

Integrated Geospatial Multi Influencing Factor Approach to Delineate and Identify Groundwater Potential Zones in Kabul Province, Afghanistan

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Abstract

This study was an attempt to evaluate the groundwater potentiality in Kabul province, Afghanistan using geospatial multi influencing factor (MIF) approach. The influencing parameters employed for the assessment of groundwater potential zones (GWPZ) includes slope, geology, soil, land use/land cover, lineament density, rainfall and drainage density. The sub-classes within each influencing parameter were sub-divided, based on their effectiveness in groundwater potentiality as major, minor and no effect, and subsequently assigned a score value. The combined score value of these parameters was used for calculating the relative weight. The delineated GWPZ were classified in four groups, i.e. poor, moderate, good and very good GWPZ. The study results revealed that very good GWPZ covered an area of 354.87km² (2% of the total area), good 1523.86 km² (20%), moderate 2250.99 km² (73%) and poor 477.19 km² (5%). The study concluded that geospatial assisted MIF approach was very useful and efficient techniques for the assessment of GWPZ and can be effectively employed to enhance the conceptual understanding of groundwater resources of Kabul Basin, Afghanistan.

Highlights

- Multi influencing factor approach was used to evaluate groundwater potential zones.
- Seven influencing parameters were used for groundwater potential zones' evaluation.
- Satellite images and secondary data was used for the influencing parameters layers.
- The generated map revealed 73% of Kabul province area covered by moderate GWPZ.
- The validation suggested multi influencing factor approach as an effective tool.

1. Introduction

Water scarcity and inexpedient management of available water resources is a global concern especially in arid and semi-arid regions of the world. In the current scenario of climate change, unprecedented population growth, rapid urbanization, increased agricultural and industrial usage, the demand for freshwater is increasing enormously. The situation is further exacerbated by the increasing contamination of surface water, making groundwater more precious and a valuable alternative natural resource (Nicholl, 2000; Nedaw and Walraevens, 2009).

Almost 1.5 billion of the world population are dependent on groundwater for their daily need. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO) report, by 2025 approximately 1800 million global inhabitants will have to face water scarcity (UNESCO, 2006; Murasingh, 2014). The Kabul province is Kabul River Basin, about 80 km long and 10–35 km wide. The inhabitant of the province predominantly relies on groundwater for domestic as well as agricultural irrigation. The population of Kabul has increased from 2.4 to 4.8 million between 2000 to 2015 (UN, 2016). This rapid growth in population and the potential impact of climate change, has invoked fear for the groundwater availability for a substantial proportion of population in Afghanistan in general and

Kabul province in particular (Mack, 2018). In these circumstances there has been an overwhelming increase in the demand for groundwater and surface water harvesting (Nasir et al., 2018).

Groundwater is an important element of hydrological cycle and it is referred to the water present in the pores of soil and rocks below the earth surface. Groundwater percolate down instantly after precipitation and from other water bodies i.e. rivers, streams, lakes etc. The term groundwater potentiality (GWP) refers to the possibility of water availability below the earth surface of a region (Al-Abdi and Shammaa, 2014).

Incorporation of space-born data and geographic information system (GIS) for GWP is a paradigm shift and significant development in the field of hydrology (Silwal and Pathak, 2018). Integration of remote sensing (RS) and GIS for the evaluation of GWP enables the storage, manipulation, analysis and display of data in various forms and magnitude (Ahmad et al., 2020; Abijith et al., 2020; Raju et al., 2019). Several assessments techniques for delineation of groundwater potential zones (GWPZ) have been developed recently, these include single factor analysis (Xin-feng et al., 2012), multifactor analysis (Nag and Kundu, 2018), Fuzzy-analytical hierarchy process (F-AHP) (Shao, et al., 2020), Fuzzy clustering (Ahmad et al., 2020), geographic information fusion system (Raju et al., 2019), Fuzzy analytical hierarchy process indices (Pinto et al., 2017), multi-criteria decision making (Celik, 2019) and multi influencing approach (MIF) (Nasir et al., 2018).

For the assessment of GWP various influencing parameters have been used including fault and lineament density, rainfall distribution, altitude, gradient, aspect, stream density, land use/land cover (LULC), geology, geomorphology, physiography, soil texture etc. (Pinto et al., 2017; Ghorbani-Nejad et al., 2017; Nasir et al., 2018; Mohammadi-Mehzad et al., 2019). Therefore, for the assessment and delineation of GWPZ, the GIS and RS are integrated for creating various thematic parameters layers with assigned weight/score in a spatial domain.

A study carried out in 2004 in Kabul province, Afghanistan, suggested that for an estimated population of 4,089,000 in 2015, the water demand will be around 123.4 million m³/year (JICA, 2011). The increasing withdrawal results in a declining water table. It is estimated that more than 50% of shallow wells may be dried by 2057. Similarly, the water quality of the well water in urban areas may be deteriorated due to poor sanitation. The per capita water use in the study area was 110 liters/day (Bockh, 1971), 50 liters/day (Government of Afghanistan, 2005 cited by Mack, 2018), and 40 liters/day (Niard, 2007). However, the estimated groundwater availability in the city of Kabul, at about 44 million m³/year, can only provide about 2 million people at a modest per capita consumption of 50 liters/ day (Saffi and Hassan, 2011). Several studies conducted were carried out on monitoring and depletion of water table in Kabul Basin. But the present research is a pioneer study on the assessment of groundwater potentiality of Kabul Basin and is aimed to delineate GWPZ within Kabul province with the help of advanced approach of multi influencing factors (MIF) integrated in RS and GIS.

2. Material And Methods

2.1 Study Area

Kabul province is located in central Afghanistan, bordered by Laghman province in the east, Kapisa province in northeast, Logar province in south, Parwan province in northwest and Maidan Wardak province in southwest. It is geographically located between 34° 8' 60" to 34° 54' 36" North latitude and 68° 49' 48" to 69° 57' 0" East longitude. Administratively, the Kabul province is sub-divided into fourteen districts, with Kabul city as the provincial capital. The total area of the province is 4524 Km², sharing only 0.7% of the national land out of 652,225 Km². The province is surrounded by mountains and more than half of the province (56.3%) is mountainous and piedmont while the remaining (37.7%) is plain area sculptured by river Kabul (JICA, 2011). Fig. 1 is illustrating the locational map of the Kabul province.

According to United Nation, Department of Economics and Social Affairs, in 1950, the population of Kabul was 170,784, which increased to 4221532 in 2020. It is estimated that since 2015, the population of Kabul has increased by 107503 persons, with an annual growth rate of 2.61% (UN, 2019). According to National Statistics and Information Authority (NISA) estimates, the population of Kabul province is well over 5 million in 2020 of which 85% are urbanites (Government of Afghanistan, 2019).

Methodology

The present study aims to assess and delineate the GWPZ in Kabul province. Therefore, different influencing parameters data were used and acquired from various sources. The boundary of the base map was taken from Afghanistan Geodesy and Cartography Head Office (AGCHO), the slope and stream density layers were generated from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) 2.0, downloaded from NASA website, with 30-m resolution and overall accuracy of 17-m (Tachikawa et al., 2011; ASTER, 2011). The LULC and lineament density layers were generated from Landsat OLI, 30-m resolution imagery. Soil map was derived from the existing map of the soil regions of Afghanistan, Geology map from Geologic age and lithology of Afghanistan and the rainfall data for past five years (2013-2017) of six meteorological stations was collected from the Afghanistan Meteorological Department.

To achieve the study objectives several influencing parameters (IP) were selected and subsequently analyzed by MIF approach. The MIF approach is one of the best approach for the assessment of GWP (Thapa et al., 2017; Nasir et al., 2018; Bhattacharya et al., 2020; Zghibi et al., 2020). It consists of the following steps:

The first step was based on literature review for the determination of parameters that are influencing and involved in the delineation of groundwater potentiality. Geology, soil, lineament density, slope, rainfall distribution, LULC and stream density were the seven parameters which were used in the present study.

The second step of MIF approach was assigning score to selected parameters sub-classes and standardization. The subclasses in each IP were examined for their effectiveness in groundwater aquifer recharge and a suitable score was assigned. Table 1 illustrates the effect of IPs and assigned score. The

subclasses which were highly effective (X) in groundwater recharge (GWR), were assigned a score value of 1, the subclasses moderately effective (Y) were assigned a score value of 0.5. The subclasses which were not helpful in GWR have assigned a score value of 0. The cumulative score (X+Y) of both highly effective (X) and moderately effective (Y) were considered for calculating the relative effect. The weight of each IP was calculated using the following formula (Thapa et al., 2017; Zghibi et al., 2020);

$$Score = \frac{Major\ Effect(X) + Minor\ Effect(Y)}{\Sigma(Major\ Effect + Minor\ Effect)} \times 100 \quad (1)$$

This step was followed by assigning weight to selected parameters' subclasses. The weight computed for every IP was divided equally and assigned a rank to every subclass (Gumma and Pavelic, 2012). Table 2 shows subclasses of each influencing parameters and their rank.

The third step was the rasterization and reclassification of all the IP layers along with the computed score with the help of ArcMap 10.5.2 spatial analyst extension.

Then the fourth step was the merging of all IPs and reclassification of the output layers into four groups, viz. very good, good, moderate and poor GWPZ. Fig. 2 shows the methodology adopted for present study.

Table 1 Effect of influencing parameters, assigned score and proposed weight

Parameter	Major Effect X	Minor Effect Y	Proposed Relative effect (X+Y)	Proposed weight of Each influencing parameter
Slope in Degree	1+1	0.5+0.5	3	15
Geology	1+1	0.5	2.5	12
Rainfall (mm)	1+1+1	0.5	3.5	17
Lineament density (km/km ²)	1+1	0.5	2.5	12
Drainage density (km/km ²)	1+1	0.5+0.5	3	15
Land use land cover	1+1+1	0.5+0.5	4	19
Soil	1	0.5+0.5	2	10
			∑ 20.5	100

Table 2 Ranks and weightages for various parameters for groundwater potential zones

Influencing Parameters	Sub Classes Within Influencing Parameter	Qualitative Rank	Proposed weight of Each Influencing Parameter based on $(X + Y) / \sum (X + Y) \times 100$	Groundwater Prospects (Quantitative Rank)
Slope in Degree	0 – 25	Good	15	15
	26 – 50	Moderate		11
	51 – 75	Poor		05
	76 – 89.99	Very poor		01
Geology	Sedimentary Rocks	Good	12	12
	Igneous Rocks	Moderate		08
	Igneous/Metamorphic Rocks	Poor		04
	Metamorphic Rocks	Very poor		01
Rainfall (mm)	316 - 328.6	Very good	17	17
	206 - 315	Good		13
	291 - 205	Moderate		09
	281 - 290	Poor		05
	271 – 280	Very poor		01
Lineament Density (Km/km ²)	0.96 - 1.52	Very good	12	12
	0.66 - 0.95	Good		09
	0.36 - 0.65	Moderate		06
	0.16 - 0.35	Poor		03
	0 - 0.15	Very poor		00
Drainage density (km/km ²)	7.9 - 9.4	Very good	15	15
	5.4 - 7.8	Good		12
	3.4 - 5.3	Moderate		08
	1.4 - 3.3	Poor		04
	0.07 - 1.3	Very poor		01
Land use/ Land cover	Waterbody	Very good	19	19
	Agriculture land	Good		15
	Forest	Moderate		10

	Bushland	Moderate		05
	Settlements	Poor		03
	Barren land	Very poor		01
Soil	Haplocambids with Torriorthents	Very good	10	10
		Good		07
	Rocky land with Lithic Cryorthents	Moderate		04
	Rocky land with Lithic Haplocambids	Poor		01
		Very poor		00
	Rocky land with Lithic Haplocryids			
	Xerochrepts with Xerorthents			

3. Results And Discussion

3.1 DEM pre-processing, derivation of topographic and hydrologic parameters

3.1.1 Slope

According to Selvam et al. (2015), slope gradient influences the retention of water and percolation capability of the surface, thus is one of the important parameter for the assessment and delineation of GWPZ. The surface runoff is slow on a gentle slope and hence allowing more time for the surface water to infiltrate down, while steep slopes assist rapid runoff and less infiltration (Mumtaz et al., 2019; Sarker et al., 2020). The slope layer was derived from the analysis of ASTER GDEM 2.0, downloaded from <https://search.earthdata.nasa.gov> with 30-m resolution.

The slope was categorized into four classes which were; Flat slope (0° – 25°) with low runoff and good infiltration, gentle slope (26° – 50°) can be considered as moderate infiltration, Moderate slope (51° – 75°) fall into poor category, and high slope (76° – 89.99°) (very poor) with very low infiltration rate and high runoff (Table 2). Figure Fig. 3 (A) map A, shows the slope classes of the study area.

3.1.2 Geology/Rocks

Geology of an area is considered as an important parameter for the groundwater aquifer recharge assessment and thus in the delineation of GWPZ (Ramu et al., 2014). The rocks storage capacity relies on its porosity and permeability. The water moves from groundwater recharge zone to discharge zone under hydraulic gradient which depends on the hydraulic conductivity or permeability of geological formation (Manikandan et al., 2014). The geology of Kabul province was acquired from the Geologic age

and lithology of Afghanistan. The geology map was scanned, imported to ArcMap 10.5.2. georeferenced, area of interest was extracted by masking, digitized, rasterized and subsequently reclassified and weight was assigned to various sub classes based on their groundwater recharge potential. In Kabul province almost half of the area is comprising sedimentary rocks. For present study the Kabul province was categorized into four geological units which were; sedimentary rocks, igneous rocks, igneous and metamorphic rocks and metamorphic rocks (Table 2). The high score was assigned to sedimentary rocks for its high porosity and permeability. Figure 3 (B) show the geology/rock formation of the study area.

3.1.3 Rainfall

The groundwater aquifers are usually recharged by the effective rainfall. The amount of rainfall is useful for the assessment and delineation of GWPZ. It depends on the environmental condition of an area (Minh et al., 2019; Shao et al., 2020). The existence of groundwater is very good in the high rainfall regions and the prospects are poor in the low rainfall areas. The annual mean rainfall data from the year 2013 to 2017 of six metrological stations including Laghman, Kabul, Mazari Sharif, Jabul Saraj, Jalalabad, and Kunduz obtained from Afghanistan Meteorological Department. The rainfall data were interpolated spatially and then reclassified in ArcGIS 10.5.2 software. The study area was categorized into five classes which were; (i) 316-328.6 mm, (ii) 206–315 mm, (iii) 291 – 205 mm, (iv) 281–290 mm and (v) 271–280 mm (Table 2). A high score was assigned to high rainfall regions. Figure 3(C) depicts the rainfall regions of the study area.

3.1.4 Lineament density

The lineament is the linear feature on the earth surface which are the expression of the underlying geological structure. The lineaments are geological structures i.e. fractures, faults, joints, and discontinuity surfaces which can be detected by remote sensing images (O’Leary et al., 1976). According to Nag (2005), the lineament density is a significant parameter for the assessment and delineation of GWPZ. For present study the surficial lineaments were generated and extracted from the panchromatic band 8 of Landsat 8 OLI using PCI Geomatica 2017 version. Subsequently the lineament density was calculated through density analysis tool of ArcMap 10.5.2. The analysis revealed that Kabul province is covered by major and minor lineament varies in size from 0.15 km to 1.52 km. The computed lineament density layer was then classified into five density zones. The area with high lineament density (0.95–1.52) was assigned a high score (very good) due to its effectiveness in groundwater recharge potential, whereas area with very low lineament density (0-0.15) was considered having very poor groundwater potential and was assigned with the lowest score (Table 2). The lineament density map is illustrated in Fig. 3(D).

3.1.5 Drainage density

According to Strahler (1964), drainage density is a proportion exists between the total length of the streams to the total area of watershed. It is expressed as the length of stream per km². Drainage density is also a good indicator of good groundwater potentiality due to its association with water permeability and runoff (Magesh et al., 2012). For present study the drainage network was generated from ASTER

GDEM 2.0 (30 m resolution), using Archydro tool of ArcMap 10.5.2. The drainage network was then used to compute the drainage density through line density analysis tool of ArcMap 10.5.2. The stream density layer was then rasterized and reclassified into five classes i.e. 0.07–1.3 (Very poor), 1.4–3.3 (poor), 3.4–5.3 (Moderate), 5.4–7.8 (good) and 7.9–9.4 (Very good) km/km², respectively (Table 2). The drainage density is indirectly proportional to the terrain perviousness, therefore, the high score value was attributed to the poor and very poor drainage density classes, due to the fact that it is a strong indicator of water retention zones i.e. high infiltration and low runoff (Mahmoud and Alazba, 2016). Figure 3(E) illustrates the drainage density of the Kabul province, Afghanistan.

3.1.6 Land use / Land Cover (LULC)

Land use / Land Cover is the most crucial human stimulated influencing parameter responsible for the occurrence and groundwater aquifer recharge potential. The LULC change could alter the aquifer recharge rate, which could have negative impact on groundwater potentiality (Chen et al., 2019). The land use refers to the anthropogenic activities relevant to specific piece of land, while land cover referred to the natural covering of earth surface (Lillesand and Kiefer, 1979). The LULC of the Kabul province was derived from Landsat 8 OLI satellite image downloaded from United State Geological Survey (USGS) web site for the month of April 2019, having a 30-m resolution. The supervised classification algorithm has been performed in spatial analyst tool of ArcMap 10.5.2. The image was classified into six LULC classes i.e. water bodies, natural vegetation, agriculture land, bush land, built-up area and barren land. Figure 3(F) shows the LULC map of the Kabul province, Afghanistan.

3.1.7 Soil

Soil texture plays a crucial role in the water transport processes controlling infiltration of surface water and recharging groundwater aquifers (Ahmad et al., 2020). Soil texture refers to the relative percentage of silt, clay and sand within a soil layer. Soil texture is related to the soil porosity which in turn effect the water holding capacity and infiltration capability of soil. The rate of water percolation and cumulative infiltration is higher in sandy soil than in loamy soil. The average infiltration rate in sandy soil is 0.35 cm to 2.38 min⁻¹ compared to 2.97 cm min⁻¹ in loamy soil. The infiltration rate is comparatively lower in fine textured soil than in coarse textured soil (Ma et al., 2016).

The soil types of Kabul province were acquired through the existing map of the soil regions of Afghanistan. The map was imported to ArcMap 10.5.2, georeferenced, the area of interest was extracted, digitized, rasterized and ultimately reclassified into five classes. The five classes were Haplocambids with Torriorthents (Very good prospect), Rock outcrops with Lithic Cryorthents (Good), Rock outcrops with Lithic Haplocambids (Moderate), Rock outcrops with Lithic Haplocryids (Poor) and Xerochrepts with Xerorthents (Very poor). Figure 3(G) depicts the soil types map of the Kabul province.

3.2 Groundwater potentiality

The GWP was computed using seven weighted thematic parameters layers integrated into ArcGIS 10.5.2 software. The ranking and weight were assigned to different thematic layers using MIF approach. The

parameters used were geology, rainfall, slope, lineament, soil, LULC, and drainage network. The generated GWP layer was reclassified into four GWPZ which were; (i) very good GWP, (ii) good, (iii) moderate and (iv) poor GWP. Figure 4 is showing the GWPZ's map of Kabul province, Afghanistan.

The map revealed that the GWP was restricted to the central districts of Kabul, Dih Sabz, and Bagrami districts (Wilayat), while the eastern and western districts have the lowest GWP. The eastern and western districts are mostly mountainous. Kabul is surrounded by Koh-e-Paghman mountain and Koh-e-Orough mountain in the east and southwest and Koh-e-Shirdarwaza in the northeast. The spatial extents of various GWPZ are depicted graphically in Fig. 4. The analysis revealed that very good GWPZ accounts for an area of 354.87 km², good 1523.86 km², moderate 2250.99 km² and poor 477.19 km². Figure 5 is showing the district wise GWP of Kabul Province.

The present study is the pioneering research that delineates the groundwater potential areas of the Kabul province. Other researches were mainly limited to determine the recharge potential of the Kabul Basin i.e. Akbari et al., (2007), Akbari et al., (2008), Mack et al., (2009). Mack et al., (2009) presented the results of their research conducted between 2005 and 2007 regarding the water availability for the growing population and the potential impact of climate change in Kabul province of Afghanistan. The aquifer recharge in the basin is highly variable both temporally and spatially. The high recharge takes place near irrigated agricultural land, streams, and rivers. In these areas, the recharge rate is 1.2×10^{-3} meter/day. While at lower altitudes in the areas away from streams and rivers the recharge may be about 0.7×10^{-3} meter/day. During 2009 the amount of water needed was 112,000 cubic meter/day, which was likely to increase to 725,000 cubic meter/day by the year 2057. This research is in line with the present study results. The majority of GWPZ delineated by the current research are located in the vicinity of rivers and streams. Very good and good GWP was observed in the central districts with high aquifer recharge capability (Figs. 4, 5 and 6).

3.3 Validation of study

To validate the study results, the wells' data was acquired from the National Groundwater Monitoring wells network Afghanistan. The Afghanistan Geological Survey, Hydrology Group, and United States Geological Survey monitoring network are monitoring the groundwater table in the Kabul province since 2004 (Akbari et al., 2007). Their inventory constitutes a total of 148 monitoring wells, out of which 61 wells were selected for validations of study results, from the Kabul Basin which was spatially distributed in the five central districts. The majority of wells (44) are concentrated in the Kabul district where the water depth was ranging from 9.5 to 90 meters. The wells location Map was derived from United States Geological Survey (USGS) Scientific Investigation Report 2009–5262 (Mack, et al., 2009). The map was georeferenced and the 'location of the well were digitized and overlaid on top of the delineated GWPZ computed through MIF techniques in ArcGIS 10.5.2 Spatial analyst. Figure 7 shows the location and number of well superimposed on top of the GWPZ. The analysis revealed that the majority of well falls in the very good and good GWPZ. None of the well fell in the low GWPZ. Out of 61 total wells, 49 wells (80.30 % of total sample wells) fell in very good and good GWPZ. Besides the well that felled in very good

and good GWPZ, the wells were shallow and water depth was ranging from 9.5 to 35 meters, which further validates the study results.

4. Conclusion

The generated map revealed that majority area of the Kabul province is covered by moderate (73 %) GWPZ. Satellite images and secondary data acquired from various sources was employed to generate the influencing parameters layers of geology, drainage density, soil, rainfall, land use/land cover, slope and lineament density. The generated layers were rasterized in ArcMap 10.5.2 using the feature to raster convertor tool. The rasterized thematic layers were reclassified and assigned the appropriate score and weight depending on its effectiveness in groundwater recharge using MIF approach. Besides, each weighted parameter layer was finally added together using raster calculator to compute the final GWPZ's map of the study area. The GWPZ's map classified the Kabul province into four GWP zones, namely; very good, good, moderate, and poor. The generated groundwater potential map was verified with well location map of USGS Scientific Investigation Report 2009–5262. The validation suggested that the geospatial multi influencing factor (MIF) approach is an efficient tool for the assessment and delineation of GWPZ in the Kabul province, Afghanistan. It is cost and time effective techniques compared to conventional methods. The adopted methodology is empirical in nature and is the most widely used technique for the assessment and delineation of GWPZ. The results of the present study are valuable for sustainable groundwater management and can be utilized for future planning of aquifer storage and recovery (ASR) program in Kabul province Afghanistan.

Declarations

Author contribution

Muhammad Jamal Nasir: Conceptualization, Roles/Writing-Original Draft preparation, Supervision, Methodology, Software. **Sajjad Khan:** Roles/Writing-Original Draft preparation, Software, Data Curation. **Tehreem Ayaz:** Visualization, Writing-Reviewing, Editing, and Formatting. **Amir Zeb Khan:** Visualization, Writing-Reviewing and Editing. **Waqas Ahmad:** Software, Reviewing and Editing. **Ming Lei:** Reviewing and Editing.

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Conflict of Interest

The authors have declared no conflict of interest

Declaration of Interest Statement

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work.

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Figures

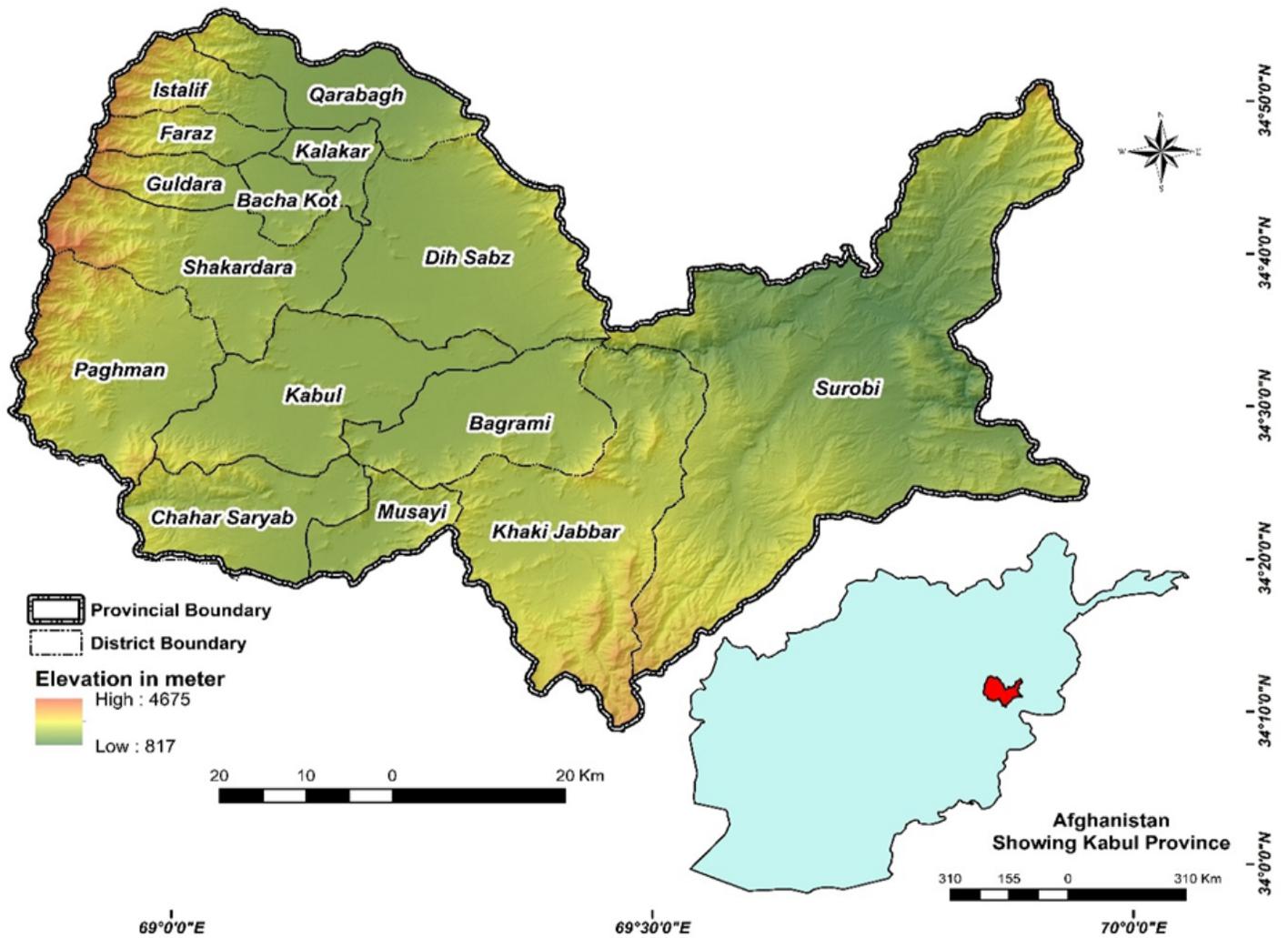


Figure 1

Location map of Kabul province, Afghanistan. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

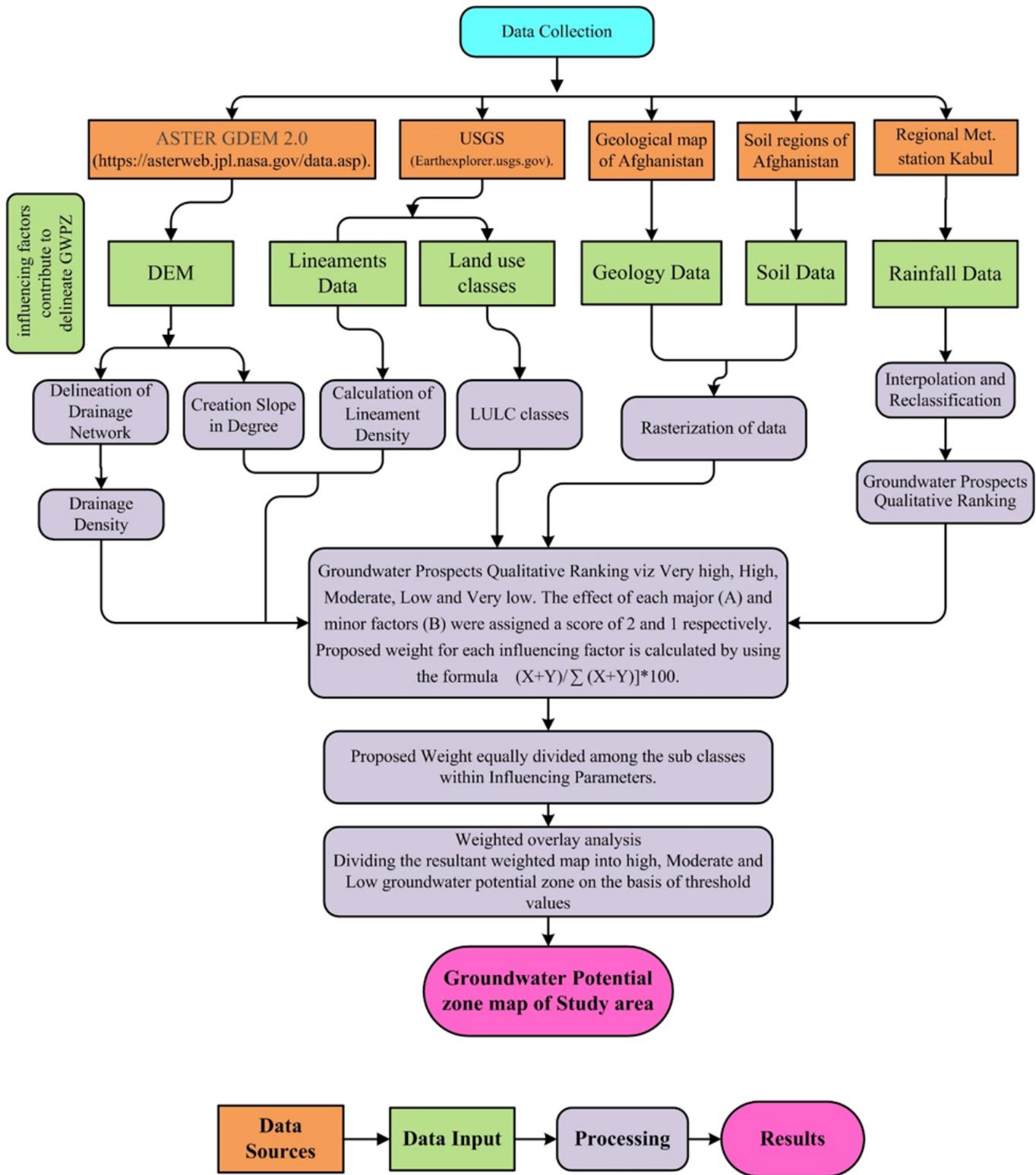


Figure 2

Flow chart of methodology adopted for delineation of GWPZ of Kabul Province, Afghanistan.

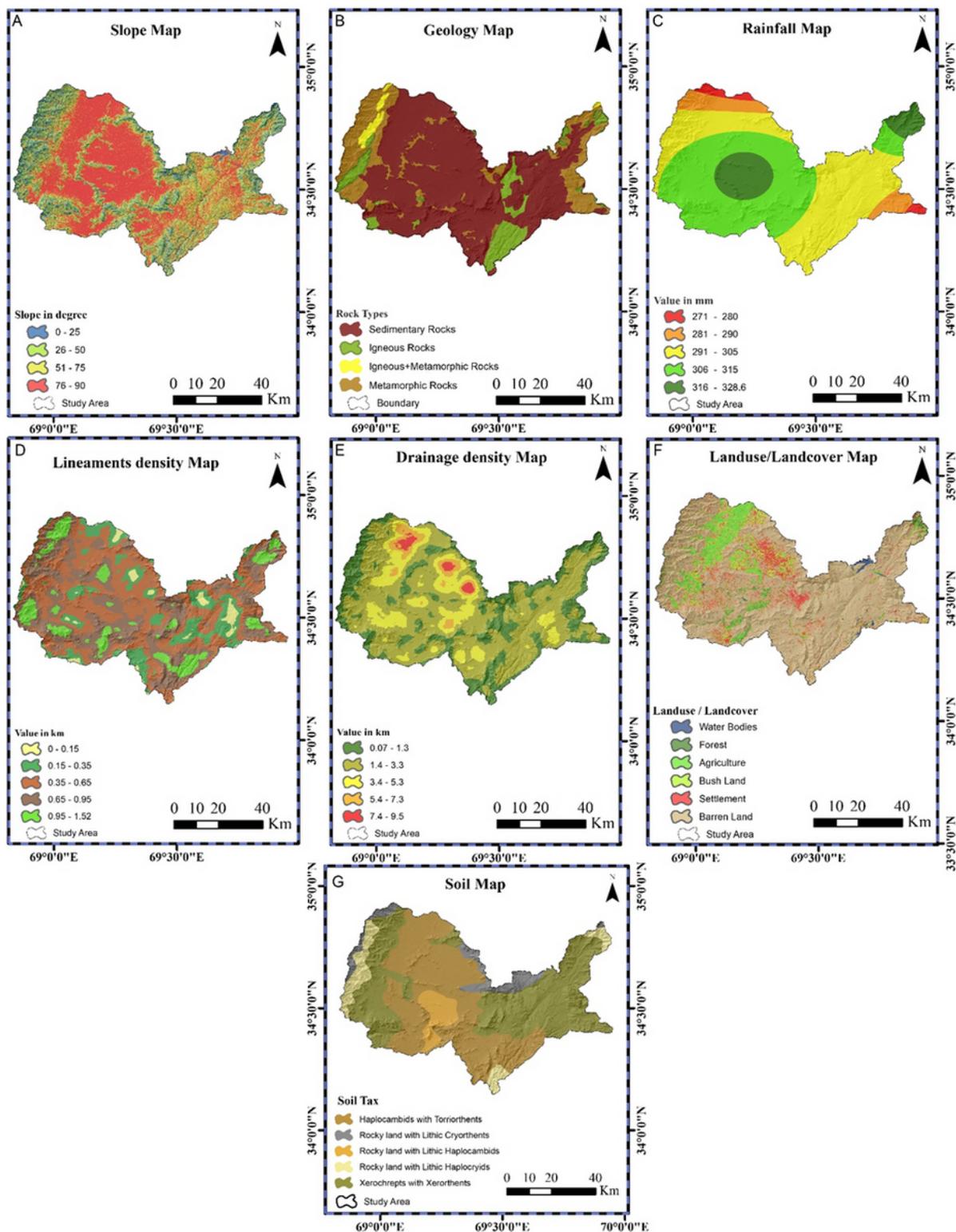


Figure 3

Thematic parameter layers of multi influencing factor (MIF) techniques A (Slope), B (Geology), C (Rainfall), D (Lineament density), E (Drainage density), F (Land use/Land cover), G (Soil), used for delineation of GWPZ of Kabul Province, Afghanistan. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its

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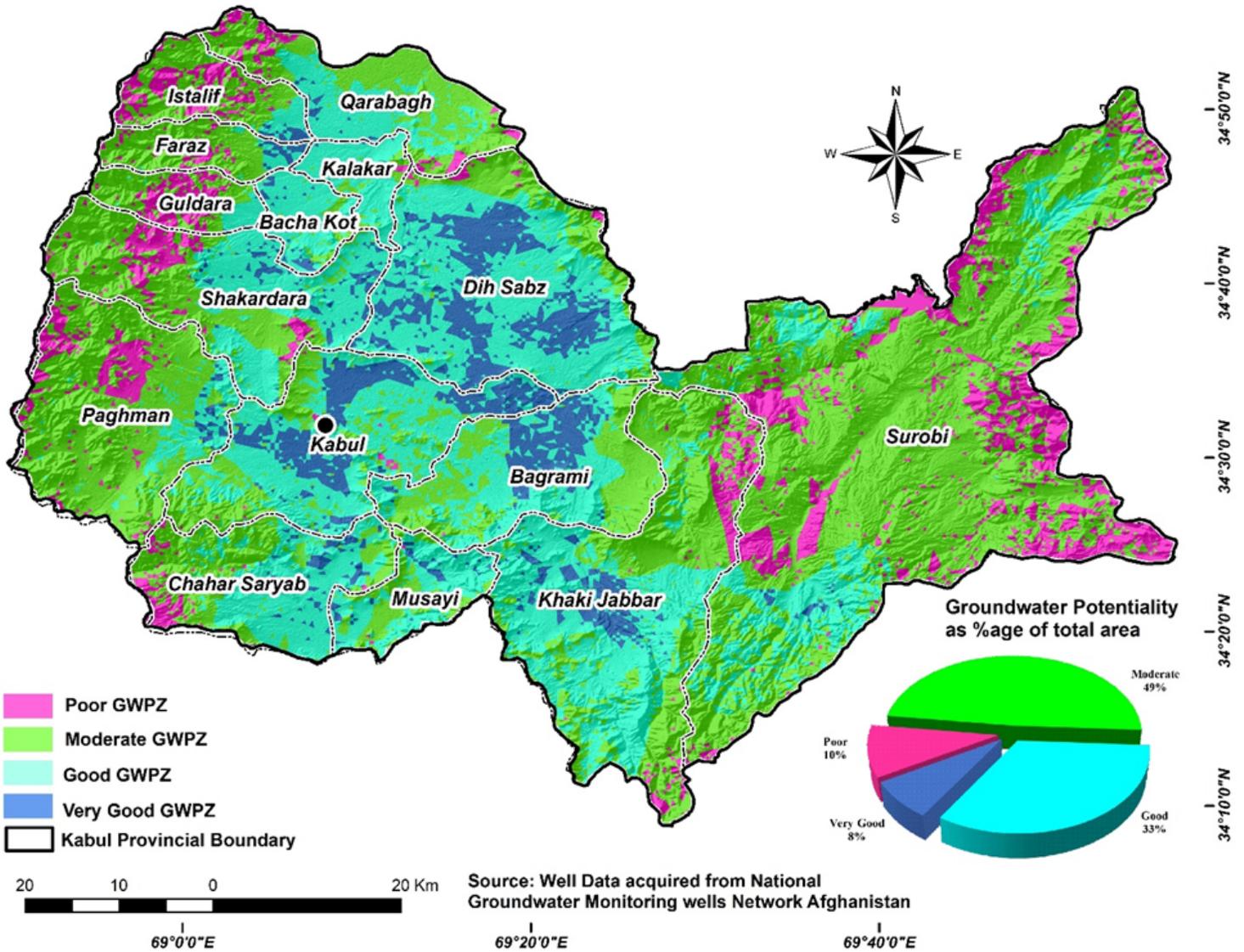


Figure 4

Groundwater Potential Zones Map of Kabul province, Afghanistan. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

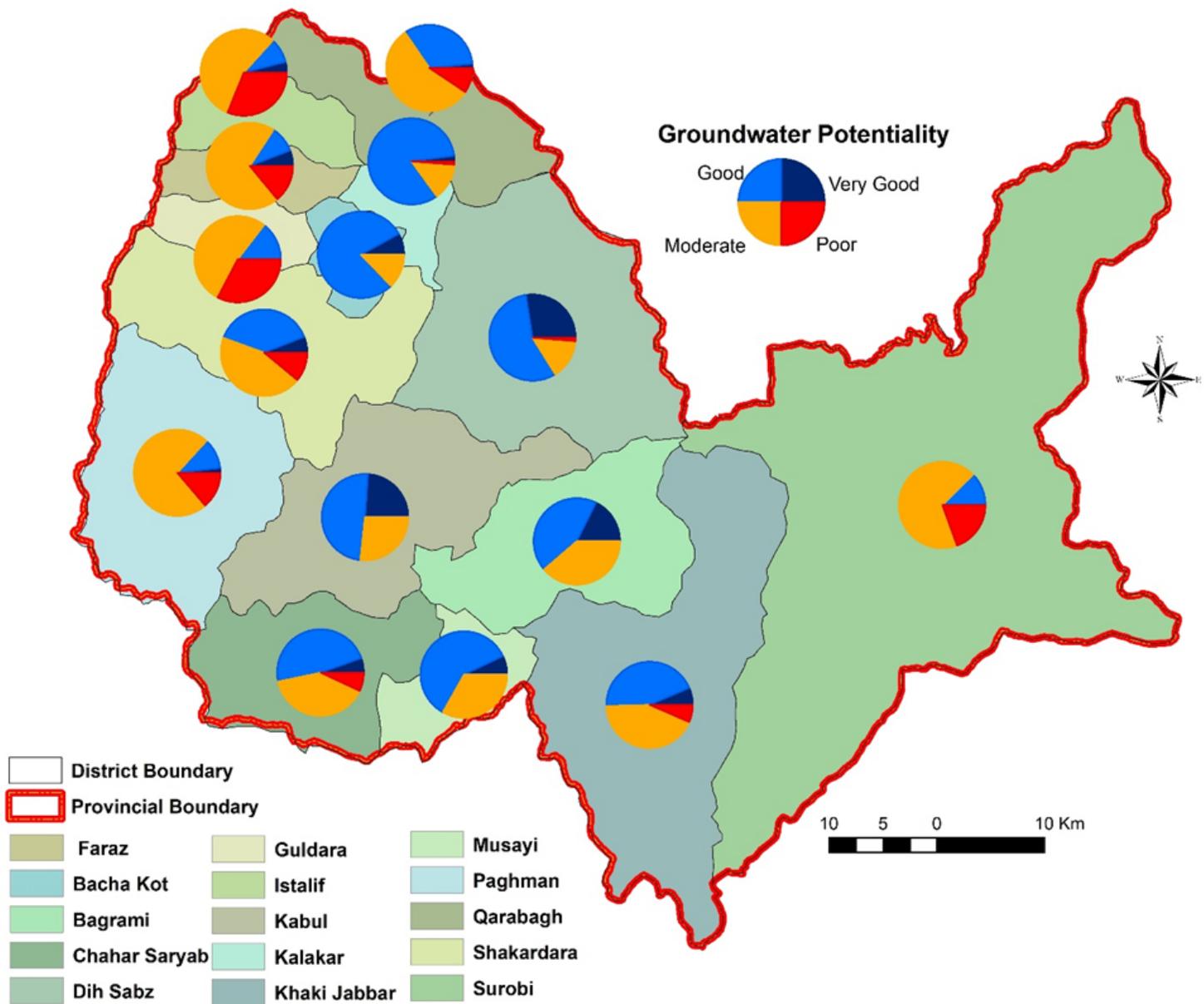


Figure 5

District Wise Groundwater Potentiality, showing the GWPZ by Pie graph. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

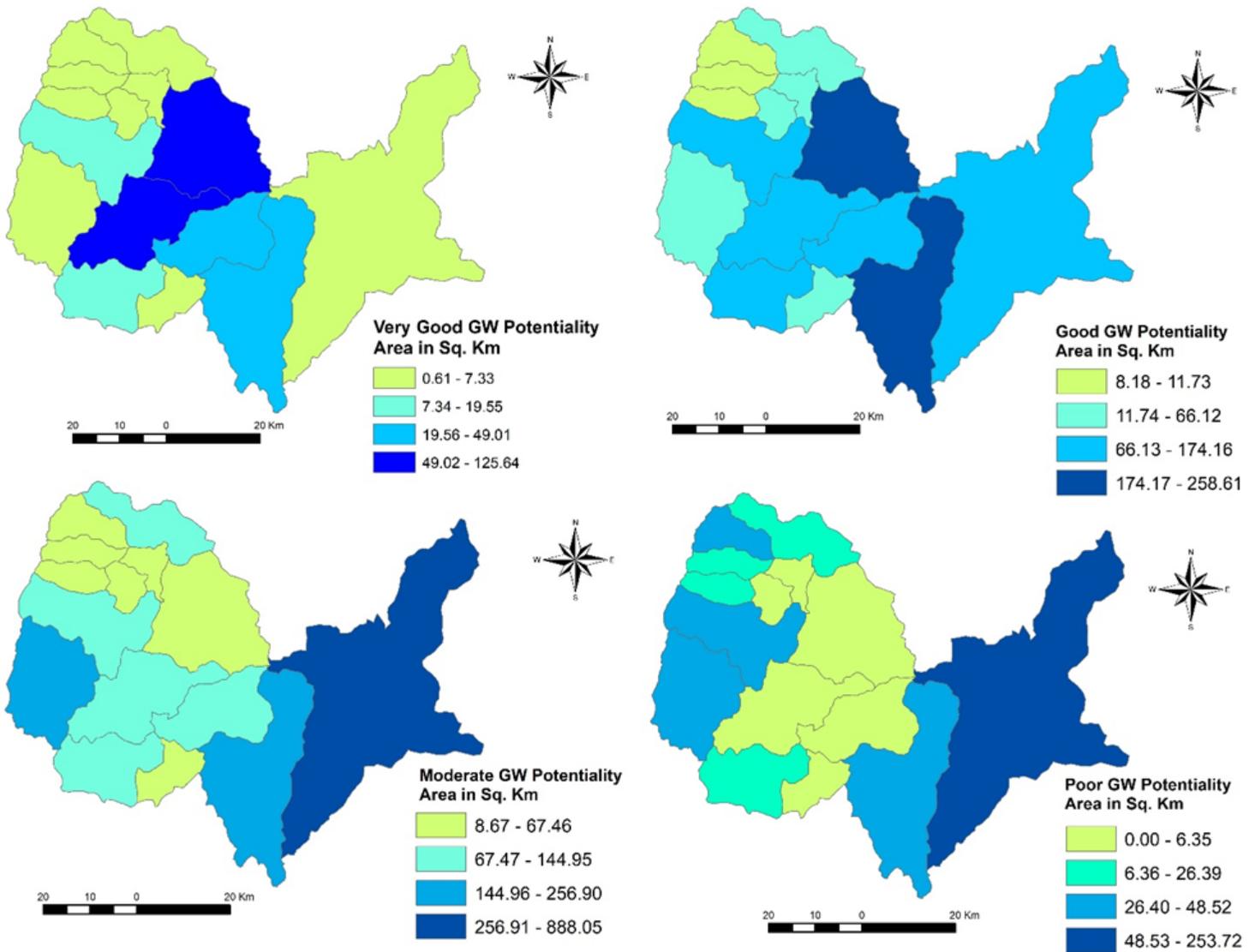


Figure 6

District wise distribution of Very Good, Good, Moderate and Poor Groundwater potentiality. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

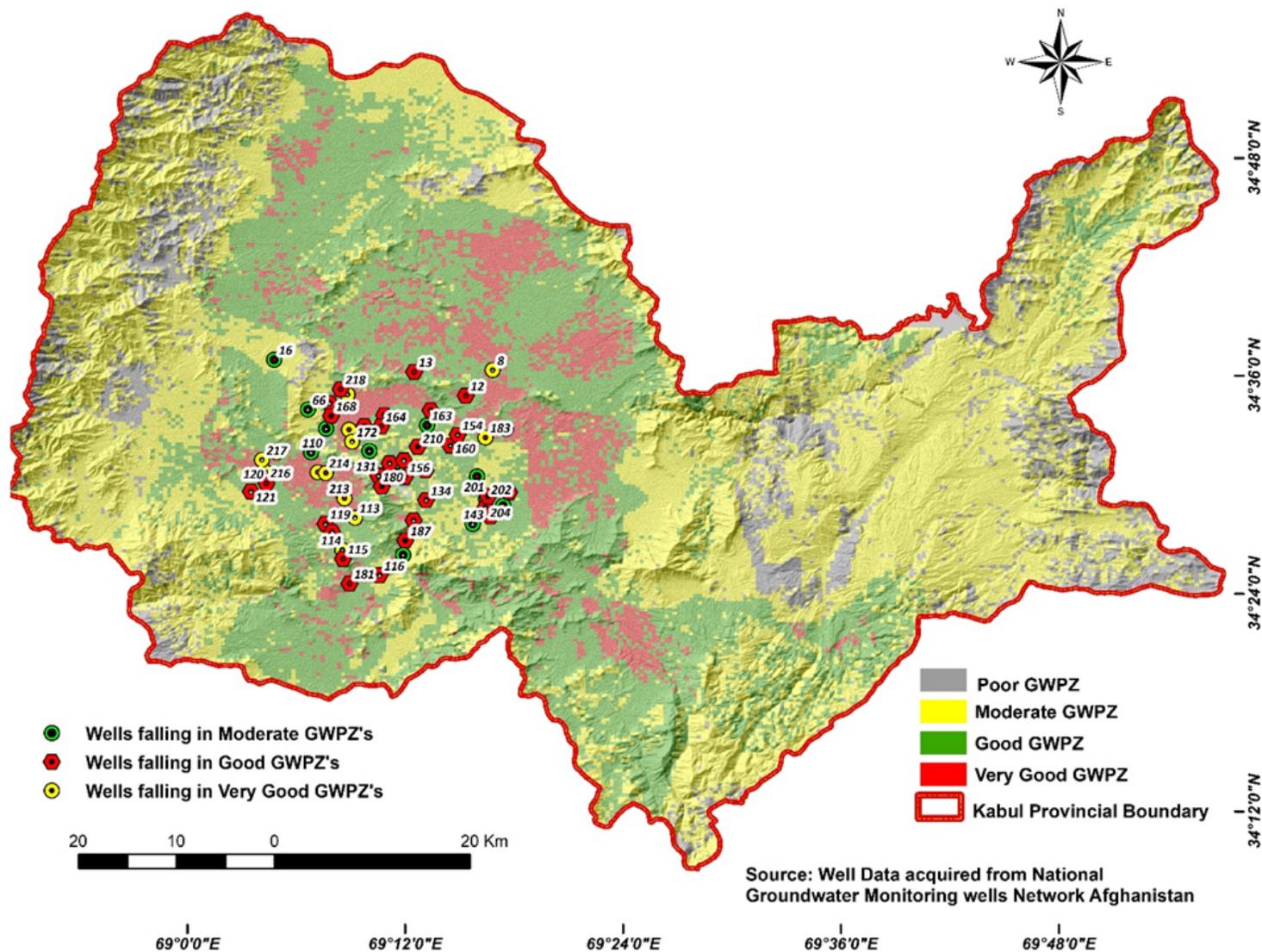


Figure 7

The location and the number of well superimposed on top of the GWPZ delineated through MIF techniques in ArcGIS 10.5.2. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.