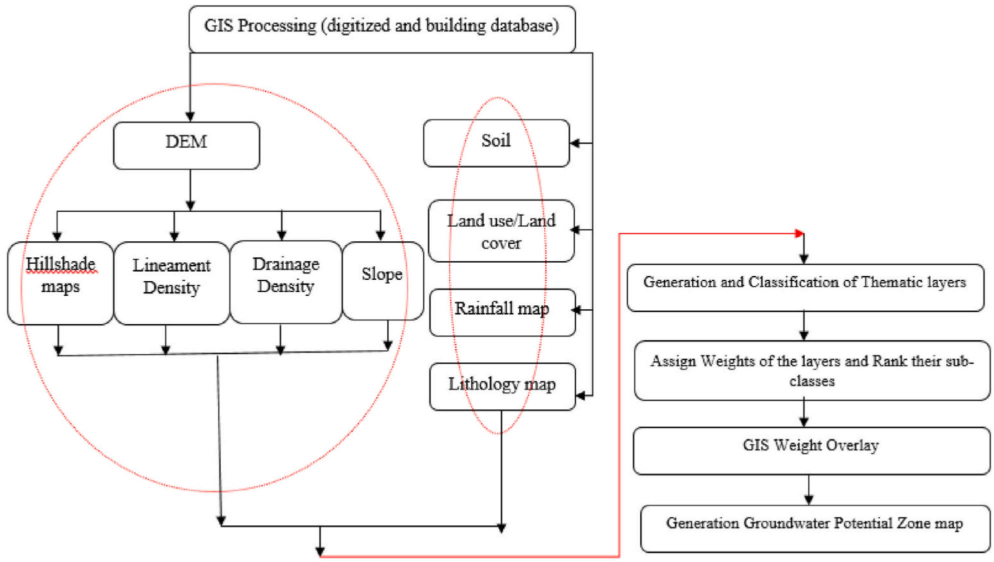

Fig. 2. Flowchart of the methodology.

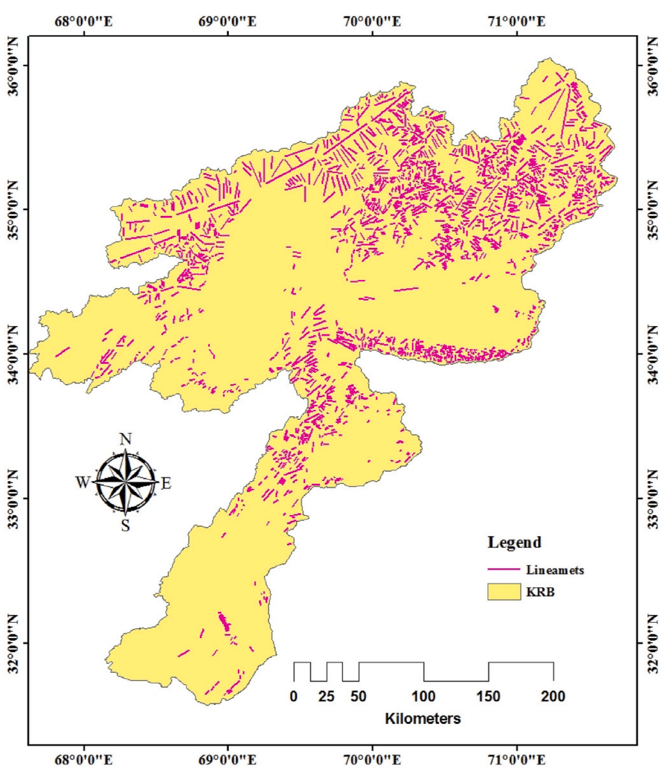

Fig. 3. Lineaments map of the KRB

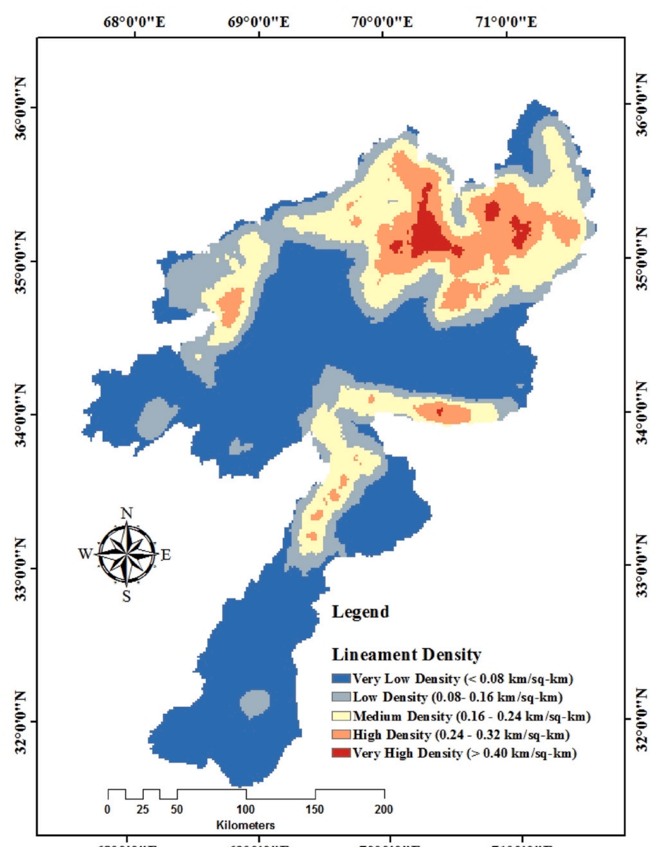

Fig. 4. Lineament Density map of the study area (KRB).

southwestern parts of the basin. As seen in Fig. 4, the cumulative length and the frequency of the lineaments located in the northeastern part of the basin are very dense compared to the other regions of the basin. The northeastern region of the basin has very high groundwater potential as the number of lineaments are predominantly dominant in this area.

3.2. Drainage density

The drainage patterns represent the evolutionary history of the Earth's crust. It can provide information about the surface and subsurface formation, such as the dendritic drainage showing predominantly homogeneous rocks, rectangular and parallel drainage patterns show structural and lithological control (Roy et al., 2020). The drainage network is an important indicator of the water permeability as it is basically determined by the underlying lithology (Shaban et al., 2005). The drainage density and the presence of lineaments, faults, crevices, large and small joints can have a significant impact on the recharge and movement of groundwater and they can also provide highly groundwater movement paths, which are of great hydraulic importance (Deepa et al., 2016). The drainage density reflects the proximity of channel spacing and surface properties. The information related to runoff, infiltration, relief, and permeability can be obtained by evaluating the drainage density and the drainage type. The drainage system in an area depends on the nature and structure of the bedrock, the type of vegetation, and the ability of the soil to absorb rainfall, infiltration, and slope. In areas with low drainage densities, there is more infiltration and less surface runoff. It implies that the areas with low drainage density are ideal for the development of groundwater (Rahmati et al., 2014).

In the present study, the GIS is employed to extract the drainage pattern directly from the DEM (see Fig. 1). The surface drainage density (*DD*), which is defined as the ratio of the total length of the streams to the size of the area of the grid under consideration, is calculated as follows:

$$DD = \sum_{i=1}^{i=n} \frac{\mathrm{Di}}{\mathrm{A}} \tag{2}$$

where $\sum D_i$ represents the length of all streams in the mesh *i* (km), and A indicates the area of the grid (km^2). In the present study, the drainage map, as shown in Fig. 5, is used to generate the drainage density map of the KRB and it is reclassified into five groups as; *very low, low, medium, high,* and *very high* (see Fig. 6). As it can be observed in Fig. 6, the *high* (0.54–0.88 km/km^2) and the *very high* (0.21–0.54 km/km^2) drainage densities are located in the southwestern and at the center parts of the basin covering areas of 8292 km^2 and 5208 km^2 respectively. The *medium* drainage density (0.88–1.21 km/km^2) is mostly located in the northeastern, southwestern, and western parts of the basin, occupying around 27 697 km^2 area. The *low* (1.21–1.55 km/km^2) and the *very low* (1.55–1.88 km/km^2) drainage densities are generally located around the boundary of the basin that covers 22 486 km^2 and 8967 km^2 area of the basin, respectively. Areas with the *low* drainage density have better groundwater potential zones than those with the *high* drainage density.

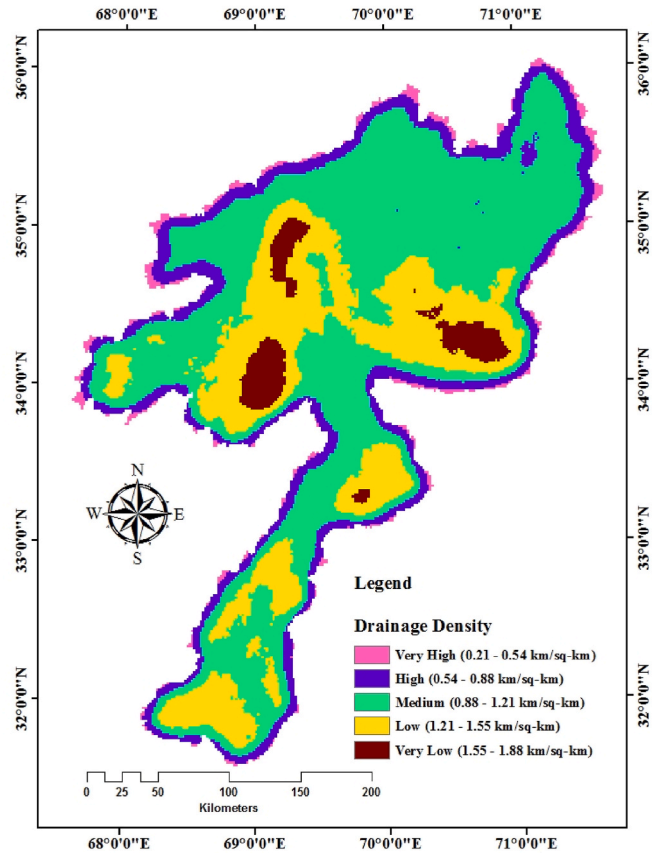

Fig. 6. Drainage Density map of the KRB.

3.3. Lithology

The lithology of an area has a strong impact on the generated quality and quantity of the groundwater (Ghorbani Nejad et al., 2016). In this study, the lithology map obtained from the U.S Department of the Interior is digitalized for the entire study area. As shown in Fig. 7, the KRB contains 20 different types of geologic lithology, among Gneiss, Sand, Conglomerate and sandstone, Clay and shale, Granite, Lava, Limestone and dolomite, and Fan alluvium and colluvium are found to be the most extensive classes that cover the majority of the region. Among the 20 different lithological classes, the Fan alluvium and colluvium, the Conglomerate and sandstone, the Limestone and dolomite, and the Sand are considered to be most favorable for the groundwater potential. Therefore, high weight values are assigned to these classes (see Table 1). The Basalt, the Volcanic and sedimentary rocks, the Basaltic and andesite, and the Rhyolite to andesite are also favorable zones for the groundwater recharge potential zones. The remaining classes of the lithology are considered as the unfavorable zones for the generation of groundwater potential due to low permeability that favors less infiltration, resulting in a low potential for the groundwater storage.

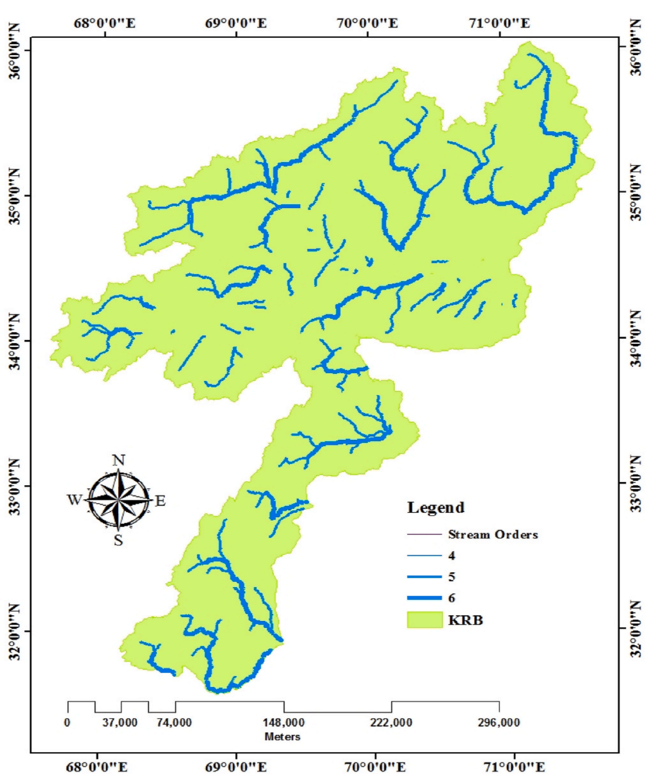

Fig. 5. Drainage map of the KRB.

3.4. Precipitation

A major component of the water cycle and a major cause of groundwater recharge is the precipitation. The hydrological conditions of a region are primarily affected by the amount and spatio-temporal distribution of a precipitation (Patra et al., 2018). The intensity of precipitation combined with other favorable factors helps to classify the groundwater potential zones. High rainfall is likely to increase the groundwater. Table 2 and Fig. 8 show the locations of meteorological stations and the drainage areas of the stations at the study area. The maximum precipitation is observed at Bagh-i-Lala station with 233 mm while the minimum is observed at Keraman, Khawak, Omarz, and Qala-i-Malek with 0.001 mm. The variation in the precipitation is significant at stations Bagh-i-Omomi and Tang-i-Gulbahar while there is

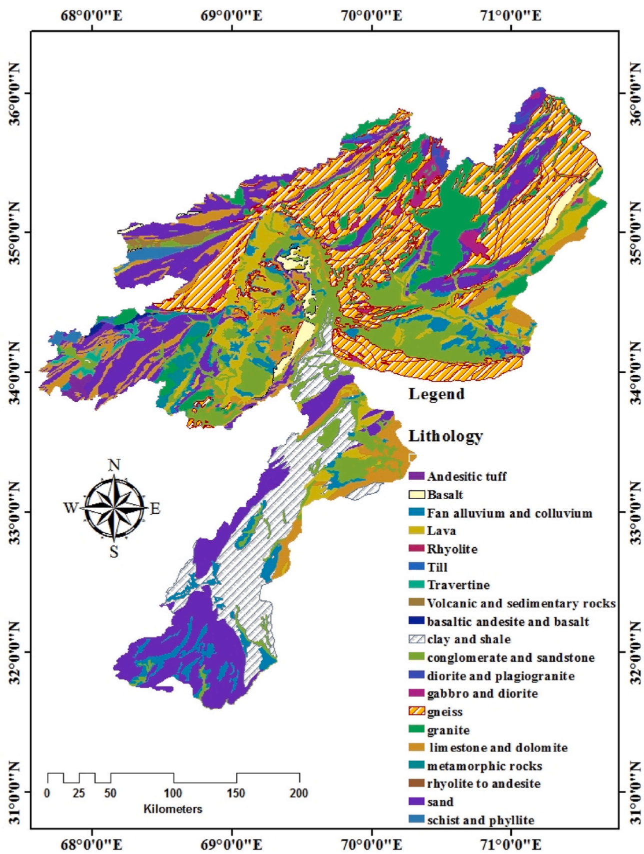

Fig. 7. Lithology map of the KRB.

less variation at station Pul-i-Kama. As seen in Table 2, Dakah has larger drainage area of 67 370 km^2 while Qala-i-Malek has smaller drainage area of 69 km^2. Table 3 presents the summary of precipitation statistics. In order to identify the groundwater potential zones, it is necessary to determine the effects of the precipitation. The spatial distribution of the average annual rainfall map (see Fig. 8) is generated by the Inverse Distance Weighting (IDW) interpolation method using the ArcGIS and it is reclassified into five classes as; *Very Low, Low, Medium, High,* and *Very High*. As shown in Fig. 8, the north, northeastern, and some central parts of the study area have the *high* precipitation in the range of 278.2–315.19 mm/year, where the *very high* rainfall of 315.6–352.99 mm/year covers some small portions of the basin located in the north, northeastern, and central parts. The *medium* precipitation of 240.81–278.19 mm/year largely covers the western, and southeastern parts of the region. The *low* (203.4–240.8 mm/year) and the *very low* (166–203.4 mm/year) precipitation covers the same regions located in the west and east of the study area, respectively.

3.5. Slope

The topographical slopes in any region have certain importance in affecting the surface runoff, recharging, and water movement. The gradient of the slope directly affects the runoff and infiltration. Larger slopes create a smaller recharge since, during rainfall, water flows quickly off the surface of a steep slope, not having sufficient time to infiltrate into the sub-surface and recharge the saturated region (Yeh et al., 2008). In terms of the groundwater recharge, the areas with flat land are classified as the *very good* with significantly higher infiltration, while the areas with gentle slopes have runoff with somewhat undulating terrain, therefore, it is considered as the *good* for the groundwater storage. In terms of possible groundwater zones, the regions with steeper slopes are classified as the *poor* because of the occurrence of high runoff and low infiltration. The slopes of the study area are calculated in degrees based on the DEM model using the ArcGIS 10.3 and it is classified into five groups as; *Low, Very Low, Medium, High,* and *Very High* as shown in Fig. 9. The *Very Low* slopes (0–8.92°) cover largely the western, southwestern, and partial eastern parts of the region and they are more favorable for the groundwater potential zones. The *Very High* slopes (39.39–78.48°) cover parts of the northern, northeastern, eastern, and southwestern regions, indicating high runoff and no groundwater infiltration.

3.6. Land use/land cover (LULC)

The land use and land cover primarily indicate the nature and extent of the land by providing detailed information. From a hydrological point of view, the land cover has a strong impact on the groundwater and it affects the rate of recharge, runoff, and evapotranspiration. For instance, water bodies and snowy areas are favorable for the groundwater potential zones, whereas the wastelands and build up lands are being considered to be unsuitable for the groundwater generation. The land use and land cover changes are one of the major anthropogenic activities that change the production and development of the groundwater resources. They are important indicators of the extent of groundwater requirements and groundwater utilization (Jhariya et al., 2016). Presently, the Remote Sensing (RS) and the GIS technologies have been widely used to obtain the accurate land use/land cover mapping information.

The land use/land cover is included in this study as an important factor influencing the groundwater recharge process. As shown in Fig. 10, the KRB contains 13 different land cover classes, namely, *Barren or Sparsely vegetated, Close Shrublands, Croplands, Evergreen Needle leaf forest, Grasslands, Mixed forests, Open Shrublands, Permanent Wetlands, Savannas, Snow and Ice, Urban and Build-Up, Water Bodies,* and *Woody Savannas*. Of 13 land cover classes, the Grasslands, and the Barren or Sparsely vegetated ones are the most extensive classes that cover 35 396 km^2 (49%), and 21 924 km^2 (30.2%) of the total basin area, respectively.

3.7. Soil

In the assessment of the groundwater recharge and quality, soil type plays a vital role. Mogaji et al. (2014) stated the water-retaining capacity, infiltration, and permeability are all depend on the soil type. Hence, the soil type thematic layer is created from the soil survey data collected by the United States Department of Agriculture (USDA). As shown in Fig. 11, the KRB has 11 different soil types, each of which has its own influence on the regional groundwater system. Among these; the *Xerochrepts with Xerorthents, Rocky land with Lithic Haplocryids, and Rocky land with Lithic Cryorthents* soils are found to be the extensive classes that cover 16 583 km^2, 12 919 km^2, and 12 581 km^2 areas, respectively. The *Xerochrepts with Xerorthents* soils have strong sloping and thus lose water through the runoff, indicating an inadequate groundwater potential zones. Among the 11 soil classes, the *Torripsamments* type soils support more vegetation than other soils with an aridic moisture regime, presumably because they lose less water as the runoff and represent favorable groundwater potential zones (USDA, 1999).

4. Normalized weights for thematic maps based on the Analytic Hierarchy Process

A pairwise comparison matrix is used under the Analytic Hierarchy Process (AHP) method to compare the significance of the two layer maps to demonstrate that one has a greater impact on the groundwater generation than the others. The AHP uses the Saaty's scales 1–9 to create a judgment matrix, assigns weights to the elements of each rank, and calculates their relative importance. The value of 1 represents *Equally important* and 9 represents *Extremely important* (Saaty 1980). More details of the other relative importance values are shown in Table 4. The

Table 1
Assigned weights of different thematic layers and their corresponding sub-classes.

Influencing Factors	Classes	Potentiality for the groundwater storage	Rank	Factors on the recharge potentiality capacity in % or Normalized Weight (W)	Weighted rating of each class	Area (km^2)
Rainfall	166–203	Very Low	1	0.31 = 31%	31	1572
	203.4–240.8	Low	2		62	5993
	240.81–278.19	Medium	3		93	33 905
	278.2–315.19	High	4		124	24 951
	315.6–352.99	Very High	5		155	6148
Lithology	Andesitic tuff	Low	2	0.28 = 28%	56	229
	Basalt	Medium	3		84	1068
	Fan alluvium and colluvium	High	4		112	4069
	Lava	Low	2		56	5125
	Rhyolite	Low	2		56	12
	Till	Very Low	1		28	55
	Travertine	Low	2		56	378
	Volcanic and sedimentary rocks	Medium	3		84	313
	Basaltic and esite and basalt	Medium	3		84	128
	Clay and shale	Very Low	1		28	6993
	Conglomerate and sandstone	Very High	5		140	9766
	Diorite and plagiogranite	Very Low	1		28	315
	Gabbro and diorite	Very Low	1		28	1067
	Gneiss	Very Low	1		28	15 104
	Granite	Very Low	1		28	6331
	Limestone and dolomite	High	4		112	5627
	Metamorphic rocks	Low	2		56	735
	Rhyolite to andesite	Medium	3		84	0.6
	Sand	High	4		112	13 810
	Schist and phyllite	Low	2		56	519
Lineament Density	<0.081	Very Low	1	0.12 = 12%	12	28 053
	0.081–0.161	Low	2		24	14 129
	0.161–0.242	Medium	3		36	11 820
	1.242–0.323	High	4		48	12 457
	>0.407	Very High	5		60	6191
Drainage Density	0.21–0.54	Very High	5	0.10 = 10%	50	5208
	0.54–0.88	High	4		40	8292
	0.88–1.21	Medium	3		30	27 697
	1.21–1.55	Low	2		20	22 486
	1.55–1.88	Very Low	1		10	8967
Slope	0–9	Very High	5	0.05 = 5%	25	58 385
	9–19	High	4		20	5683
	19–29	Medium	3		15	3842
	29–39	Low	2		10	3333
	39–78.5	Very Low	1		5	1402
Soil	Calcixeralfs with Xerochrepts	Very Low	1	0.06 = 6%	6	3279
	Haplocambids with Torriorthents	Low	2		12	8920
	Haplocambids with Torripsamments	Low	2		12	118
	Rocky land with ice-capped bare rock	High	4		24	999
	Rocky land with Lithic Cryorthents	Low	2		12	12 581
	Rocky land with Lithic Haplocambids	Medium	3		18	12 555
	Rocky land with Lithic Haplocryids	Low	2		12	12 919
	Torrifluvents with Torripsamments	Very Low	1		30	1541
	Torriorthents with Torrifluvents	Very High	5		6	664
	Xerochrepts with Xerorthents	Low	2		12	16 583
	Xerorthents with Xeropsamments	Low	2		12	1014
Land use/Land cover	Barren or Sparsely Vegetated	Medium	3	0.07 = 7%	21	21 924
	Closed Shrublands	Medium	3		21	27
	Croplands	Low	2		14	2074
	Evergreen Needleleaf Forest	Low	2		14	196
	Grasslands	Very Low	1		7	35 396
	Mixed Forest	Low	2		14	0.57
	Open Shrublands	Very Low	1		7	7700
	Permanent Wetlands	Medium	3		21	32

(*continued on next page*)

Table 1 (*continued*)

Influencing Factors	Classes	Potentiality for the groundwater storage	Rank	Factors on the recharge potentiality capacity in % or Normalized Weight (W)	Weighted rating of each class	Area (km^2)
	Savannas	Low	2		14	4520
	Snow and Ice	Very High	5		35	189
	Urban and Built-Up	Very Low	1		7	132
	Water Bodies	Very High	5		35	3
	Woody Savannas	Low	2		14	429

Table 2
Meteorological data (ministry of energy and water of Afghanistan).

Meteorological data period 2009–2018				
Stations	Latitude (N)	Longitude (E)	Elevation (m)	Drainage Area (km^2)
Pul-i-Kama	34.46870556	70.55703056	558	26 005
Naghlo	34.63726389	69.71703611	998	26 046
Pul-i-Qarghayi	34.54697778	70.24248889	643	6155
Bagh-i-Omomi	35.14879722	69.28754167	1587	205
Tang-i-Gulbahar	35.14879722	69.28868333	1625	3565
Bagh-i-Lala	35.15176111	69.22051111	1698	485
Pul-i-Ashawa	35.08880000	69.14188611	1624	4020
Qala-i-Malek	34.57745833	69.97010278	2211	69
Asmar	34.91500833	71.20171667	832	19 960
Chaghasarai	34.90926944	71.12883611	847	3855
Dakah	34.23070556	71.03855	419	67 370
Doabi	35.34829722	69.61877222	2059	789
Keraman	35.28355278	69.65692778	2232	110
Khawak	35.56481111	69.89494167	2405	369
Omarz	35.375825	69.64085278	2042	2240
Nawabad	34.81969167	71.12031944	796	23 960
Payin-i-Qargha	34.55253889	69.03574444	1970	1970
Pul-i-Surkh	34.36684167	68.76965278	2216	1305
Shokhi	34.93616667	69.48439444	1374	10 850
Pul-i-Behsod	34.442347	70.459831	555	36 980
Tang-i-Sayedan	34.408975	69.10441111	1870	1625

weights are assigned to various thematic layers based on the existing literature review and field experience. The applied weights of different thematic layers are normalized by the eigenvector and the AHP technique. The normalization process reduces the subjectivity associated with the assigned weights of the thematic maps and their features (Machiwal et al., 2010). The Consistency Ratio (CR) is applied to check the consistency of the normalized weights of the thematic layers. The CR is computed by performing the following steps:

Step 1: Create the judgment matrices by the pairwise comparison (see Table 5):

$$A = \begin{bmatrix} P11 & P12 & \cdots & P1n \\ P21 & P22 & P23 & P2n \\ \vdots & \vdots & \ddots & \vdots \\ P1n & P2n & \cdots & Pnn \end{bmatrix} \quad (3)$$

where, P_{ij} being the judgment matrix element.
Step 2: Calculate the normalized weights (see Table 6) as follows:

$$W_n = \frac{GM_n}{\sum_{n=1}^{Nf} GM_n} \quad (4)$$

where the geometric mean of the ith row of the judgment matrix is calculated as follows:

$$GM_n = \sqrt[Nf]{P1n^*P2n^*.....PnNf} \quad (5)$$

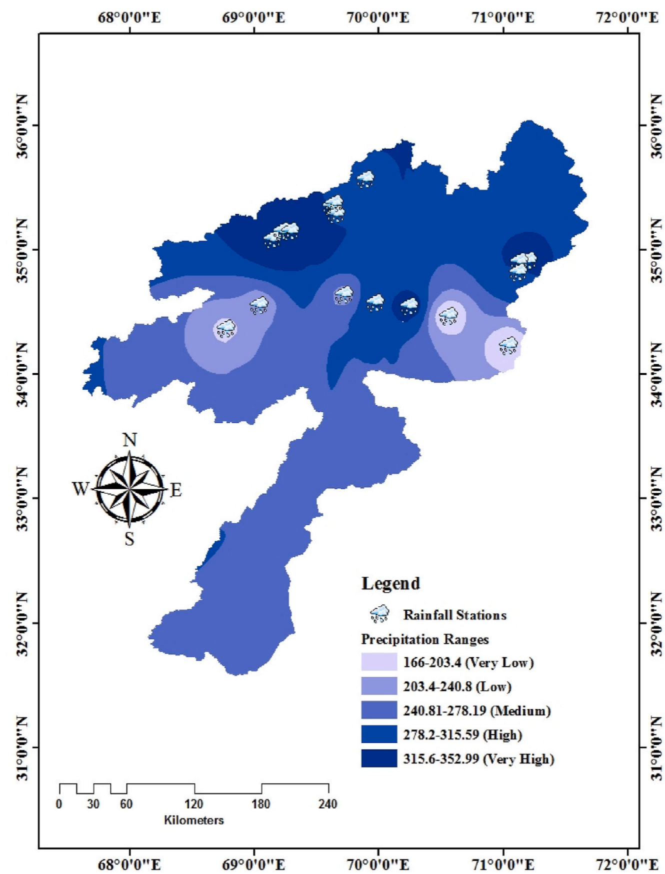

Fig. 8. Average annual rainfall map of the KRB.

Step 3: Calculate the Consistency Ratio (CR), (see Table 7):

$$CR = \frac{CI}{RCI} \quad (6)$$

where, CI is the Consistency Index and RCI is the random consistency index that can be obtained from the Standard Table given in Saaty (1980). In this study, for N = 7, the value of RCI is 1.45 (see Table 4).
Step 4: Calculate the Consistency Index (CI) as follows (see Table 7):

$$CI = \frac{(\lambda\max - N_f)}{N_f - 1} \quad (7)$$

where, N_f shows the number of criteria or factors, and λ_{max} is the principal eigenvalue which can be computed as follows (see Table 7):

$$\lambda\max = \sum_{n=1}^{Nf} \frac{AW_n}{Nf^*W_n} \quad (8)$$

where, W is defined as the weight vector.

For consistent weights, the value of consistency ratio (CR) should be less than 10%, if not, the related weights should be re-evaluated to

Table 3
Precipitation statistics at gauging stations.

Rainfall Statistics (2009–2018)				
Stations	Max Rainfall (mm)	Min Rainfall (mm)	Mean Rainfall (mm)	Standard Deviation (mm)
Pul-i-Kama	114.4	0.003	16	20.6
Naghlo	186	0.1	24.33	30
Pul-i-Qarghayi	134	0.21	22.2	27.3
Bagh-i-Omomi	195.3	0.6	37.21	49
Tang-i-Gulbahar	194.5	0.0012	38	47.2
Bagh-i-Lala	233	0.002	39.20	51.8
Pul-i-Ashawa	207.7	0.003	32	41
Qala-i-Malek	159	0.001	31.20	33.11
Asmar	140.2	2.03	38	32.2
Chaghasarai	152.3	0.5	37.6	32.2
Dakah	119.5	0.002	20/76	23.3
Doabi	174	0.4	30	36.2
Keraman	167.4	0.001	29.35	33
Khawak	138	0.001	23.55	29.7
Omarz	164.4	0.001	29	35.55
Nawabad	127	1	36	31.20
Payin-i-Qargha	145.5	0.1	30.47	34.5
Pul-i-Surkh	131.5	0.117	27	29.5

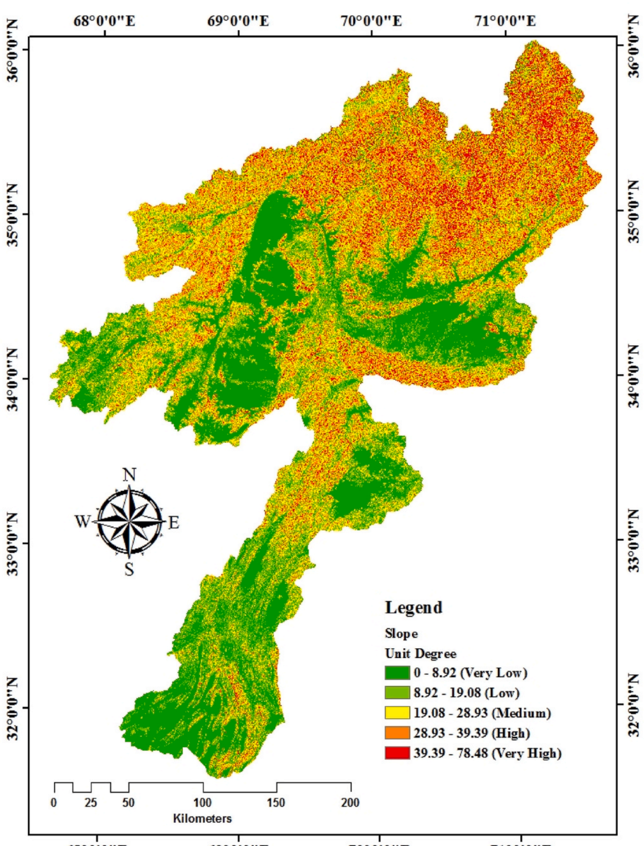

Fig. 9. Slope map of the KRB.

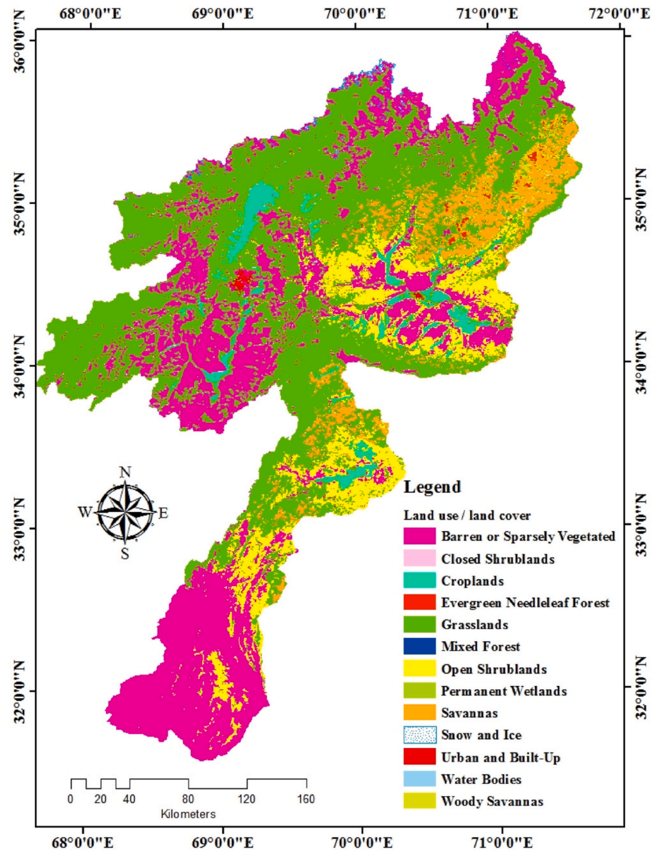

Fig. 10. Land use/Land cover map of the KRB.

prevent the inconsistency. Refereeing to Table 7, it can be seen that the value of CR (4%) is less than 10% indicating that there is a reasonable level of consistency in the pairwise comparison and hence the weights of 0.31, 0.28, 0.12, 0.10, 0.05, 0.06, and 0.07 (i.e. 31%, 28%, 12%, 10%, 5%, 6%, and 7%, respectively) can be assigned to rainfall, lithology, lineament density, drainage density, slope, soil, and land use/land cover, respectively.

The thematic layers for each factor are categorized based on the groundwater storage potentiality. The groundwater storage potentiality of each factor is reclassified to a uniform rank of 1–5, the value of 1 indicates *very low*, and 5 shows *very high* groundwater storage potential. The thematic layers with the influence weightage and the corresponding rank of each parameter are shown in Table 1. Finally, the weighted overlay option in the ArcGIS is used and the influence weighted values are added for each thematic layer in order to generate the groundwater potential zones of the study area, as presented in Fig. 12 in the next section.

The crisp values are used to assign the weightages in AHP method and this makes it more applicable to create a potential groundwater zone map especially in the data-scarce areas (Rahmati et al., 2014). However, note that, there are other methods that do not assign crisp values, rather employ the Multi Criteria Decision Analysis (MCDA) methods using the machine learning algorithms (Swetha et al., 2017; Andualem and Demeke 2019; Jesiya and Gopinath 2020).

5. Results and discussion

All the seven thematic layers of *rainfall, lithology, lineament density, drainage density, soil, slope, and land use/land cover* are integrated into the ArcGIS software and a single groundwater potential map is generated by assigning the different influence weight values to each thematic layer and to their corresponding classes under the GIS weighted overlay option (see Table 1). The groundwater potential map of the study area is classified into 4 groups as *poor, very poor, good, and very good* based on the input thematic layers (see Fig. 12). The *poor* and the *good* areas of the groundwater potential zones are found to be randomly distributed over the study area (KRB) that occupy about 56% and 39% of the total basin

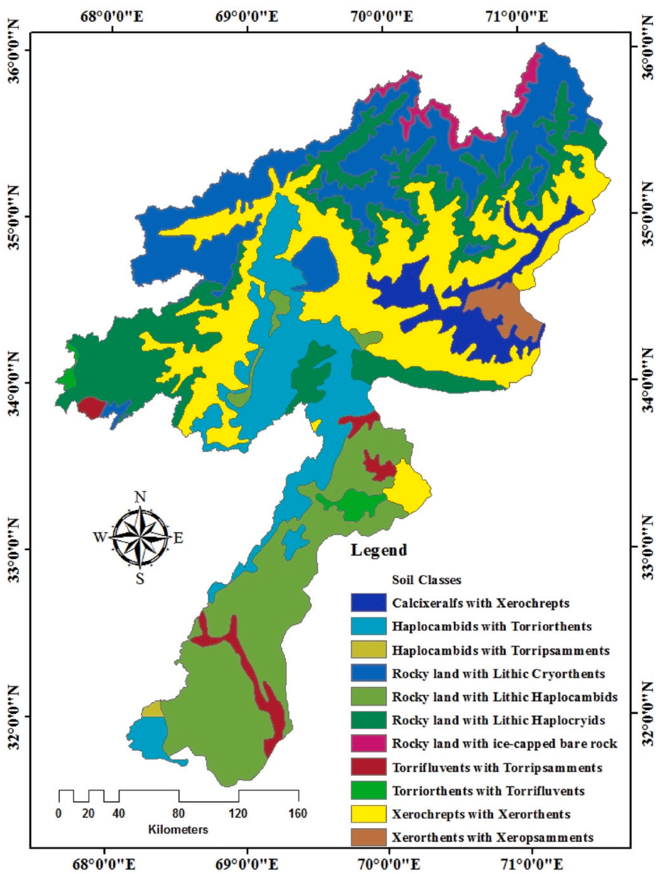

Fig. 11. Soil map of the KRB.

area, respectively. The *very poor* area of the groundwater potential zones that cover around 3.2% of the total basin area are mostly located in the west, southwest, and in some central parts of the basin. The *very good* groundwater potential regions, located in the south, southeast, north, northeast, and in some parts of the southwest, constitute about 2.2% of the total study area. In general, the downstream part of the study area is considered to be the most favorable for the groundwater potential due to the distribution of gravelly stratum and agricultural land with a high infiltration ability and less runoff. Additionally, the location of high drainage density in the downstream parts of the area has a strong effect on the groundwater and helps the streamflow to recharge the groundwater system. The upstream part of the study area has low groundwater potential, which could be due to the gentle slopes of the regions or the location of some lithological factors that decrease the infiltration of water and increase the surface runoff.

The recharge potential zones found in this study are used to estimate the amount of water recharged to subsurface medium (Table 8). As mentioned before, the average annual rainfall of the KRB is estimated to be around 530 mm/year and the total surface area of the basin is 72 000 km^2 and therefore the total volume of the precipitated water of the KRB is computed as about 3.82×10^{10} m^3/year. The following equation is used to estimate the total recharged water (W) of the four potential zones.

$$W = P^{*}R^{*}\%A \tag{9}$$

where P indicates the volume of the precipitated water, R represents the recharge ratio from Table 8, and A shows percentage of the area. Thus,

$$W = 3.82 * 10^{10}[(0.475 * 0.022) + (0.325 * 0.39) + (0.075 * 0.56) + (0.025 * 0.032)] = 6.876 * 10^{9} m^{3} / year$$

This indicates that from the total precipitated water, only 18% contributes to the groundwater recharge, and the remaining 82% is lost by either through evapotranspiration or by the surface runoff.

6. Summary and conclusions

The groundwater potential zones in Kabul River Basin in Afghanistan are determined using the state of the art technology. By the GIS, the maps of *rainfall, lithology, land use/land cover, slope, soil, drainage density, and lineament density* are first prepared. Then, the AHP is employed to assess the weights of different themes. The generated groundwater potential zone (GWPZ) map of the study area is classified into four as the *very good, good, poor*, and *very poor,* covering areas of 2.2%, 39%, 56%, and 3.2% of the basin, respectively. The *Very Good* zones are found to be located in the downstream and central parts of the basin while the *Good* and the *Poor* zones are randomly distributed, occupying the larger portions of the basin and the *Very Poor* zones are located in the west, southwest, and in some central parts of the basin. The contribution to the recharge from the precipitation is found about 18%.

The following conclusions are drawn from this study:

Table 4
Scale of relative importance and RCI values.

Definition	equally important	extremely less important	strongly less important	less important	moderately less important	moderately important	strong important	very strong or demonstrated important	extremely important
Intensity of Importance	1	2	3	4	5	6	7	8	9
n	3	4	5	6	7	8	9	10	11
RCI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Table 5
Matrix of pair-wise comparisons of 7 criteria for the AHP process.

Parameters	Rainfall	Lithology	Lineament Density	Drainage Density	Slope	Soil	Land use/Land cover
Rainfall	1	1	5	4	6	5	2
Lithology	1	1	3	3	4	6	3
Lineament Density	1/5	1/3	1	1	3	3	2
Drainage Density	1/4	1/3	1	1	3	1	2
Slope	1/6	1/4	1/3	1/3	1	1	1
Soil	1/5	1/6	1/3	1	1	1	1
Land use/Land cover	1/2	1/3	1/2	1/2	1	1	1
TOTAL	**3.32**	**3.415**	**11.17**	**10.83**	**19**	**18**	**12**

Table 6
Normalized Weight calculation.

Parameters	Rainfall	Lithology	Lineament Density	Drainage Density	Slope	Soil	Land use/Land cover	Normalized Weight (W)
Rainfall	0.301	0.29	0.45	0.37	0.31	0.28	0.17	0.31
Lithology	0.30	0.29	0.27	0.28	0.21	0.33	0.25	0.28
Lineament Density	0.06	0.09	0.08	0.09	0.16	0.17	0.17	0.12
Drainage Density	0.07	0.09	0.08	0.09	0.16	0.05	0.17	0.10
Slope	0.05	0.07	0.03	0.03	0.05	0.05	0.08	0.05
Soil	0.06	0.05	0.03	0.09	0.05	0.05	0.08	0.06
Land use/Land cover	0.15	0.09	0.04	0.05	0.05	0.05	0.08	0.07
TOTAL	**≅ 1**	**≅ 1**	**≅ 1**	**≅ 1**	**≅ 1**	**≅ 1**	**≅ 1**	**0.99 ≅ 1**

Table 7
Consistency vector, λ_{max}, CI, and CR calculation.

Parameters		Consistency vector	λ_{max}	CI	CR
Rainfall	0.31(1)+0.28(1)+0.12(5)+0.10(4)+0.05(6)+0.06(5)+0.07(2) = 2.33	2.33/0.31 = 7.52	51.68/7 = 7.38	0.063	0.04 = 4% < 10%
Lithology	0.31(1)+0.28(1)+0.12(3)+0.10(3)+0.05(4)+0.06(6)+0.07(3) = 2.03	2.03/0.28 = 7.25			
Lineament Density	0.31(1/5)+0.28(1/3)+0.12(1)+0.10(1)+0.05(3)+0.06(3)+0.07(2) = 0.84	0.84/0.12 = 7			
Drainage Density	0.31(1/4)+0.28(1/3)+0.12(1)+0.10(1)+0.05(3)+0.06(1)+0.07(2) = 0.74	0.75/0.10 = 7.5			
Slope	0.31(1/6)+0.28(1/4)+0.12(1/3)+0.10(1/3)+0.05(1)+0.06(1)+0.07(1) = 0.375	0.375/0.05 = 7.5			
Soil	0.31(1/5)+0.28(1/6)+0.12(1/3)+0.10(1)+0.05(1)+0.06(1)+0.07(1) = 0.43	0.43/0.06 = 7.2			
Land use/Land cover	0.31(1/2)+0.28(1/3)+0.12(1/2)+0.10(1/2)+0.05(1)+0.06(1)+0.07(1) = 0.54	0.54/0.07 = 7.71			
TOTAL		**51.68**			

1. The rainwater is quite important for the groundwater regeneration.
2. From the total precipitated water, only 18% contributes to the groundwater.
3. The *good* GWPZ clearly shows that the KRB has sufficient groundwater potential.
4. The *good* and the *very good* zones would have a key role in the future expansion of the drinking water and irrigation development.
5. The creation of reservoirs or digging of pits, especially in snowy areas would be useful to recharge the groundwater.
6. The gentle to mild steep slopes regions are deemed to be fair areas for the groundwater recharge processes. These regions could be used for the development of water management structures such as the check dam, water absorption trench, and farm ponds to store rainwater and to avoid excess surface runoff.

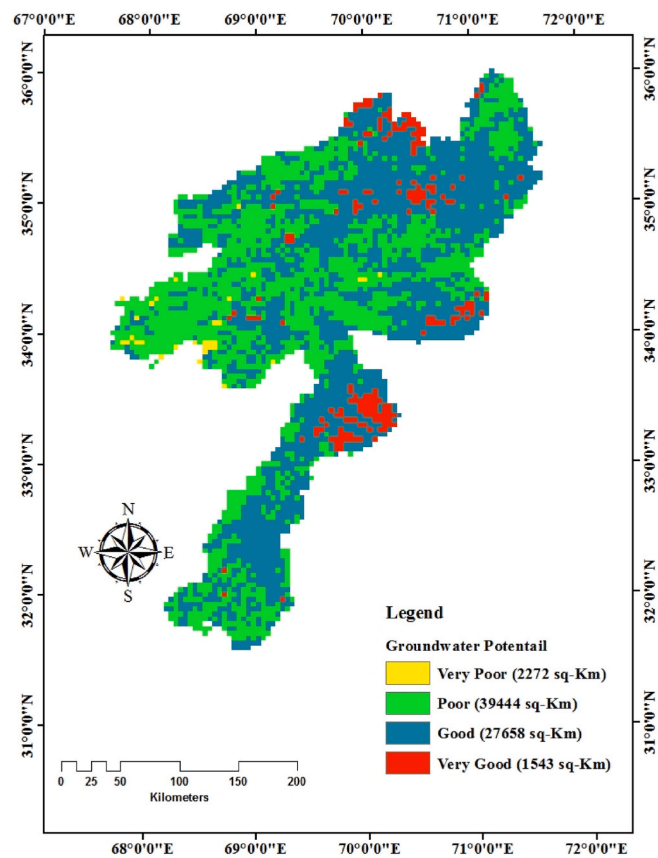

Fig. 12. Groundwater potential zones of the KRB.

Table 8
Categorization of groundwater recharge potential zones.

Recharge potential category	Very High	High	Moderate	Low	Very Low
Estimates according to FAO[a]	45–50%	30–35%	10–20%	5–10%	<5%
Average Recharge ratio (%)[a]	47.5	32.5	15	7.5	2.5
Area extent (km^2)	1543	27 658	–	39 444	2272
Area extent (%)	2.2	39	–	56	3.2

[a] Shaban et al. (2005) and Souissi et al. (2018).

7. The recognition and selection of the appropriate number of thematic layers and the legitimate allocation of the weights are the key factors in the GIS applications for the determination of the potential groundwater resource zones.
8. The GIS-based AHP method for the groundwater potential mapping could be successfully implemented.

Population growth, climate change, improper digging of deep wells, violations of government-mandated laws, and long-standing droughts are all factors contributing to the depletion of groundwater in the region. Therefore, it is imperative that the government should take some necessary steps to prevent the groundwater shortages in the area. Hence, some sort of sustainability measures, such as the creation of reservoirs or digging of pits, especially in snowy areas would be useful to recharge the groundwater.

Sufficient groundwater level data (well data) are required to validate the generated map. Unfortunately, in a country like Afghanistan which has been in a war since 1979, there is substantial lack of data that makes the validation impossible. However, by using the art of the technology and the actual available data on the precipitation, soil, land use, land cover, slope, etc., this study was able to generate the groundwater potential zone map for the basin. This map can be beneficial for the authorities to develop water resources management strategies and projects at the basin. The GWPZ map could also be applied for the drought risk assessment in the basin.

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Availability of data and material

The data that support the findings of this study may be available from the Ministry of Energy and Water of Afghanistan, upon request.

Code availability

Not applicable.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publish

Not applicable.

Authors' contributions

Hamidullah Tani: Carried out all the data collections and model applications and contributed on the writing of the paper. Gokmen Tayfur: Discussed the application problems and modelling tools, advised the student during the research, and revised the paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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