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GIS-based multi criteria decision analysis techniques used to identify potential groundwater recharge zones in Quetta Valley, Pakistan

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ABSTRACT

Many urban centres worldwide must depend on groundwater resources for domestic water supply due to less deteriorate and accessibility. The unplanned population growth and anthropogenic activities has been affected the sustainability of groundwater resources globally. Quetta, the provincial headquarter of largest province of Pakistan, is facing serious issues of water scarcity, decline and less recharge. The objective of current study is to identify groundwater recharge potential zone using latest techniques of multi criteria decision analysis based on geographic information system and remote sensing applications for the Quetta Valley. The satellite images and other data sources are used to develop the thematic layers, viz., land use land cover, drainage density, lineament density, soil, rainfall, slope, geology, and geomorphology of the study area using various tools within ArcGIS. By using multicriteria decision analysis technique, the thematic layers are integrated and weighted overlay index analysis is employed to rank the parameter by its influence on groundwater recharge. Based on multi criteria decision analysis technique, the weight is allocated to each significant parameter. The recharge zones map is categories into three categories: high, moderate, and poor zones base on groundwater recharge potential. The final map covers 48.9% high recharge area and moderate recharge area 28.2% while least recharge is observed in 22.9% area of total study area. The final map of potential groundwater recharge zone could help to suggest artificial recharge sites groundwater in the study area to sustain depleting groundwater resources which could be Urak, Balali, Jinnah Town, Killi Chiltan Lehri, Nawa Killi etc. The findings are useful for water resource development and management for provincial headquarter of biggest province of Pakistan.

Keywords: Groundwater; Geographical information system; Recharge zones; Remote sensing; Multi criteria decision analysis; Quetta

1. Introduction

Water is undoubtedly a crucial natural resource for the matter of life on earth and important for socio-economic development [1]. Surface water and groundwater both are significant contributions to support various anthropogenic activities. The surface water and precipitation infiltration could sustain groundwater level and enhance its quality [2]. Groundwater is a substantial natural resource of freshwater which supports food security, health of human, the

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economic development of an area, ecological diversity, and the sustainability of agriculture [3–5], however, its availability is confined.

According to United Nations, the average availability of water should be 50–100 L/cap [6], but barely 38 L water per capita is made available and accessible to around 60% of the population of Balochistan, hence there has been a huge gap between needs of water and availability of water in the province of Balochistan, Pakistan. Durrani et al. [7] established that misuse of groundwater is significantly higher than the rate of recharge, which is the key reason of depletion of water table uninterruptedly. Another researcher presented his verdicts and explored that depletion of groundwater has an adjacent connection within precipitation variation. Faces of drought has affected replenishment of groundwater whereas changes in water table highly depend on consumption or demand [8]. Poor management of water amplified by increase in population and climate change effects pushed Balochistan to unparalleled situation of shortage of water where water recharge is considerably slower than the utilization that creates crisis of water in present and future [9].

Recharge of groundwater is determined by spatial variation in lithology formations. These regulate the penetration and filtration of water into the aquifer and its consequent movement into the groundwater [10]. There are several methods that are in use to assess the governing factors of status and recharge of groundwater. Generally, resources of groundwater can be evaluated by means of geophysical, geological and hydrogeological methods [11]. Various researchers have efficiently implemented geospatial technologies to demarcate groundwater in recharge zones. These conservative methods are frequently costly, time-consuming, and labor-intensive and are consequently considered inefficient [12,13], particularly in large drainage basins. Geology, geomorphology and hydrogeology are the natural factors that play a vital role in determining the potential of groundwater, but it is now progressively affected by anthropological activities because of the variations in land use or land cover, distressing the variation and quality of groundwater level [14,15]. In turn, such variations are very much dependent on the following factors: geological formation, geomorphology, the soil textural characteristics, lineaments, slope, and the density of drainage [16,17].

Geographical information system (GIS) and remote sensing (RS) have been broadly utilized over the last decade as an operative tool that is time efficient and economical, specifically in the appraisal of the water resources [18,19]. It is used in assessing, evaluating, monitoring, and exploring water resources [20–22]. GIS and remote sensing are utilized to make diverse kinds of thematic layers (maps) and amalgamate them for several purposes of groundwater resource mapping. Potential zone of groundwater recharge is principally evaluated utilizing techniques of remote sensing (RS) and data of geophysical, hydrogeological, and geological. Mapping of groundwater recharge potential zone has become easier and more economic in current years because of developments in modern geospatial techniques for hydrological applications. Literatures identify that many researchers have integrated statistical approach analytic hierarchy process (AHP) with GIS tools to identify groundwater potential recharge zones [23,24] and, machine learning [25]. Among the various multi-criteria decision analysis (MCDA) techniques, AHP is widely used to delineate groundwater recharge zones [12,26]. On the bases of the sensitivity and importance of each selected parameter, the AHP technique was proposed for potential recharge zoning in the study area.

Therefore, these tools are considered best for this research to explore the recharge potential zones at Quetta Valley.

The identification of feasible sites of artificial recharge is grounded on a knowledge-driven parameters examination that takes into consideration a diversity of parameters which include geology, geomorphology, lineament density, slope, type of soil and density of drainage [27,28]. Mapping of groundwater recharge potential zone would aid creative management of this important source and decrease the susceptibility of groundwater of the region in study. The objective of this research is to outline the potential groundwater recharge zones in Quetta, Balochistan, Pakistan and to suggest proper artificial recharge structures at the recognized sites. The main objectives of present research were to develop thematic maps of relative parameters, allocate appropriate weightage and ranking utilizing the technique of multi-influencing factor, and delineate potential recharge zone employing AHP method in GIS environment. The key findings of this study will provide valuable information for decision-makers and government agencies to develop a sustainable plan for the groundwater use and its management for Quetta Valley.

2. Description of the study area

This study is designed for the Quetta Valley to cover a total area about 1,697 km^2. The provincial headquarters of the province Balochistan, Pakistan (Quetta city) is situated in the Quetta Valley, which is included in the top ten cities of Pakistan with respect to its population. It is located between latitude 30.05° N and 30.45° N and longitude 66.733° E and 67.3° E, respectively [29].

The valley of Quetta is surrounded by the mountains of Murdar, Chiltan, Takatu, Zarghoon in which gaps between mountains are used for roads and railway tracks. The northern Takatu Mountains lead towards Chaman Spin Boldak border with Afghanistan. The gap in Mashlak hills in the west leads towards Noshki to Zahidan border with Iran. The Chiltan hills gap through Lak pass in the south leads towards Mastung which opens the routes towards Kalat and Bolan pass. The Zarghoon and Murdar hills in the east-north lead towards Punjab through Loralai and Barkhan, respectively [30].

The last census held in 2017 counted total population of the district as 2,275,699 persons with 44% in urban areas and 56% in rural. The annual population growth rate was observed 3.27% in Quetta. There were 276,711 housing units recorded in 2017 with average 8.2 persons per household. Quetta consists of four Tehsils and 38 Union Councils [31]. The area considered for this study is focused on the Quetta Valley which is shown in Fig. 1. Quetta has a clear weather pattern in which rainy season is seen in December. Quetta has dry periods in May, June, July, August, September and October (Fig. 2). Thereby, on average, June is the driest month.

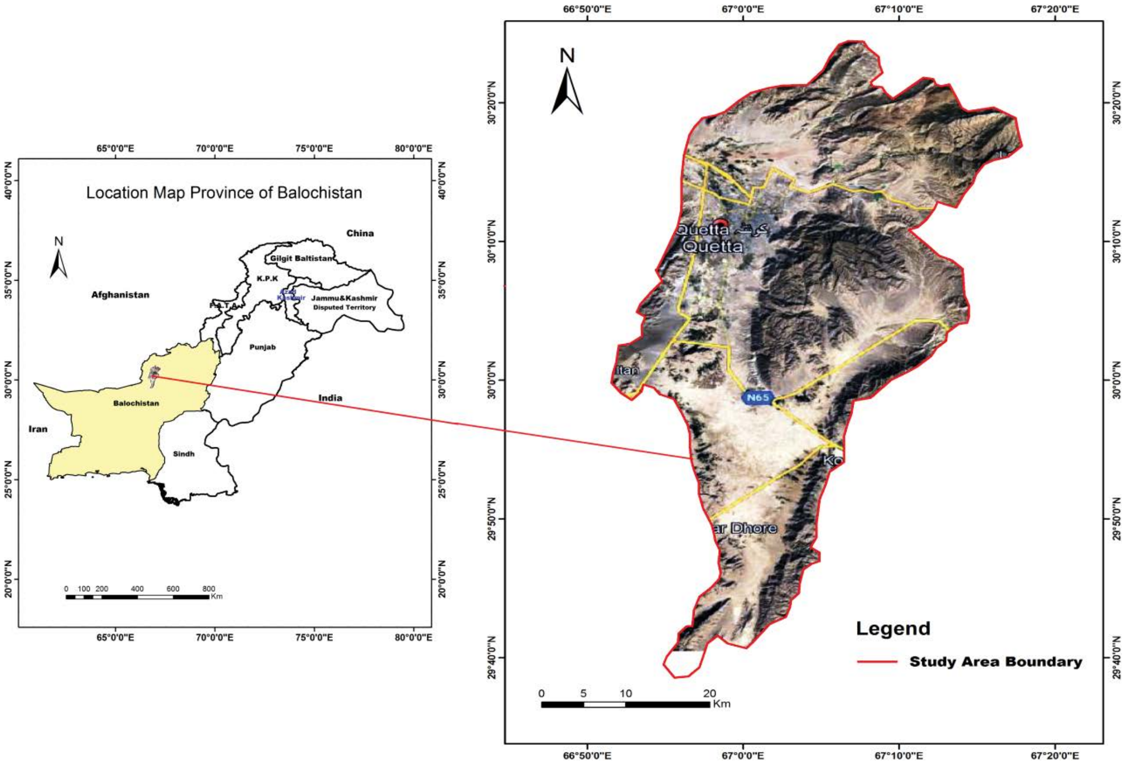

Fig. 1. Location map of the study area.

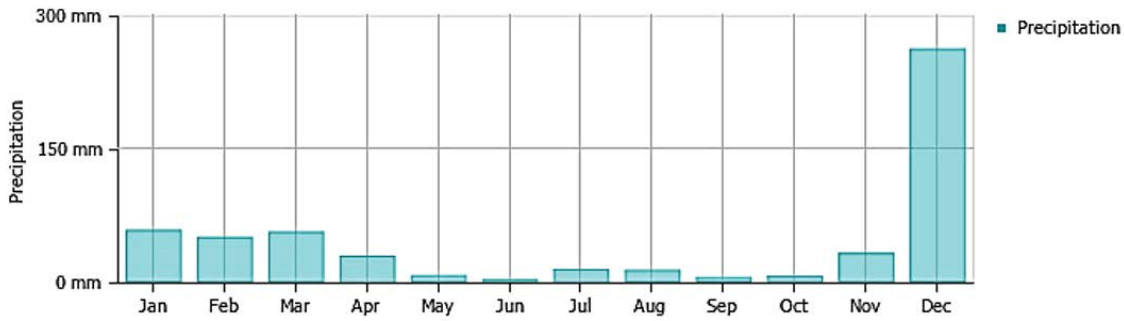

Fig. 2. Average precipitation in Quetta Valley, Pakistan (Source: www.weather-and-climate.com).

From the perspective of both rain and snow, December is the wettest month.

2.1. Geology and hydrology of Quetta Valley

The location of Balochistan is in Triassic strata, characterized by plentiful tectonic and sedimentary basins. This province comprises of Sulaiman (middle Indus), the Balochistan Basin and part of the seam of the Indus and Kirthar of the Indo-Pakistan subcontinent, a portion of Gondwana. The Balochistan Basin is disengaged from the Suleiman Basin to the northeast by a seam region called "Indus Suture" and from "Kirthar Basin" in the southeast. The suture of the Indus is a belt that is subdivided into a northern belt (a general east-west trend in the north) [32].

Quetta Valley is a totally groundwater dependent area. The groundwater is extracted through the boreholes at an alarming rate in the region. Groundwater exhaustion is hasty, and the problematic nature is getting weightier due to rapidly increasing population, industrialization, deforestation, less than average precipitation, irrigation, and domestic uses. The water table is draining at an alarming rate due to which Quetta Valley is fronting deficiency of water and will no longer depend on groundwater. The water resources of Quetta city are decreasing quickly and are limited and cannot sustain the demand for the existing population, agriculture, industry, and nature for long [33].

2.2. Data

The parameters that influence the recharge of groundwater are geomorphology, geology, drainage density, texture of soil, lineament density, slope, and land use or land cover. All these parameters and their causes of base map collection are briefed in Table 1. Thematic maps of all the parameters that affect replenishment of groundwater were made utilizing images of remotely sensed satellite and GIS software to delineate recharge potential zones.

3. Methodology

To obtain the final groundwater recharge potential zone map of the study area, ranks and weightage were assigned to each thematic map using the multi-influencing factor (MIF) technique [34]. Then, employing the weighted overlay index (WOI) method in GIS environment, a final groundwater recharge potential zone map was developed by overlaying the thematic maps of selected parameters.

3.1. Multi-influencing factor (MIF) technique

The technique of multi-influencing factor appraises the distinct weight that has been prearranged to each factor measured in the study [35]. Each factor which is taken into consideration effects some other factor, but the outcome also fluctuates within them. This inter-relationship amongst diverse aspects was scrutinized with the assistance of the MIF technique. All the relationships were weighted rendering to their influence on recharge of groundwater. The summations of all the weights from other variable quantities that have negligible and main influences on the one under contemplation are concise in Table 2. The factors assigned high value have a higher effect on the capacity of recharge of groundwater than those with lesser values. The final groundwater potential zone map was developed by merging all these variables, as well as their potential weights, with the tool of weighted overlay index analysis in GIS environment.

3.2. Weighted overlay index (WOI) technique

The popular MIF technique was utilized to study the effect of one factor on other factors. To develop the final groundwater potential recharge zone map, the thematic layers were overlapped in a weighted combination after gauging the discrete potential weight of each factor [36]. The thematic layer that has the highest weight was placed at the topmost. All the other layers overlapped in the reducing order of their weights. After the categorization of overlaying was concluded, implementation of tool of WOI analysis in GIS was done. The tool provides the final potential zones map, in which there is division the entire area of study into different groundwater recharge potential zones.

The most popular multicriteria decision-making (MCDM) tool which is analytical hierarchical process (AHP) model used to find solutions of complex problems and introduced by Saaty [37]. However, AHP based developed models are widely acceptable to probe groundwater related issues by assigning weight to each thematic layer employed for the model.

4. Results and discussions

The methods, techniques and base maps that are narrated in methodology part were used to produce all the thematic

Table 1
Factors and data sources used in this study

S. No.	Factors	Source of collection
1	Drainage density	Digital Elevation Model (DEM) from USGS
2	Geology	Geological Survey of Pakistan
3	Geomorphology	Satellite images from EarthExplorer USGS
4	Lineament density	Digital Elevation Model (DEM) from USGS
5	Land use/land cover	Landsat image from EarthExplorer USGS
6	Slope	Digital Elevation Model (DEM) from USGS
7	Soil	Soil survey of Pakistan
8	Rainfall	Pakistan Meteorological Department

Base maps of these factors were utilized for preparing different thematic maps in ArcGIS (Version 10.8).

Table 2
Inter-relationship among the selected factors

S. No.	Considered factors	Major impacts	Minor impacts
1	Soil	LULC	
2	Geology	Drainage density, soil, slope, lineament density	
3	Slope	Geology	LULC, geomorphology
4	Geomorphology	LULC	Drainage density, soil
5	Drainage density	LULC	Lineament density
6	Land use land cover	Drainage density, geomorphology	Soil, lineament density slope, geology
7	Lineament density	Drainage density, LULC	
8	Rain	Drainage density, lineament density, soil	

layers required for the development of the proposed maps. This segment includes the procedure of making thematic maps and creating potential groundwater recharge zone map for the Quetta Valley.

4.1. Thematic map preparation

The thematic maps of selected parameters are prepared using available data and interpreted with result with the help of appropriate references.

4.2. Land use land cover map

Map of land use and land cover (LULC) a major aspect that affects the groundwater recharge, occurrence of groundwater, and its availability [38]. In the study area, LULC map gives the crucial evidence linked to numerous categories of land use and topographic features. The data (satellite image of 2021) extracted from the Landsat 8 (OLI) with resolution 30 m was used to develop LULC map. Superintended picture cataloguing was led to categorize and recognize LULC type. Diverse variety of LULC units exists in Quetta Valley is built-up area, infertile land, and area of vegetation and water bodies (Fig. 3a). By downloading image of Landsat from Earth Explorer (https://earthexplorer.usgs.gov/), a LULC map was created utilizing the best-case scenario classification processing instrument in GIS software. There is a direct association of the vegetative cover to surface runoff in any region and it impacts capacity of recharge [39]. The greater is vegetative area density (6.54% of total area), The faster the rate of infiltration, the less surface runoff there will be. Aqua body (0.06% of total study area) demonstrates the maximum capacity of recharge; however, the calculated built-up area is 11.3%, the recharge is practically insignificant due to the building of the cemented surfaces, which eases substantial runoff. Infertile land covers major region with 82.1% that does not contribute meaning fully because of the formation of soil. Various studies explored that LULC changes are significantly impact to control groundwater recharge, pollution infiltration and leads various environmental problem in an area [40,41]. Dawood explored during a study at Quetta that LULC classes are gradually changing due to human activities and urbanization. Therefore, a significant change was observed in the Built-up area during 2008 to 2018 at Quetta [42].

4.3. Geology map

Geological formation of a particular area has a significant influence on the groundwater distribution and its incidence. Any region's geology regulates the rocks that are exposed and capacities of soil infiltration and defines the measure and stowing of resources of water. Lithology that includes the gigantic rock, laterally with the area topology, stimuli the presence of groundwater. Fig. 3b shows the geological distribution the area under research study. The existing geological units in this research area includes: mixture of alluvium gravel, coarse, Jurassic sedimentary rocks and Jurassic and

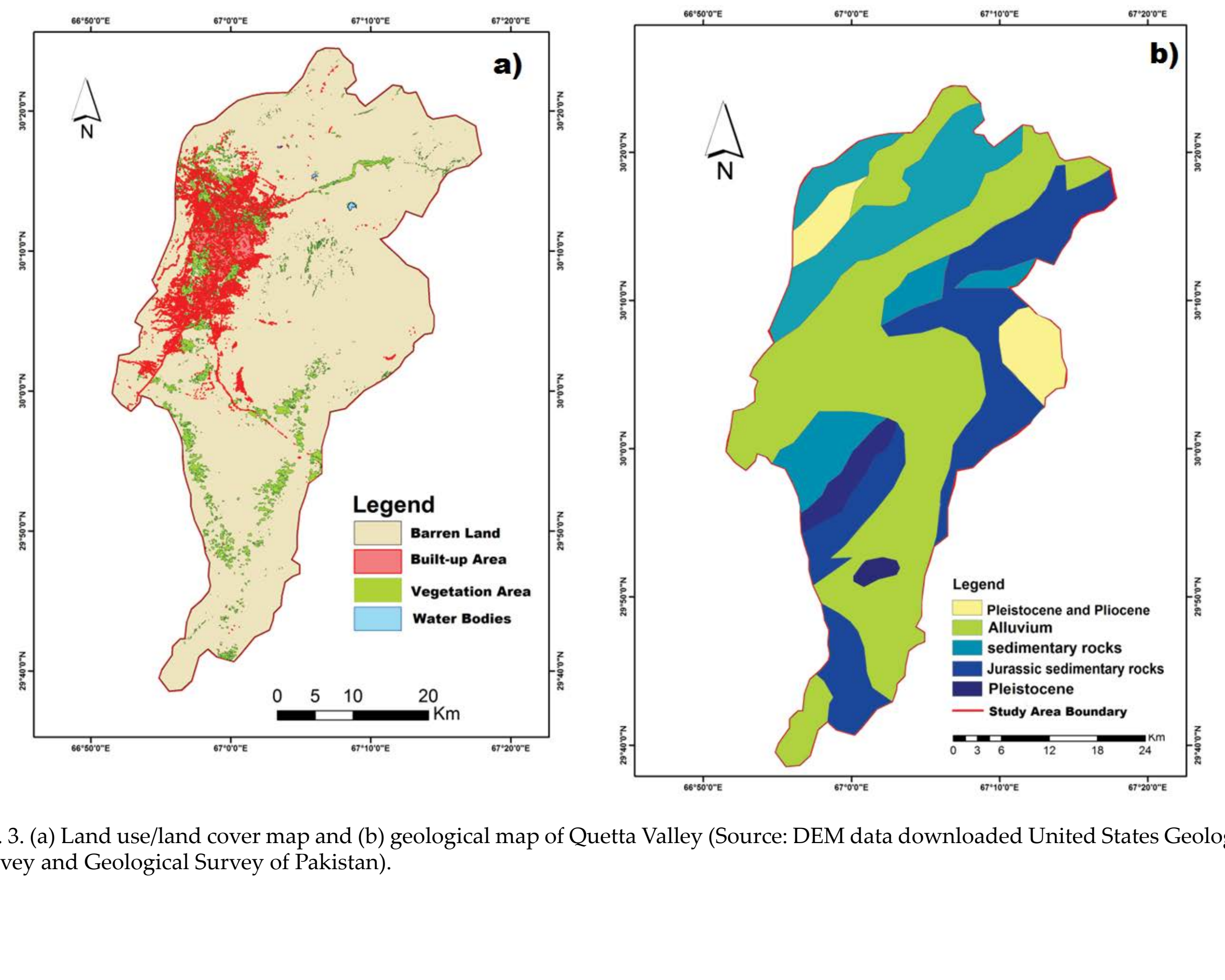

Fig. 3. (a) Land use/land cover map and (b) geological map of Quetta Valley (Source: DEM data downloaded United States Geological Survey and Geological Survey of Pakistan).

Triassic sedimentary rocks and Pleistocene and Pliocene sedimentary rocks. Alluvium geologic foundations are decent sources of recharge of groundwater in comparison to other geology formations. The soil media and aquifer lithology formation are considered to control infiltration process due to soil particles size and its composition [43].

4.4. Geomorphology map

Among the utmost vital concerns in defining potential zones of groundwater is geomorphology. It signifies an area's landform and topography and also the info connected to their dispersal. Elevation being the only landscape constituent and is measured as outward benchmark to discover potential of aquifer [43]. The underground progression of water is administered by the geomorphic units present in that zone. The recharging potential of any surface is critically impacted by geomorphology. The study area's geomorphologic map is shown in Fig. 4a. In this study area the major geomorphic units are high and moderate hills and valleys, alluvial plains and piedmont slope. The drainage network map is developed from Digital Elevation Model (DEM) and shows five levels of drains in Fig. 4b.

4.5. Slope map

The slop of a watershed explains the quantity of water accessible for recharge, run off time and terrain ruggedness. Areas with steep angles of elevation cause large volume of water runoff and lowering the time given for infiltration [44]. Henceforth, slope is among the dominant features affecting rate of infiltration and runoff. In the current study the slope was established through SRTM DEM. Allocation of weights for each class of slope were given on the basis of the level of potential of groundwater. The slope can be utilized as a vital appropriateness factor for recharge of groundwater. Subsequently it impacts the infiltration capability of the soil. A slope having lesser value agrees to runoff of smaller surface, and henceforth, infiltration value being more and vice-versa. Flat surface makes available supreme circumstances for infiltration. As the slope upsurges the run-off rises and infiltration declines. In maximum study area slope is fewer than 15%. Fig. 5a displays the variation in the slope value at Quetta Valley that ranges between 0 to 68%. High slop gradient could enhance the fluid run off capacity [43], while results show high slope value at Quetta Valley. Therefore, less groundwater rechange due to steep slope and less time to stay at valley to infiltrate [45].

4.6. Drainage density map

Groundwater prospect is directly inversely related to drainage density [46]. Drainage density, which may be thought of as the total length of the rivers and streams in the watershed divided by the total area of the drainage watershed, demonstrates the closeness of stream channel typography. The likelihood of a groundwater potential zone is diminished by expanding seepage thickness [47]. Hereafter, in ArcGIS, the strategy for piece thickness has been led to figure thickness of waste. The seepage network in the locale

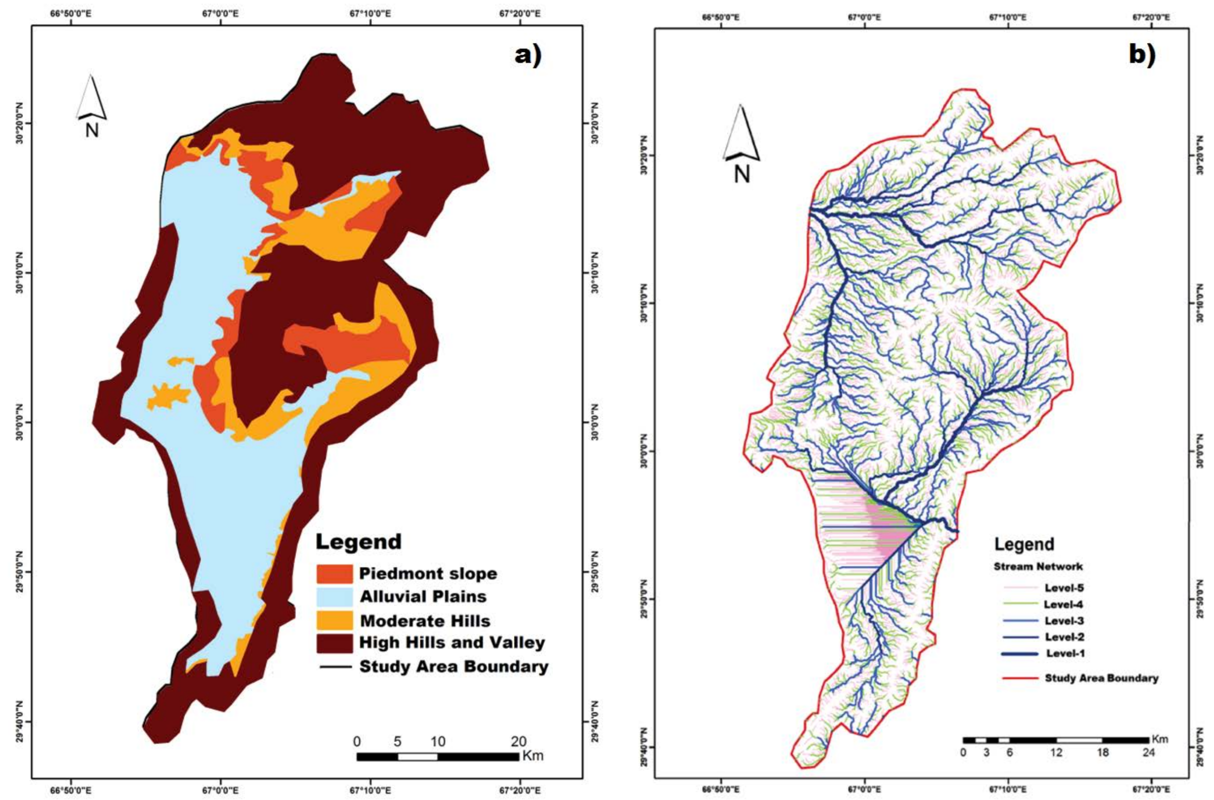

Fig. 4. Computed graphical representation of (a) geomorphology map and (b) drainage network map of Quetta Valley.

was gotten from the digital elevation mode and modernized with the assistance of satellite picture (Fig. 5b). The following formulae has been used the map exhibits that maximum research region is offset by modest to little sewerage mass denoting to higher groundwater infiltration and recharge.

$$DD = \sum \frac{LWS}{AWS} \quad (1)$$

where DD shows the sewerage mass in the formulae and the all-out length of streams in the catchment-basin are denoted with LWS, and the area of a watershed is denoted by AWS.

In any area of catchment, drainage density is defined as the ratio between whole distance covered by every one of the principal and irrelevant streams to the absolute surface region by using units' km/km^2. This is a crucial parameter to appraise the prediction of groundwater as it is always correlated to the permeability and porosity of the surface. Greater drainage density value outcomes in greater runoff and low infiltration, which distresses the capability of recharge directly. A lower drainage density shows high infiltration, clearly showing it is contributing more in potential of groundwater. The review region's seepage thickness was named most minimal (0–1 km/km^2), low (1.001–2 km/km^2), moderate (2.001–3 km/km^2), high (3.001–4 km/km^2) and the most noteworthy (4.001–5 km/km^2). Fig. 5b shows the drainage density variation in the study region.

4.7. Soil map

Soil is the upper layer of the earth and supports the percolation of water towards the aquifer [48]. Various types of soil have a noteworthy function recharging of groundwater and the area's capacity to store water [46]. The soil categories and texture of an area principally affects outflow and the rate of surface water percolation in groundwater, henceforth; it impacts the soil recharging ability directly. The suitable site for artificial recharge depends on the soil types. The appropriate soil type will be the one having a high infiltration rate, while soils that have low rate of infiltration are not regarded appropriate. In this study region, coarse loamy calcareous soil, fine loamy soil loamy skeletal soil, well-drained thermic fine loamy soil, and loamy skeletal soils with reasonable stoniness are believed to be the main types of soil. Fig. 6a shows numerous soil types of distribution within the area under study.

4.8. Precipitation

Precipitation is another significant aspect that affects the water intrusion to a susceptible aquifer [49]. Various factors are responsible for controlling precipitation frequency in the area such as climate changes, altitude, LULC change etc. The precipitation type and its concentration affect the recharge rate [42,50]. Rate of recharge to the reservoir rises during the snowfall and slow events of rainfall that have

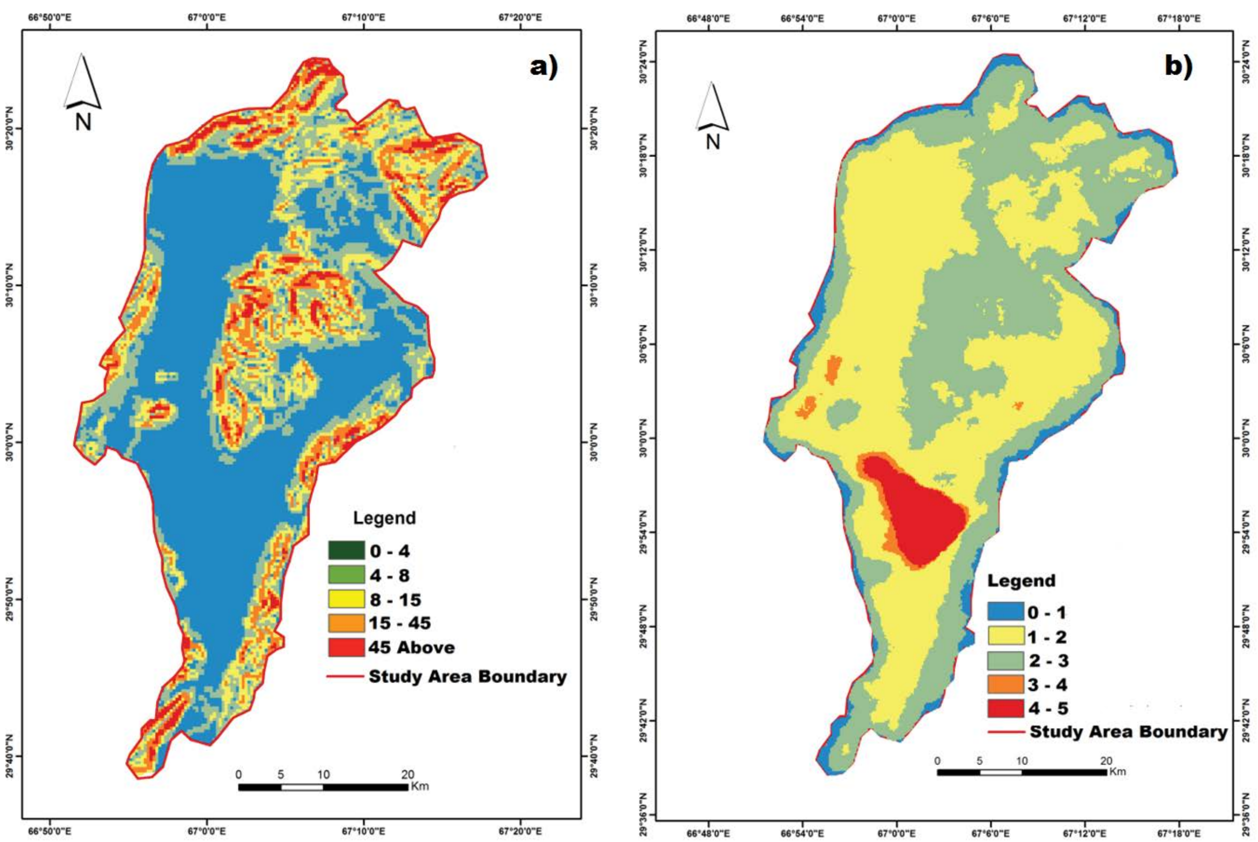

Fig. 5. (a) Slope map and (b) drainage density map of Quetta Valley.

greater notches as compared to the storm rainfall. The map of precipitation based on GIS of the area of study was created and shown in Fig. 6b. The area of study has been facing a condition of drought since the last 15 y [45], the average rainfall data of last 30 y has been observed at Quetta between 256 to 338 mm.

4.9. Lineament density map

A lineament represents the linear feature of basic geological structure [51]. These lineaments have a much capacity to hold water and assist in the durability of transmission of water. Underlying earth's linear characteristics, such as joints, folds, and fractures define the contours of the specific region. Lineament thickness is straightforwardly proportionate to the zone of groundwater re-energize. The lineament thickness was depicted as the entire component of the multitude of noted shapes separated by the locale that is under consultation [52]. The existence of features in any region is advantageous as it upsurges the hydraulic conduction, porosity of the surface of land. In a geographical landscape a lineament is a straight element, which is a sign of fundamental topographical design [4,51]. The ongoing review used the thickness of lineament, that portrays the amount of length of lineament as a unit region, as expressed [53,54].

$$L_d = \frac{\sum_{i=1}^{i=n} L_i}{A} \tag{2}$$

$\sum_{i=1}^{i=n} L_i$ = symbolizes the sum of lineament length and A designates the unit area.

The target of the lineament investigation is thusly to extend information on the relationship between the invasion of surface water and crack frameworks, administering infiltration of water and its development. The guide lineament thickness shows that the high and low piece of the explored watershed was estimated a remarkable and favorable zone of groundwater (Fig. 7).

4.10. Assignment of weightage and ranking to each factor

Remote sensing techniques and GIS applications are the most popular tools for groundwater assessment and recharge zoning among hydrologists and researchers. GIS-based multi-criteria decision-making (MCDM) is a very effective technique for the water resources planning and management [48]. All the factors and the parameters linked with those factors are assigned weights and ranks. MIF technique was used to allot particular weights to each factor. As per a significant and a minor effect, the weighting is 1 and 0.5, individually. The absolute weight decides the general significance of each contributing element. The specific load for a variable was processed using the condition beneath:

$$W = \frac{P + Q}{\sum(P + Q)} \times 100 \tag{3}$$

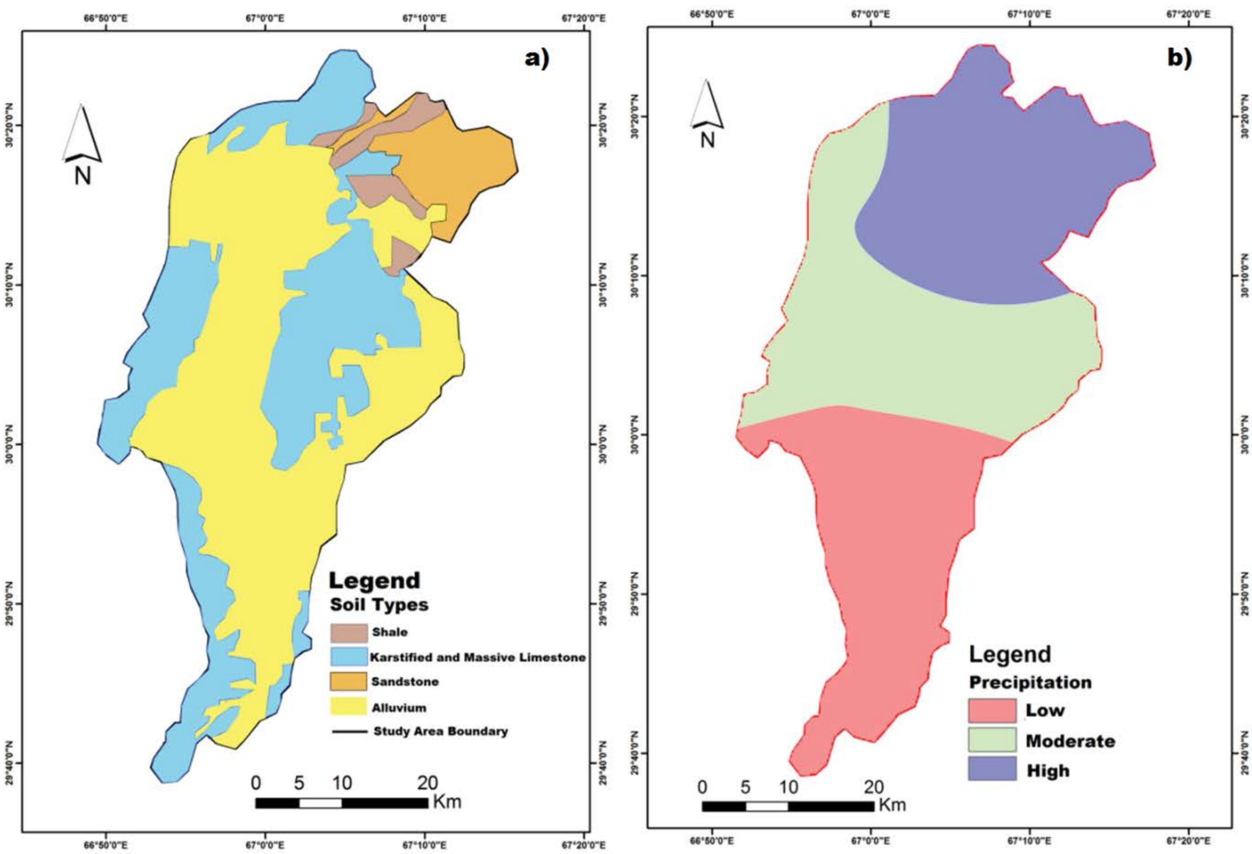

Fig. 6. (a) Soil map and (b) precipitation map of Quetta Valley.

where the major impacts in Eq. (3) is denoted by *P* and minor impacts among two influencing factors are denoted by *Q*.

Table 3 displays the individual weights assigned to each factor.

Each related factor was given a score considering its effectiveness on groundwater re-energize after the last unambiguous not entirely set in stone. Table 4 provides a detailed description of the matching weights and rankings assigned to each attribute.

Professionals have given contrasted ratings on the basis of Saaty's 1–9 scale (Table 5) for controlling each conditioning factor mass. By using a pairwise comparison matrix, conditioning factors were compared against each factor. For every thematic layer using inverted ranking has been approved to allot a normalized weight. The groundwater potential zones are signified by the ranking between 1–5, such as lowest, low, medium, high, and the highest respectively [55,56].

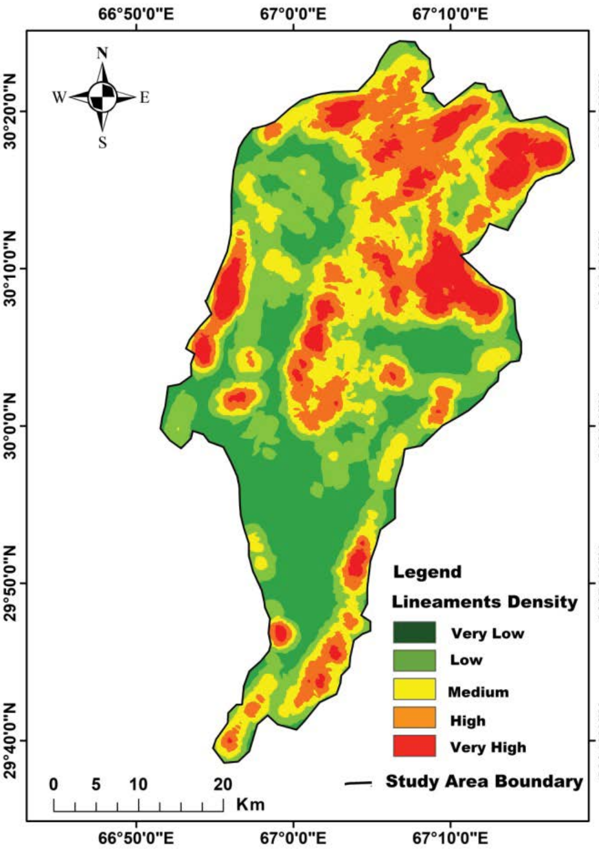

Fig. 7. Lineaments density map of Quetta Valley.

4.11. Groundwater recharge zone map

By combining all the thematic maps with the collected ranks and weights in GIS using the weighted overlay analysis tool, the potential groundwater recharge zones map was created of Quetta Valley (Fig. 8). The established map is categorized into three diverse classes of potential groundwater recharge zones of re-energize, that is, exceptionally high, moderate and poor. The category of high potential recharge zone covers about 829.8 km^2 which is 48.9% of total area. Additionally, the category moderate potential recharge zone and poor recharge zone comprises of 478.6 and 388.6 km^2 of the watershed under study, respectively (Fig. 8).

The maximum region contiguous high potential zones of recharge are streams and areas of vegetation. The AHP map shows distribution of groundwater with maximum GWP potentials mostly near the study area's northern region. Few areas of the research zone, which runs from north to south, would be more capable of utilizing their groundwater resources. Small pockets of high and the highest GWP are found between the northern and southern tips of the review area's watershed, however most of the watershed has been assigned as poor or the least fortunate. Because of lower precipitation and topographical attributes, the western and eastern bits of the Quetta watershed are viewed as having substandard groundwater potential recharge areas. The information from the yield of the drag wells is utilized to decide the end-product guide of the conceivable groundwater zone created utilizing the AHP technique. Following, as shown by the outcomes and obviously apparent from field perception, land use, land cover, precipitation, rise, and seepage thickness impact the versatility and sign of groundwater in the examination district. Considering the final recharge zone map, it is probably going to create maintainable groundwater the board and water system rehearses in light of the fact that the region is great for agrarian.

Table 3
Impact score, relative rates and individual weight of selected factors

Sr.#	Factors major	Impact score (P)	Minor impact score (Q)	Relative rates (P + Q)	Individual weight (W)
1	Geology	1 + 1 + 1 + 1		4	24
2	LULC	1 + 1	0.5 + 0.5 + 0.5 + 0.5	4	24
3	Geomorphology	1	0.5 + 0.5	2	12
4	Slope	1	0.5 + 0.5	2	12
5	Lineament density	1 + 1		2	12
6	Drainage density	1	0.5	1.5	10
7	Soil	1		1	9
8	Rain	1	0.5	1.5	9
			Total	18	100

Table 4
Assigned rank and weightage of selected factors

S. No.	Factors/themes	Associated parameter	Rank (in words)	Rank (in number)	Weightage (%)
1	LULC	Water bodies	Very high	1	24
		Vegetations area	High	2	
		Built-up area	Moderate	3	
		Barren land	Poor	5	
2	Geology	Alluvium mixture of gravel, coarse	Very high	1	24
		Pleistocene and Pliocene sedimentary rocks Jurassic sedimentary rocks	Low	2	
		Jurassic and Triassic sedimentary rocks	Poor	4	
		Pleistocene		5	
3	Geomorphology	Alluvial plains	Very high	1	12
		Highly hills and valley	Poor	4	
		Piedmont slope	High	2	
		Moderately hills	Moderate	3	
4	Lineament	Present very	Very high	1	12
		Not present	Very poor	5	
5	Slope	0%–4%	Very high	1	12
		4%–8%	High	2	
		8%–15%	Moderate	3	
		15%–45%	Poor	4	
		<45%	Very poor	5	
6	Drainage density	4.001–5 km/km	Very poor	1	10
		3.001–4 km/km	Poor	2	
		2.001–3 km/km	Moderate	3	
		1.001–2 km/km	High	4	
		0–1 km/km	Very high	5	
7	Soil	Shale	Poor	1	9
		Limestone	Moderate	2	
		Sandstone	High	3	
		Alluvium	Very high	4	
8	Rain	<300	High	3	9
		300–200	Moderate	2	
		>200	Low	1	

The groundwater potential recharge map was categorized into three zones, namely, 'poor', 'moderate', and 'high'. Total covered study area is 1,697 km^2. Fig. 9 shows the percentage of the potential recharge zones of the three categories whereas maximum areas in Quetta Valley have a "high" recharge area with 48.9% while "moderate" and "poor" recharge zones have 28.2% and 22.9%, respectively. Loe Nekan, Spezand, Shah Barhah, Pashtun Abad and Akhtar Abad are in "poor" recharge zone while Killi Sarangzai, Dagari and Sardar Khal exist in poor potential recharge zone area. Chashma Achozai, Chiltan, Haji Bahram Khan Town, Zahri Town and Kumbela are located in high recharge zone as computed using various factor in this research. The "high" recharge zone area has good potential for the artificial recharge structure to sustain depleting water resources of Quetta Valley. Various research findings support that the Quetta Valley has potential to recharge because of the alluvial fan in valley [57] but water depends on frequency of precipitation. Quetta Valley has been facing several sever and medium drought spells during last three decades [58].

The findings of this research work revealed that the latest techniques of AHP, GIS and remote sensing are very effective for the identification and delineating of recharge zones for sustainable groundwater use and regional economic development.

4.12. Proposed artificial recharge structures and their suitable locations

A guide of the groundwater potential recharge zones was developed for Quetta Valley and exhibited that the work of remote detecting, AHP, and GIS procedures is commonsense and successful for recognizing imminent groundwater potential zones. The delivered guides can be utilized to plan a feasible groundwater improvement and the board methodology. One objective of the review was to suggest

Table 5
Saaty's 1–9 scale of relative importance of different factors

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

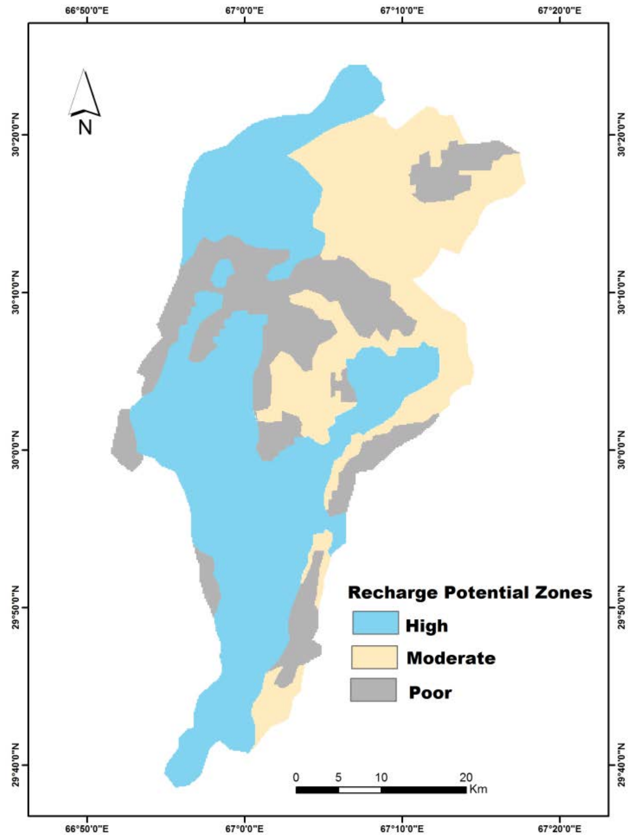

Fig. 8. Final groundwater potential recharge zones map of Quetta Valley.

structures for counterfeit potential in the few appropriate spots in the Quetta Valley. Seepage thickness and lineament thickness topical guides were overlaid to exactly recognize the places where these structures might be constructed.

The key finding of the groundwater potential zones model expressed those significant factors such lineament thickness, topography; incline, height, and so forth unequivocally impact potential zones in the study area. The northern segment of the review district is remembered to have a huge limit with regards to water capacity because of higher precipitation and a more limited degree

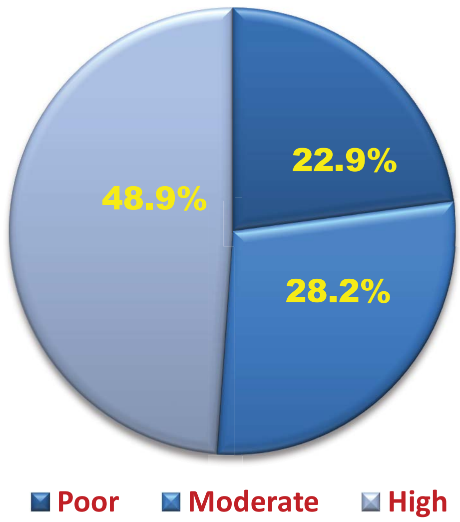

Fig. 9. Area with percentage of three categories of the groundwater potential recharge zones of Quetta Valley.

of slant, as indicated by a guide of the groundwater possible zone (Fig. 8). Most of the area is in the west side, where there is extraordinary potential for groundwater recharge and development. Equivalent outcomes have been seen in other exploration examinations [53]. The guide of groundwater potential recharge zones developed using AHP tool affirmed agreeable result in anticipating the recharge of groundwater in Quetta Valley watershed, Pakistan. Based on the final recharge potential zones map, significant artificial groundwater recharge opportunity is available in Quetta Valley. In Fig. 8, the blue area which is suitable to construct the artificial recharge sites to enhance groundwater table. The developments proposed for poor, moderate and high potential zones incorporate, check dams, rock bunds and permeation tanks.

5. Conclusions

The research demonstrates a method to explore potential groundwater recharge zones and suitable sites of artificial recharge to sustain groundwater resource in Quetta Valley. The multi criteria decision analysis technique used in GIS by employing various parameters such as land use land cover, drainage density, lineament density, soil, rainfall, slope, geology, and geomorphology of the study area. In final potential groundwater recharge zones map, three categories "high", "moderate" and "poor" were used to show different zones. The computed high recharge areas are 829.8 and 478.6 km^2 covers moderate recharge while poor recharge zone consist of 388.2 km^2 in the total study area. Most of built-up area is in high recharge zone. Therefore, the heavy groundwater exploitation and less groundwater recharge opportunity is observed in this area. After a detailed study of all the possible factors, there would be a need to make a master plan of the Quetta Valley which should ensure availability of space for any possible MAR sites and thus preventing built-up areas in that space. The findings of the current study demonstrated that defining possible groundwater recharge zones can be accomplished using a combination of AHP, remote sensing, and GIS techniques. a conclusion that planners can utilize as a starting point for water resource management and land use planning based on the findings of the groundwater potential map. According to groundwater prospective, the application of geospatial technology with the incorporation of AHP approaches is a viable strategy and can be used in the same context. Artificial groundwater recharge, public awareness and wastewater reuse could be effective option to conserve and sustain water resources management at Quetta Valley.

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Declarations

Conflict of interest the authors declare no potential conflict of interest regarding the publication of this paper.

Authors' contributions

All authors listed have made substantial, direct, and intellectual contributions to the work and approved it for publication.

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