Proceedings of the Pakistan Academy of Sciences: B
Life and Environmental Sciences 61(2): 189-198 (2024)

ISSN (Print): 2518-4261; ISSN (Online): 2518-427X
http://doi.org/10.53560/PPASB(61-2)862

Pakistan Academy of Sciences

Research Article

Geographical Information System, Remote Sensing and Multi Influencing Factors Techniques for Delineation of Groundwater Potential Zones in District Charsadda, Khyber Pakhtunkhwa, Pakistan

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Abstract: The effective harvesting of groundwater and its sustainable management is possible with the proper identification of zones on its potential basis. For this purpose, geographical information system (GIS) and Remote Sensing (RS) data approaches were combined and used for the investigation, preservation, and evaluation of groundwater supply. This study aimed to assess groundwater delineation and availability-based potential of groundwater area in Charsadda District, KPK, Pakistan, by applying the approach of RS, GIS, and multi-influencing factors (MIF). For this purpose, digital elevation model (DEM), shuttle radar topographic mission (SRTM), and sentinel 2 satellite images were employed to produce numerous thematic layers, i.e., land use land cover (LULC), drainage density, lineament density, geology, slope soil, and rainfall as MIF in this study. After assigning a fixed score and weight to each thematic layer (MIF techniques), then an analyzed spatial layer was combined with a weighted overlay using ArcGIS software (ArcMap 10.5) and finally potential area for groundwater was defined. The obtained potential area of groundwater was categorized spatially as, very high, high, moderate, and low zones which depict most of the area is covered with moderate (547.66 km^2) to high (306.7 Km^2), as well as, high highest groundwater potential in 7 km^2. The results of this study and the approach will be applicable and insightful for regional and extensive levels of developmental planning and harvesting of groundwater resources.

Keywords: Geographical Information System, Remote Sensing, Multi Influencing Factor, Groundwater Potential Zones, Weighted Overlay Tool.

1. INTRODUCTION

Water is vital resources on earth surfaces which form the foundation as of life [1]. It is present in different forms on the earth surface such as in ocean, glaciers, rivers, lacks, pounds, spring, as well as, underground water. Generally, the groundwater is mentioned for the water quantity present beneath the surface of earth. It is most vital natural resources on which the life of human depends to a great extent. Due to its importance the demand of groundwater for domestic and agriculture purposes is also increasing [2-4]. In perspective of groundwater as a fresh water source, it is now a constraining asset in major regions of the world which may grow further due to expanded population, urbanization and environmental changes. In perspective of largest fresh water source on earth, the potential based assessment of groundwater is crucial to conserve this resource [5]. Groundwater is also a key natural resource for a continuous provision of drinking water. At present, it contributes a major share in the total annual supply of water globally. Hence, sustainable for groundwater management systems, focused assessment for natural resource is very critical. In Pakistan, the groundwater resource is of critical importance due to its agrarian economy. Additionally, modern industrial, population as

Received: March 2023; Revised: May 2024; Accepted: June 2024
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well as agriculture have built-up pressure on groundwater and appropriate accessibility of surface water resources. Hence, there is a need for an applicable approach which is economically viable and gives reliable and time assessment of areas with sustainable groundwater potential. For this purpose, integration of Geographical Information System (GIS) and remote sensing (RS) is a reliable tool to determine and delineate the potential groundwater zones and extensively used for natural resource management [6]. In recent years, applications of satellite data coupled with mapping-based approaches has made it relatively convenient to ground based information for determination of groundwater potential zones [7-9]. Various studies were conducted on the identification and assessment of hidden potential zone of groundwater by applying integrated geospatial approaches and analytical hierarchy process (AHP) [10-14].

The studies with a focus on potential zones of groundwater has already been conducted globally which revealed that various factors which influence the determination of groundwater potential show variations, hence, in accordance, the final results also varied. Integrated studies using conventional data in integration with GIS tools and interpretation of satellite image data techniques are reliable as well as, economically viable and it increases the results of the accuracy [10-15]. Furthermore, it is extensively followed for characterization of the earth surface and assessment of groundwater recharge areas [3]. With combination of geospatial technologies (GIS and RS), potential area for groundwater have been delineated [6, 16]. Other related studies focused on merging of different related geophysical and hydrological factors [3, 17, 18]. These results are based on the field survey and are relatively reliable and varies to region basis due to different geoenvironmental conditions. In northwestern China a comparative study was carried out for simulating groundwater dynamic with applications of machine learning and numerical models, as well as for groundwater potential zone a combined approach of geospatial and geophysical was applied [19-23]. Various studies were conducted with a focus on delineating the groundwater potential for prospective planning using integrated multi-influencing factors (MIF), AHP, GIS modeling and geospatial approaches to find out the potential zones [24-30]. Integration of GIS and RS for preparation of assigned weightage base thematic layers in a spatial domain can help to find out the area of groundwater potential. This research aimed at finding out and demarcate the area of groundwater potential in the Charsadda District of KPK using an integrated approach of multi influencing factors, i.e., soil data, geology, lineaments data, rainfall data, drainage network, slope, Land use land cover (LULC), GIS and RS.

2. MATERIALS AND METHODS

2.1. Study Area

Charsadda District lies within Peshawar Division of KPK province, Pakistan. This area stretches from 34°-03´ to 34°-28´ N latitudes and 71°-28´ to 71°-53´ E longitudes. In the North it is surrounded by Malakand District, Mardan District by East, District Nowshera and Peshawar is on the South and Mohmand agency in the West as shown in Figure 1. On administrative basis, District Charsaddda has three tehsils that are Shabqadar, Charsadda and Tangi. It covers an overall area of 996 km^2 and is situated at an altitude of around 276 meters (906 ft) above sea level. The total population of Charsadda District is 1,835,504 (Census 2023).

In perspective of climatic aspects, summer season in Charsadda District remain hot from May to September. During summer, month of June remains relatively very hot with a temperature rise of over 40 °C. Monsoon season remains from July to September while months of July and August are hot and humid. The summer season changes in October and mid of February. A pleasant spring season starts from mid of the March. Highest summer rainfall prevails in the month of August while in winter, due to western disturbances, rainfall shows high record in the month of March and April.

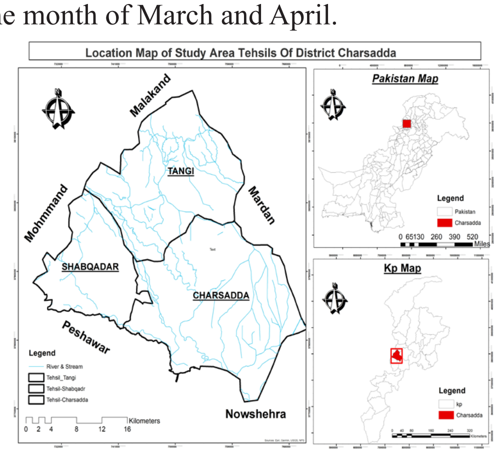

Fig. 1. Study area map.

2.2. Methodology

Weighted overlay analysis and multi influencing factor (MIF) approach are applied as methodology for this research. This approach is robust to retrieve factors which influence groundwater potential. This methodology comprises step wise approach as: the determination of parameters (variable) which have critical influence on groundwater potential. These critical factors are than used in this research to map out potential of groundwater in District Charsadda KPK, Pakistan including rainfall data, lineaments data, geology, soil data, slope, drainage network and LULC. Subsequent step was then weight and rank assignment to these parameters for ensuring uniformity. The final step was weighted overlay method in which all the determined data were reclassified for weighted overlay analysis. The output of the groundwater potential area and weighted overlay analysis is categorized as, low, moderate, high and very high. The flow methodology of present study is shown in Figure 2.

2.2.1. Determination of multi influencing factors (variables)

For the this study the variables which were applied as MIF to determine groundwater potential zones include: geology, soil, slope, LULC and drainage density.

2.2.2. Land use land cover (LULC)

Land use show that how much land is utilized by people for development, conversion and for other usages, i.e., area covered by agriculture, forest, water, built up and barren land. LULC analysis is very critical for groundwater study because the build-up area cannot hold water due to high runoff on that surface; while vegetation like forest, agriculture and plantation can trap and hold water through roots. For this purpose, a 10 m resolution image of sentinel-2 was processed to analyze the LULC. The method includes the process of supervised classification in GIS (ArcMap 10.5) environment. As a spatial output, the whole District was categorized into four different classes including water bodies, barren, vegetation and built up as illustrated in Figure 3.

2.2.3. Slope

Through slope analysis infiltration rate and runoff of surface water was determined. Gentle slope decrease runoff and increase infiltration into surface while steep slope expedites runoff water

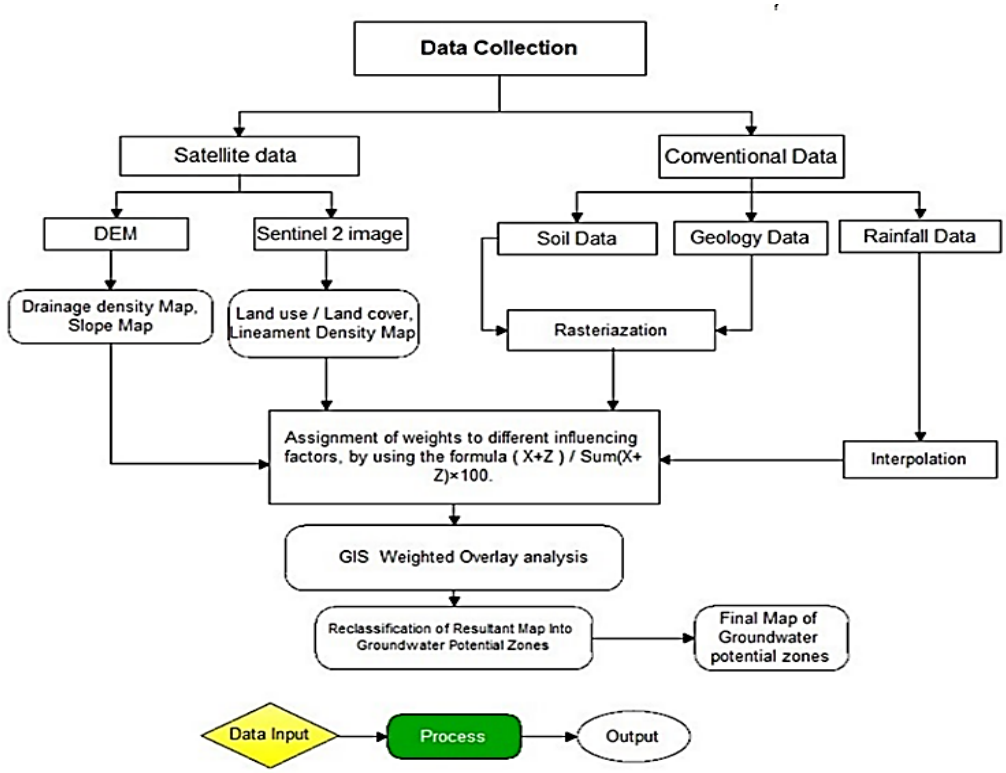

Fig. 2. Methodology flowchart.

and decrease water infiltration into ground. For this purpose, digital elevation model (DEM) and shuttle radar topographic mission (SRTM having 12 m resolution) were analyzed for the slope of study area through Arc Map.

2.2.4. Drainage density

Drainage density is also a critical factor due to its inverse function of permeability. The runoff of water will be high if the drainage density is more and resultantly penetration into ground will be lower while in low drainage density area the runoff going to be low and seepage into ground is more. For this study, drainage density was calculated from DEM data and SRTM with 12 m resolution in Arc Map 10.5 environment through built-in hydrology tools.

2.2.5. Rainfall

For detection of ground water potential based zones, rainfall is one of significant variables. The amount of rainfall due to which the atmospheric variation is not uniform in all places and varies spatially, as well as, temporally. For determining the influence of rainfall in any region, long time data-based study is necessary. When rainfall is high the volume of groundwater will be high, while in low rainfall area, the groundwater volume will also be resultantly low. For this study, the rainfall data of the years 2015 to 2019 was considered which was obtained from Peshawar meteorological station. The tabulated data was imported to ArcGIS environment and interpolated through 'Spatial Analyst' (built-in extension) to extract the spatial results.

2.2.6. Lineament density

Lineament, like a basic geological structure, can be easily identified on the ground. By lineament density, the subsurface faults and fractions, as well as, the presence of groundwater resources can be observed. High lineament density is the indicator of more groundwater while low lineament density means less groundwater. Hence, area with high lineament density have relatively high potential for groundwater. In this study, to extract lineament density, Sentinel 2 image obtained from European Space Agency was processed within PCI Geomatica (2018) software.

2.2.7. Geology

The surface geology determines the presence and distribution of groundwater. The level of groundwater (low or high) depends on the rock type. Rocks with high porosity have more water potential for water storage while low porosity rocks have less water storage capability. The water transfer from recharge area to discharge area during rock formation under the impact of hydraulic gradients is dependent on permeability. For geology of study area, the data was collected from existing geological map of Pakistan.

2.2.8. Soil

Ground and surface water infiltration depends on permeability and porosity of soil; therefore, it is considered one of the most critical factors for delineation of groundwater [6]. The study of soil is critical for determination of groundwater potential zones. To analyze the soil of area, soil map was digitized from soil data which was collected from soil conservation department.

2.2.9. Weight and rank assignment to parameters

For the present study, we selected seven factors such as lineament density, drainage density, rainfall, slope, soil, geology, and LULC, for delineation of groundwater potential zones has diverse influence towards the groundwater. For that purpose, weight of each factor was given depending on its effect to the storage and movement of water [3, 18-31]. Proposed weight of each influencing factors was found by the equation (1) as follows:

$$\frac{X+Z}{\Sigma(X+Z)} \times 100 \tag{1}$$

While, X show major effect while Z show minor effect of factors. Total weightage of each parameter was equally divided among the sub-classes of each parameter. The weigh was assigned to each-sub class between 9 to 1, where 1 shows very low or no groundwater while 9 shows area with possibility of high groundwater concentration [32-36].

2.2.10. Weighted overlay method

The MIF data was subsequently reclassified for weighted overlay analysis. Reclassification was done through ArcMap spatial analysis tool in Arc

GIS. After assigning weightage and ranks, the overlay method was applied on reclassified data through weighted overlay analysis tool in Arc Map. The output of the weighted overlay analysis was resultan spatial product of groundwater potential based zones.

3. RESULTS AND DISCUSSION

3.1. Spatial Results of the Multi Influencing Factors (MIF)

3.1.1. Land use land cover

Supervised classification method was used for LULC mapping acquired from sentinel 2B [37]. Supervised classification image based LULC identification was classified into four classes namely: vegetation, settlement, water body, and barren. Based on its spatial results, most of the area is covered by agriculture. High weightage is given to the spatial class of 'water bodies' as these are excellent resource for groundwater recharge as shown in Figure 3.

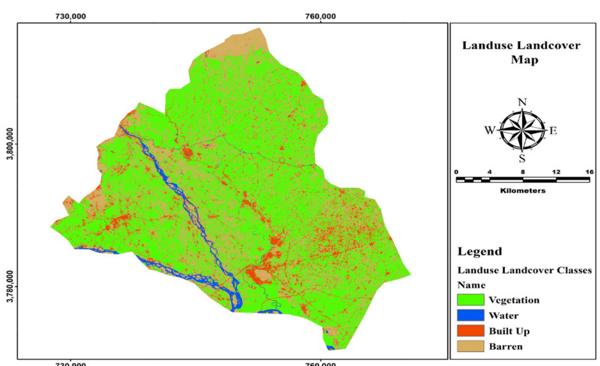

Fig. 3. LULC map.

3.1.2. Slope

Slope map was generated from DEM and categorized as suitable, most suitable, moderate, less suitable and not suitable [37, 38]. Infiltration of water is inversely proportional to runoff on the surface water which determine slope. When slope is increased, water runoff will be increased and vice versa. The slope map (in degree) was spatially classified into five classes: flat (0-2.34°), gentle (2.34-5.39°), moderate (5.39-12.18°), steep slope (12.18-24.37°) and escarpment (24.37-59.75°) as shown in Figure 4. The study area has averagely plain surface (flattened). Therefore, it increases the holding and drainage of water inside ground which resultantly leads to less runoff of water and its more infiltration.

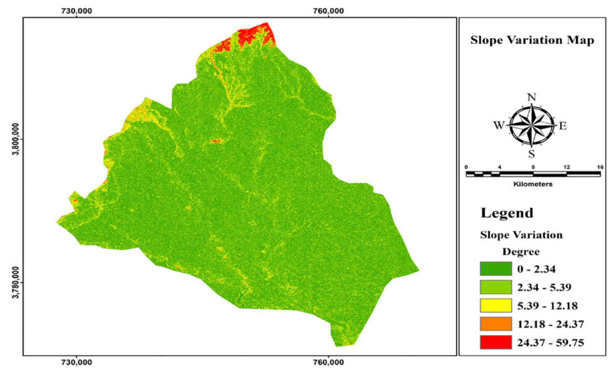

Fig. 4. Slope map.

3.1.3. Drainage density

High drainage density area has low rate of recharge, while area having low drainage density has better potential for groundwater recharge rate due to its inverse relation of groundwater. In previously studies, the drainage density for Islamabad and Rawalpindi was investigated and the map was categorized into five classes [37, 39]. Area of the drainage density extracted from DEM data was spatially categorized into five density classes having values 1-1.8 Km^2 is very low, 1.8-2.6 Km^2 is low, 2.6-3.4 Km^2 is moderate, 3.4-4.2 Km^2 is high and 4.2-5 Km^2 is very high. Figure 5 shows that the area having low drainage density has better potential of groundwater due to less stream and rivers which mean less surface runoff water.

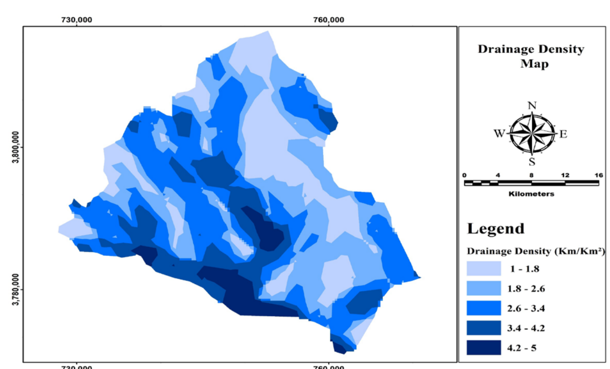

Fig. 5. Drainage density.

3.1.4. Rainfall

Interpolation method was used to acquire the monthly basis rainfall maps for different years [38].

Rainfall map (generated from rainfall data of five years: 2015-2019) was reclassified into five spatial based classes as: very low (15-22 mm), low (22-30 mm), moderate (30-37 mm), high (37-44 mm), and very high (44-51 mm) as show in Figure 6. The spatial results reveal that average annual rainfall of the area ranges from 15.7 mm up to 51.4 mm.

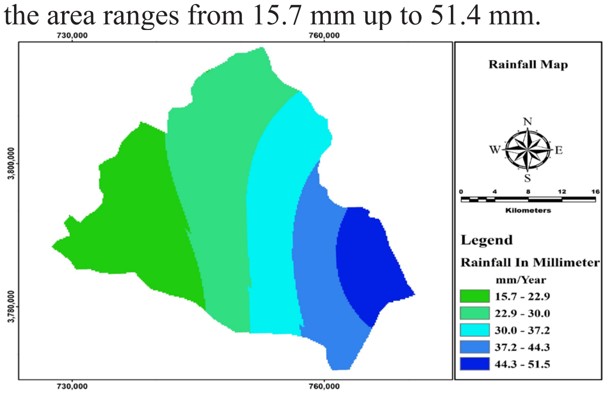

Fig. 6. Rainfall map.

3.1.5. Lineament density

The high density of lineament encompasses numerous faults which are not suitable for storage of water. Lineament disturbs groundwater recharge, surface storage and flow [40, 41]. The lineament density was spatially categorized as: very low (0-0.1 Km^2), low (0.1-0.2 Km^2), moderate (0.2-0.3 Km^2), high (0.3-0.4 Km^2) and very high (0.4-0.5 Km^2). In this study, areas with lineament density between 0.4 and 0.5 km/km^2 were considered best for prospective groundwater zones. According to its spatial results in map, it is clear that most parts of this area comprise very poor lineament density (Figure 7). Area with low lineament was assigned low weightage value while area having high lineament was assigned high weightage value.

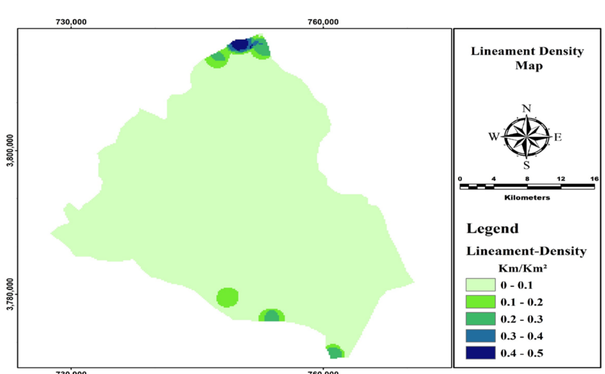

Fig. 7. Lineament density.

3.1.6. Geology map

The characteristics of geology, in effect, control the subsurface aquifer to the transfer of groundwater from up-surface stream and the divergent movement [38]. Surface geology is the controlling factor of flow and infiltration quantity of the groundwater. The research area comprises Mesozoic Meta, Quaternary Alluvium and Mélange rocks. Alluvium is unconsolidated and loose rock that can easily erode and reshape by water. For the study area, high weightage was assigned to alluvium rocks because it has high infiltration rate as compared to other rock types in the focus area as illustrated in Figure 8.

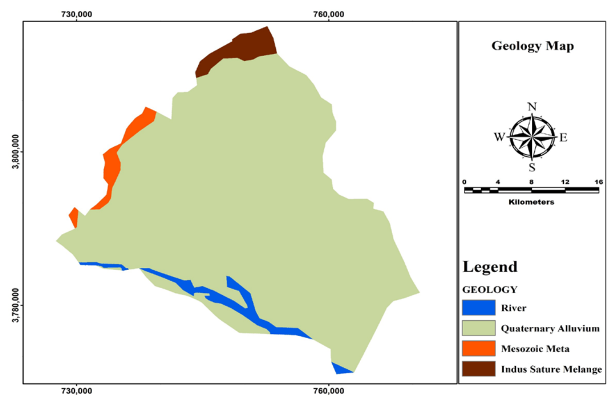

Fig. 8. Geological map.

3.1.7. Soil map

Previously Alam *et al*. [37] divided the soil map into five classes based on the permeability ratio. The study area comprise many soil types which includes loams, loamy sands, silt loams, silty clay loam and silty clays. The statistical study of the study area depicts that most part is covered by silt loams which has low penetration rate (Figure 9). The high ranks values were assigned to loamy sands and loams which are good for groundwater.

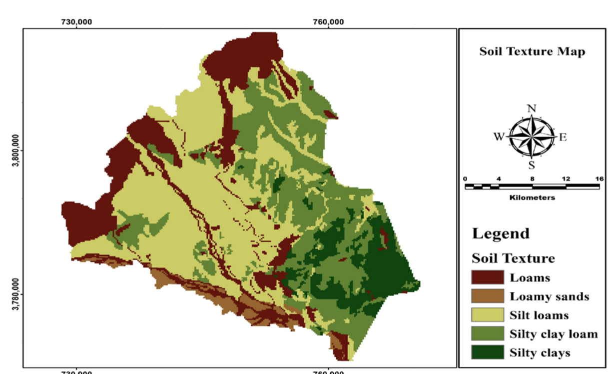

Fig. 9. Soil map.

3.1.8. Results of the influencing factors

Table 1 represents sub classes of each variable with each class influence towards groundwater, as well as, rank of each class. While, X represent major effect and Z represent minor effect of these MIF (seven factors selected for the present study).

3.1.9. Ground potential zones

The potential of groundwater in the focus area in perspective of its spatial distribution follow the regional influencing pattern of LULC, drainage density, lineament density, rainfall, as well as, physiological factors include geology, soil, and slope. Based on ground potential zone, the spatial output was classified as low, moderate, high and very high, respectively (Figure 10). Overall, moderate groundwater potential area is identified in Figure 10. Resultantly, major area is covered with zone of moderate, very high and high area of 7 km^2 and 306.71 km^2, respectively, while the low potential zones cover relatively less area of 105.91 km^2 as illustrated in Figure 11.

Table 1. Weightage of different factors.

S. No.	Parameters	Major effect (X)	Minor effect (Z)	Proposed relative effect (X + Z)	Proposed weight [Equation 1] (rounded figure)*
1	Rainfall	1 + 1	0.5 + 0.5 + 0.5	3.5	17.5 (18)
2	Geology	1	0.5 + 0.5	2	10
3	Slope	1	0.5 + 0.5 + 0.5	2.5	12.5 (13)
4	Soil	1 + 1	0.5 + 0.5 + 0.5	3.5	17.5 (17)
5	Lineament density	1	0.5 + 0.5 + 0.5	2.5	12.5 (12)
6	Drainage density	1 + 1	0.5 + 0.5	3	15
7	Land use/Land cover	1 + 1	0.5 + 0.5	3	15
	Total			Σ20	Σ100

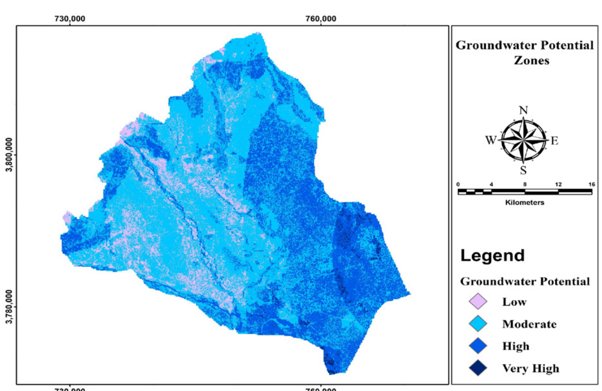

Fig. 10. Zones of groundwater potential.

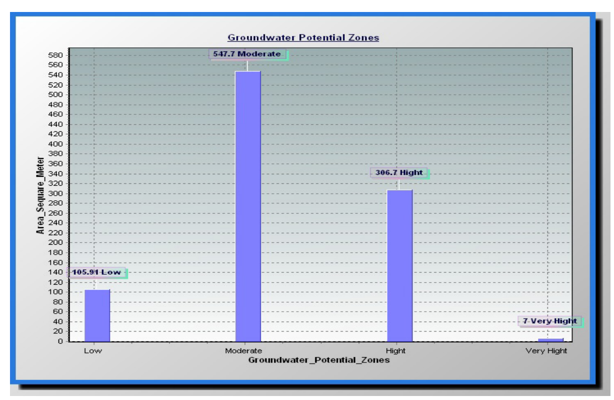

Fig. 11. Graph of zones with groundwater potential.

4. CONCLUSIONS

This study adopted the GIS, RS and MIF based techniques and approaches which are relatively reliable and applicable technologies-based methodology for delineating groundwater potential based zones. Overall, analysis of seven critical influencing parameters including geology, slope, soil, lineament density, drainage density, LULC and rainfall were carried out as MIF from RS data, GIS environment to access groundwater potential zones of district Charsadda. Finally, results of groundwater potential based zones were delineated into classes as Low, moderate, high, and very high zones (Figure 10). The resultant data reveal that this area is mostly covered with zones of relatively moderate groundwater potential zone. The 'high' potential zone cover area is 7 Km^2 while zone with 'very high' potential covering the area of 306.71 Km^2 considered as zones with high potentiality of groundwater. Overall, the low potential zone covers relatively less area of 105.91 km^2. Hence, moderate to highest potential zones will be helpful for usage of groundwater. Prospectively, this study approach may be efficient for applicable management and eco-friendly development of groundwater supply.

5. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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