Prospect Area Mapping for Geothermal Energy Exploration in Afghanistan

Mohammad Abed Anwarzai and Ken Nagasaka

Abstract—**One of the cleanest energy sources is geothermal. To generate electricity or to directly use as heat this sustainable resource proper investigation of reservoir characteristics is required. The purpose of this research is to determine the best prospect location of geothermal reservoirs for further investigation in Afghanistan. To achieve this goal, the geological, geophysical, and geochemical evidence maps (such as volcanic dome and rock, fault, high temperature, intrusive rock, geopressured, hot spring, and hydrothermal mineral areas) were created in GIS (Geographical Information System) ArcMap 10.1. The GIS geoprocessing tools (such as buffer, union, and intersection) were used to define the best prospect areas of geothermal energy resources. The result of this study is the first digital map of prospect areas for geothermal resources in Afghanistan. Besides known hot springs, it has determined the wide potential areas around the load centers and big cities of the country.**

Index Terms—**Geothermal energy, potential area mapping, geographical information system, Afghanistan.**

I. Introduction

The existence of young magmatic, volcanic, surface hot springs and recent tectonic activities are the evidence for huge geothermal potential in the country. Moreover, there are many unexplored hidden geothermal resources that have not reached the surface [1]. The geothermal energy exploited in the world has relation with recent tectonic and volcanic activities that were discovered through surface manifestations. However, there are some geothermal fields where there were not any surface manifestations [2]. Geothermal energy exploration requires the combination of several survey and investigation results (such as geological, geophysical, and geochemical) to determine the most prospect area for further development. The GIS overlay Boolean and overlay weighted techniques were used to map the best prospect areas for geothermal energy and well sitting in many countries such as Iran [3], Japan [4], [5], Turkey [6] and Mexico [7].

In Afghanistan, the historical geothermal resources are hot springs and have been used for bathing and medicinal purposes. The first investigation for hydrothermal and mineral resources started in 1969. The hot water of these resources originate from metamorphic, reducing, and oxidizing environments. One of the leading causes of the formation of the hot spring system in the country is the continuous neotectonic activity and fault system. The geothermal potential prospect fields are located along the structural domain of Hindukush and fault system, such as Harirud-Badakhshan, Hilmand-Arghandab, Farahrud, and Baluchistan. In addition, the geopressured system associated with petroleum fields [1] which cover large regions. However, still, there is neither any geothermal power plant nor well for investigation.

Another effort for geothermal reconnaissance in the west of the country is the determination of the Curie point depths from the aeromagnetic survey. The Curie point (580 °C temperature) depths estimated from 13 to 40 km with geothermal gradients from 14 to 36 °C/km and heat flow value from 36 to 90 mW/m^2 [8].

The purpose of this research is to combine and analyze the available geological, geophysical, and geochemical data for determining the best prospect regions for geothermal energy exploration. The GIS ArcMap10.1 tool was used to map the prospect areas step by step. The following sections explain the GIS model, geothermal resource evidence maps creation as input layers and the result of the study.

II. Prospect Area Mapping Method

Geothermal exploration and prospect area mapping require geological, geophysical, and geochemical evidence data set such as the hot springs, hydrothermal alteration zone, geopressured, young magmatic, hot rocks, faults, and volcanic information. The Afghanistan Geological Survey (AGS) maps and database [9] digitized by United State Geological Survey (USGS) [10] was used to extract the required data layers such as volcanic points, volcanic rocks, faults, intrusive rocks, geopressured, and hydrothermal mineral areas. The hot spring points were taken from National Renewable Energy Laboratory of US (NREL) data set for Afghanistan [11]. The temperature map in (1-12 km) depth was created in GIS from Curie point depths [8]. The flowchart of mapping process has been shown in Fig. 1. The Boolean operation such as union and intersection were used to generate the best prospect areas map for geothermal potential from the input layers. The geological, geochemical, and geophysical prospect area maps were created by union operation to combine the related evidence maps. Finally, the intersection was used to determine the most promising area for geothermal resources exploration.

III. Evidence Layers Mapping for Geothermal Exploration

To provide the geothermal potential prospect area map and apply the GIS model of Fig. 1 we need to create the geological, geophysical, and geochemical evidence maps as input layers.

Manuscript received September 2, 2016; revised February 2, 2017.

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doi: 10.18178/jocet.2017.5.6.424

The following subsections explain mapping of each input layer.

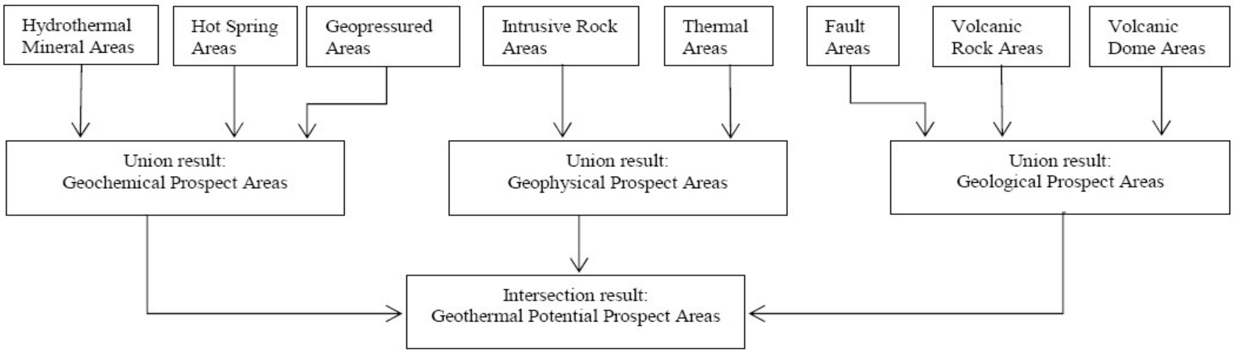

Fig. 1. The geothermal potential prospect area mapping method in GIS.

A. Fault Systems

Faults have the significant contribution in geothermal field reconnaissance. The major faults in the country provide the infiltration of water into the superheated zones of the crust to produce the geothermal reservoirs. For instance, the largest east-west strike-slip fault has up to 700 km depth into the mantle [1]. As a result, the regions in the vicinity of faults system are the most promising geothermal reservoirs. We have considered the three kinds of faults shapefiles and database available so far: First, the largest faults in the country. Second, the active young (Quaternary) faults, it had been mapped from remote-sensing imagery data and the faults slip rates were determined in major (more than 10 mm per year), minor (1 to 10 mm per year), and immeasurable categories [12]. However, the map focus on seismic hazards, it presents the active strike-slip, reverse, and normal faults. The last one is the secondary faults system. They almost cover the entire country and contains the normal faults (such as proven, buried and inferred) with thrust faults (including inferred and proven).

For prospect area mapping around faults, the buffer zone was considered for each fault system, for instance, 6000 m for largest faults [4], 2000 m for active faults, and 1000 m for secondary fault system to cover the entire possible prospect areas for geothermal around the fault systems. Then the union was used to combine prospect areas around fault systems. The Fig. 2 shows prospect areas map for geothermal resources around the largest faults, active faults, and secondary faults system in the country.

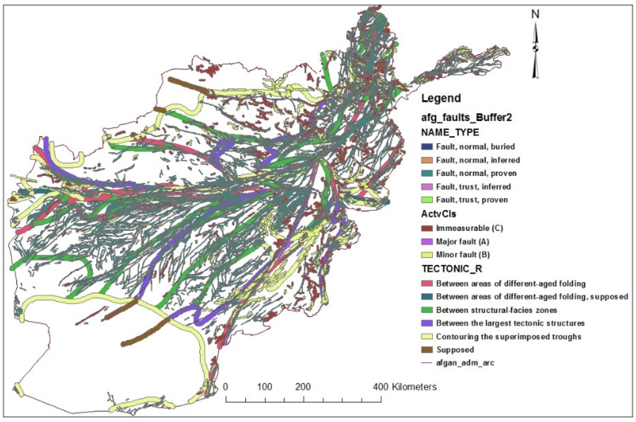

Fig. 2. Fault systems map with buffer zones in Afghanistan.

B. Volcanic Rocks and Points

The existence of either active or young volcanic domes or volcanic rocks gives the possibility of geothermal field. The active magmatism and volcanic terrain construct most of the country, and there are more than 50 dormant volcanic cones. For instance, the base diameter of the cones is 100-500 m and in some area up to 1500 m in Nawor of Ghazni, 7000 m in Khanishin of Helmand, and 3600 m of Malik Dukan in Registan region [1]. The reference [1] noted that considering the recent volcanic activities of the south and southwestern regions for geothermal energy is very promising. Fig. 3 shows the volcanic rocks and their 2000 m [4] buffer zone area with geological ages and the 5000 m areas around the volcanic points.

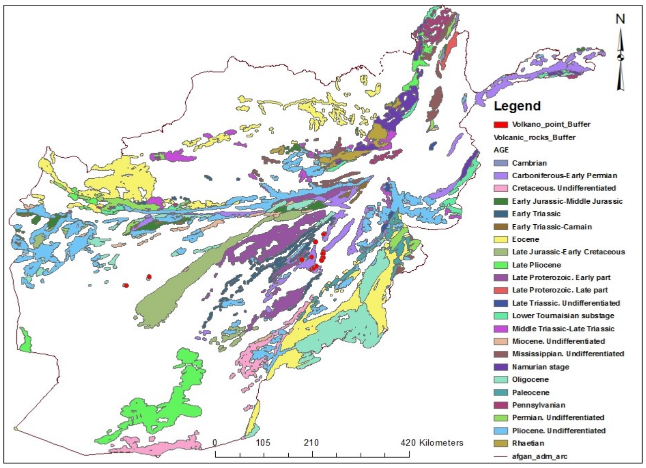

Fig. 3. Volcanic rocks and domes with buffer zone map of Afghanistan.

C. Intrusive Rocks

Intrusive, plutonic, or igneous are the active young underground magmatic bodies or heat sources that cool down slowly. The possibility of geothermal resource is very high in association with intrusive bodies in Afghanistan, where the magma chambers control the energy source [1]. The current hot springs in the country have relation with either volcanic rocks or young intrusive rocks. However, they are located around the fault systems. Some active geothermal systems in USA, Philippines, Japan, and Italy are located above and around intrusive bodies [13]. Therefore, the 2000 m buffer zone was considered for geothermal prospect area identification [4]. The intrusive rocks location with its buffer zone in the country is shown in Fig. 4.

D. Temperature Map from Curie Point Depth (CPD)

The Curie point is an isothermal region of crust, having 580 degrees of centigrade temperature where the magnetic material loses magnetization. They had been estimated from spectral analysis of aeromagnetic data for southwestern Afghanistan in the range of 13 – 40 km depth. Moreover, the geothermal gradient from 14 to 36 °C/km and heat flow from 36 to 90 mW/m² [8]. The kmz supplementary data of referenced article [8] was converted to layer and then to shapefiles in ArcMap10.1: However, the contour lines didn't contain the curie point depth, temperature gradient, and heat flow information. The CPD value was assigned according to the reference [8] such as Shallow curie depth (13.28 - 21.47 km) at Helmand basin, intermediate curie depths (21.48 - 28.5 km) at south of Helmand (Baluchistan geothermal field) and southeast of Helmand (Helmand-Arghandab geothermal field), Deep curie (25 – 35 km) at Farahrud and Pasvand field, and deepest curie (35 – 40 km) at the northwest in Herat fault system. In addition, the geothermal gradient (*q/k*) and heat flow (*q*) were calculated according to the equations 1 and 2 given in the reference [8].

Assuming the heat flux transfer to the surface through heat conduction in steady state with constant thermal conductivity, by Fourier's law, the depth-dependent temperature profile can be drawn as in the following equations [2]:

$$T_{(z)} = (-A/2k)\, Z^2 + ((q+h)/k)\, Z + T_0 \quad (1)$$

where A is the heat production, k stand for crustal thermal conductivity, q is the heat flow, and h is the crust thickness. In case, the A (constant radiogenic heat production) value has been neglected; then the simple form can be written as [14]:

$$T_{(z)} = (q/k)\, Z + T_0 \quad (2)$$

where, $T_{(z)}$ is the temperature at the given depth (z), the q/k is the temperature gradient, and the T_0 is the surface temperature.

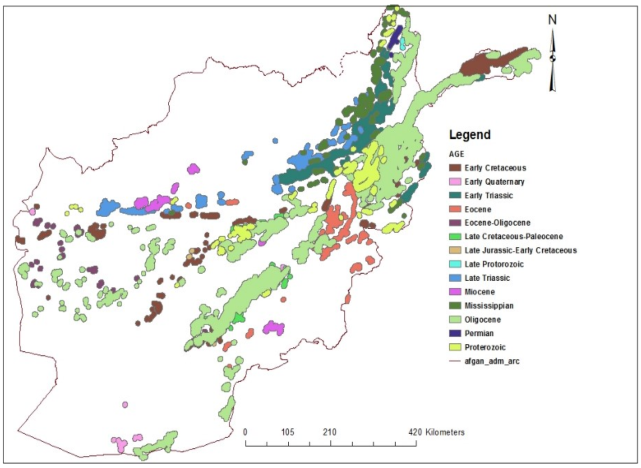

Fig. 4. Intrusive rocks with buffer zone map of Afghanistan.

Regarding temperature map creation, the 20,000m buffer zone was given to the temperature gradient contour lines to convert from lines to the shape polygon. The surface temperature shapefile was created from the earth surface temperature map [15]. Then, for both maps and attribute table combination, the GIS geoprocessing tool union was used to create a union shapefile. Finally, the Eq. 2 was used to estimate the underground temperature in the range of 1-12km depth. The Fig. 5 shows the surface temperature at the southwest of Afghanistan and the Fig. 6 shows the temperature map in 5km depth in that region. For geothermal prospect area mapping the region having above 90°C were considered.

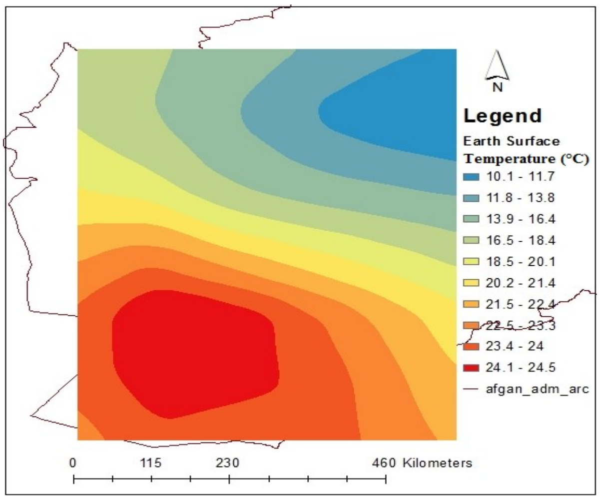

Fig. 5. Surface temperature at southwest of Afghanistan.

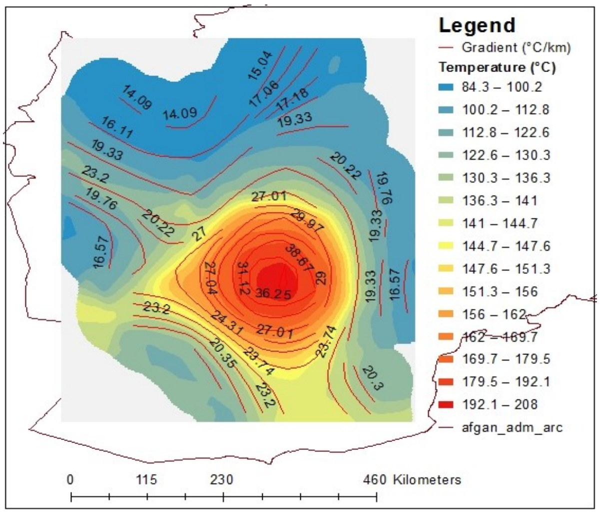

Fig. 6. Crust temperature map in 5km depth.

E. Geopressured Areas

Geopressured thermal regions are high temperature (296°C) and high pressure old fluid buried 3-8 km below clay and shale insulated surface. They are a dual source of geothermal and Methane gas, which is reported in the north of Afghanistan [1]. This type of geothermal field is associated with gas and oil industrial regions, where the power demand is high [16]. It can be the top prospect area for geothermal power generation. The clay and shale areas are located in a northern and northwestern part of the country adjacent to existing petroleum and gas fields. In addition, the clay and shale are observed in the Katawaz hypothetical petroleum basin [17]. The petroleum resources data of Afghanistan was downloaded from USGS website. The prospective structure of petroleum, the clay and shale areas of North and Katawaz region with 4000m buffer zone are shown in Fig. 7.

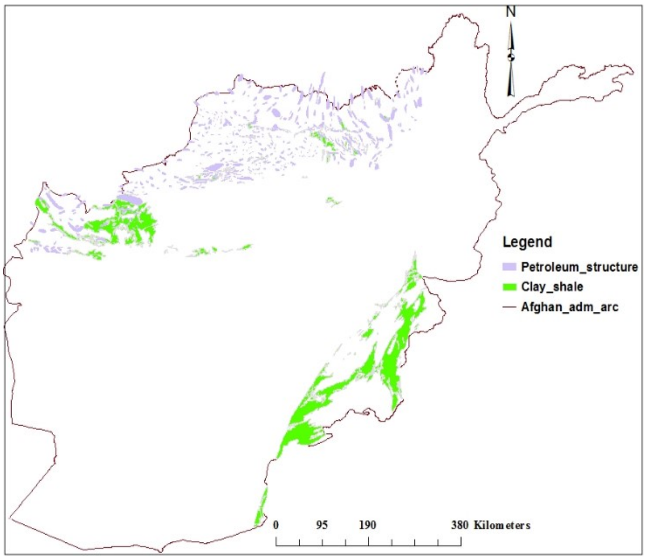

Fig. 7. Geopressured prospect area map of Afghanistan.

F. Hot Springs

Only the surface manifestation of hydrothermal resources in the country is hot springs. The geochemical condition of these springs is the CO_2, Nitrogen, and hydrogen sulfide (H_2S) bearing thermal water originating from metamorphic, reducing, and oxidizing environments respectively. The highest recorded temperatures are 52°C in Obe of Herat, 55°C in Sarab of Baghlan and Chah Ganj of Balkh provinces [1]. The Fig. 8 shows the 4000 m buffer zone of hot springs with surface water temperature. They are located around and above the fault system mainly in the joint area of the large faults, secondly in Helmand-Arghandab geothermal field.

G. Hydrothermal Minerals and Alteration

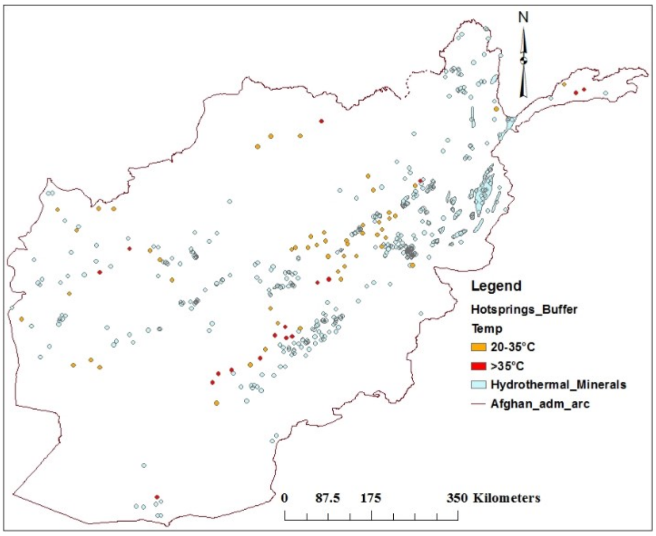

Fig. 8. Hydrothermal minerals and hot spring areas map.

Another surface appearance for the probable existence of geothermal reservoir can be either the hydrothermal minerals or the hydrothermal alteration zones. Hydrothermal alteration refers to the change in the mineralogy of rocks due to the hot water interaction. For the hydrothermal alteration zone mapping, there are several methods for instance electrical conductivity, gravity measurement, and hydrothermal alteration mineralogy. The occurrence of a hydrothermal mineral depends on the temperature, pressure, permeability and fluid composition. It also can be the indicator for the reservoir types [2]. The region having deposits types such as (Hematitic vein type, Hydrothermal, Hydrothermal barite Pb-Zn, Hydrothermal barite vein, Hydrothermal emerald, Hydrothermal gold sulphide quartz, Hydrothermal mercury argillic, Hydrothermal quartz scheelite, Hydrothermal quartz sulphide, Hydrothermal quartz wolframite, Hydrothermal sideritic vein type, Metamorphic impregnation Graphite, Metamorphosed, Metamorphosed sedimentary hosted, Metamorphosed sediment hosted Cu, Metamorphosed volcanogenic/sedimentary hosted, Muscovite pegmatites, Oxidized, Quartz cassiterite vein/stockwork, Quartz cassiterite sulfide veins, Rare earth uranium bearing carbonatites, Rare metal muscovite pegmatites, and Rare metal pegmatites) were selected from the mineral deposits map of Afghanistan to determine the hydrothermal alteration zone [2], [18]. For prospect geothermal area mapping the 4000 m buffer zone was given to the selected hydrothermal mineral deposits points, and the result map union with pegmatite deposits has been shown in the Fig. 8.

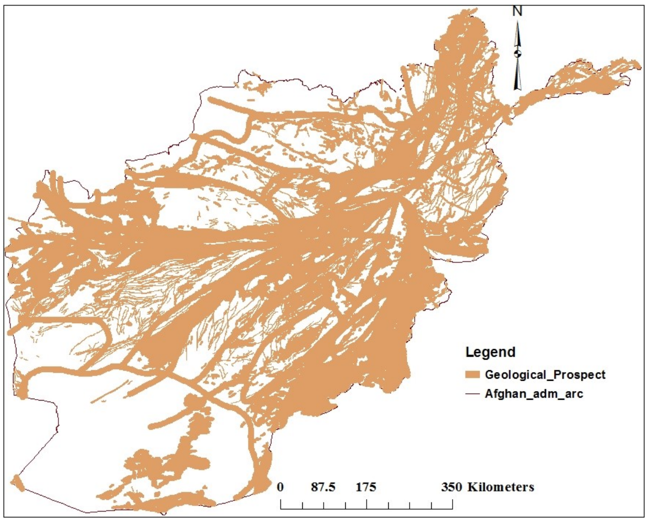

Fig. 9. Geological prospect areas for geothermal exploration in Afghanistan.

IV. Result

The result map of prospect areas for geothermal potential exploration was created from the overlay intersection of geological, geophysical, and geochemical prospect area maps. The geological prospect area was mapped from the fault, volcanic rock, and volcanic dome evidence maps' geometric unions and it has been shown in Fig. 9. The geophysical prospect area map (as shown in Fig. 10) is the geometric union of areas having temperature above 90°C in 5km depth and intrusive rocks area. The geochemical prospect area is the geometric union of hot spring, geopressured, and hydrothermal mineral areas they are presented in Fig. 11.

Based on our findings, from the GIS model and input layers of evidence maps, the intersection result of geological, geophysical and geochemical prospect areas has been determined as shown in Fig. 12. The resulting map of geothermal energy contains the most suitable (geological, geochemical, and geophysical prospect) areas for the existence of geothermal resources in Afghanistan.

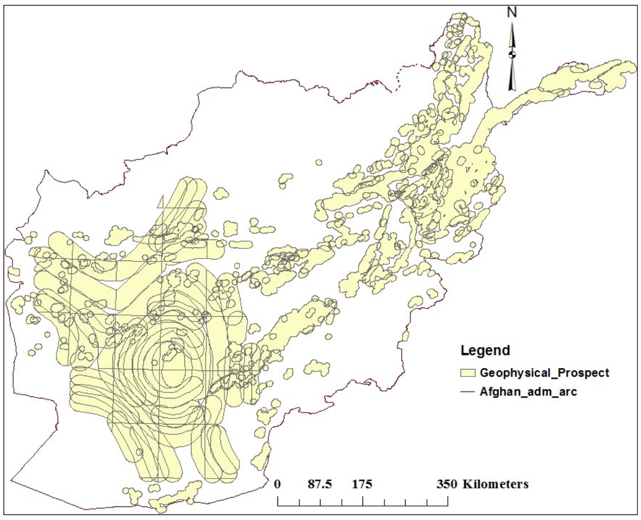

Fig. 10. Geophysical prospect areas for geothermal exploration in Afghanistan.

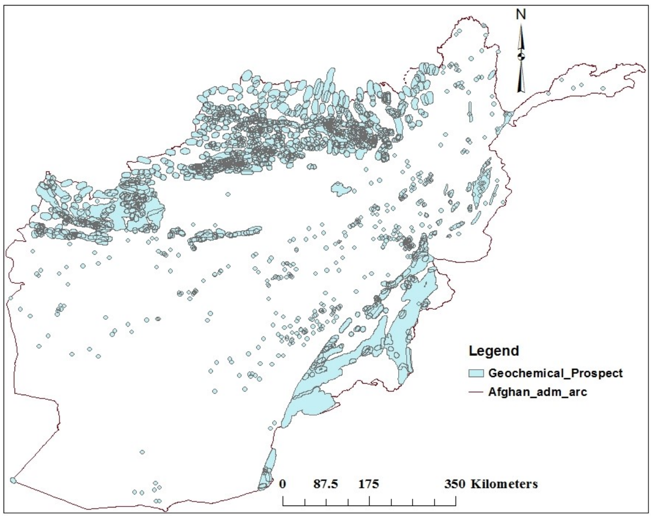

Fig. 11. Geochemical Prospect Areas for Geothermal Exploration in Afghanistan.

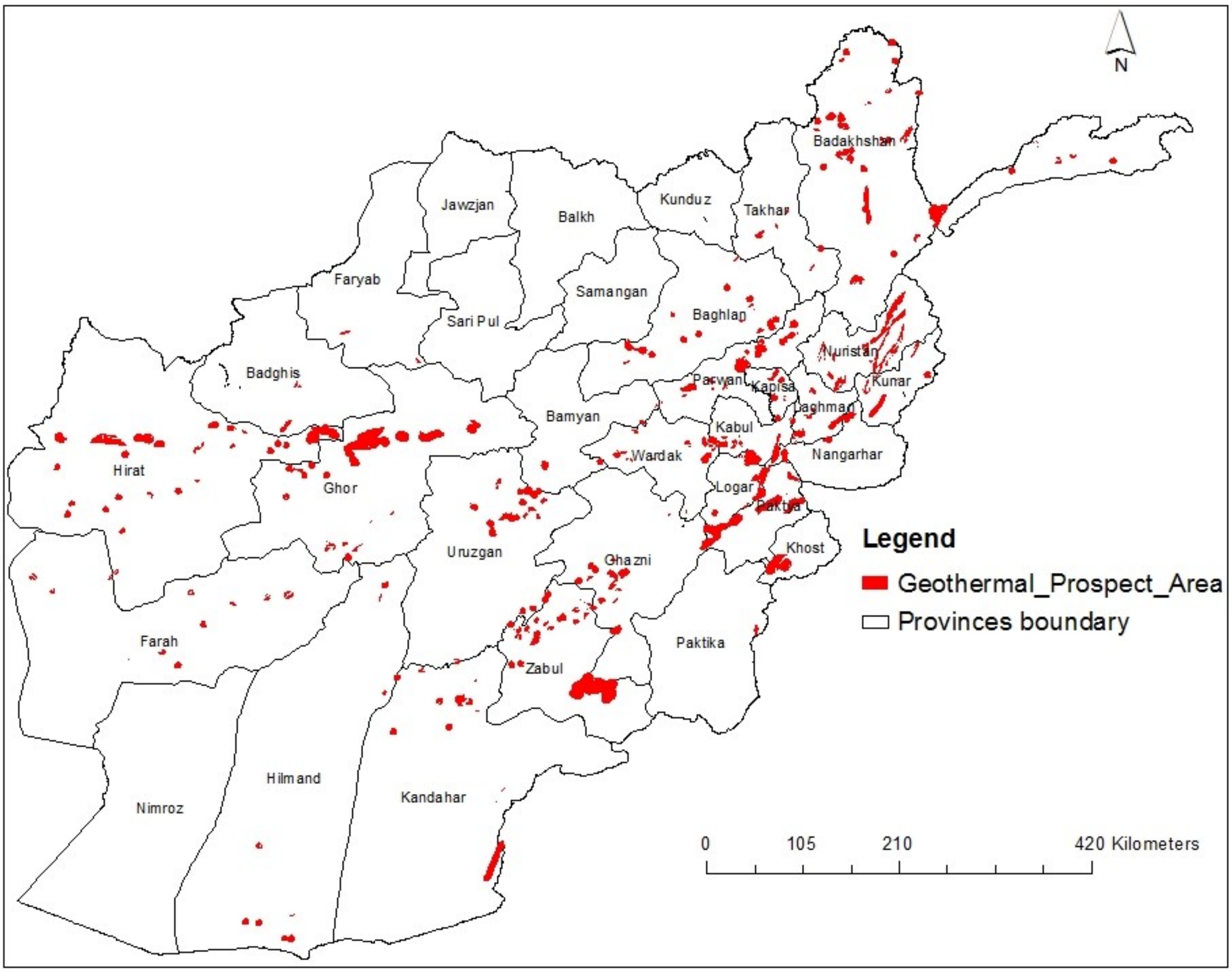

Fig. 12. The geothermal potential prospect areas map for Afghanistan on the base of this study.

V. Conclusion

The finding of this research study is the first digital map of Afghanistan geothermal resources. Besides known geothermal fields, there is an enormous potential in the east south and west of the country which is close to the load centers and big cities of the country such as Kabul, Kandahar, Hirat, Jalalabad, Ghazni, Gardez, Khost, and Charikar. The result of this study determined the specific regions have high hydrothermal possibilities. It would be the best option for further geothermal reservoir characterization and exploration.

Acknowledgements

I am grateful to Dr. SAIBI Hakim Associate Professor in Department of Earth Resource Engineering at University of Kyushu, Fukuoka, Japan. Regarding the information and article sharing. Also, I am grateful to Matthew Cushing, Geographer at US geological survey for sharing the

Afghanistan's geology digital map and database.

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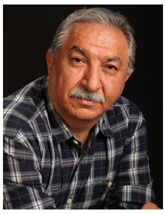

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