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ARTICLE

Hydrogeological Investigations of Paghman Valleys in Kabul, Afghanistan

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ABSTRACT

Paghman valleys are located at the foothills of the Hindu Kush Mountain range (Afghanistan) and consist of dissimilar kinds of valleys with different rocks and sediments. Valleys in this region consist of several types of streams which are clean, due to their filtration at the valley beds. Water resources, such as streams, springs, and rivers are used for drinking, irrigation, and other general-purpose usages. Due to years of regional conflict, the general water infrastructure needs to be upgraded, however since people need water for their day-to-day activities, it is necessary to characterize various sources of water to ensure their safety. Thus, this study aims to estimate the petrographic characteristics of the Paghman valleys and predict the resource suitability of the region through certain analyses: petrographic, gravel, and sieving analysis. The study is important since no such studies exist on this subject for this region, because of decades of war and much work remains to be done due to an ever-increasing population accompanied by air pollution which may affect the water resources of the region and thus causing health problems for people. The results provided through this investigation provide some preliminary quantification of heavy and light minerals, mechanical analysis, pH determination, electrical conductivity, and Cation and Anion concentrations of heavy and light minerals in water. Furthermore, as the regional population is steadily increasing, the authors highlight policy recommendations for a range of mitigation measures for the relevant authorities to keep water and soil quality within a safe range.

Keywords: Paghman Valleys; Petrography; Gravel analysis; Sieving; Water flows; Afghanistan

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1. Introduction

The Kabul Basin is a plateau surrounded by mountains located in the eastern central part of the country and contains many water basins as well. Paghman Valley is located at the foothills of the Hindu Kush Mountain range and the region consists of different types of valleys, viz. longitudinal, transverse, diagonal, and isoclinal. The valleys consist of different kinds of rocks, such as Granite, Amphibolite, Schist's, Gneiss, slats, conglomerates, and Breccia, in addition to gravel in several sizes, such as boulders, cobbles, pebbles, and granules. Around Kabul, there are several basins, which are located in and around Paghman Valley—such as in the upper part, middle part, and lower part of Kabul [1–6]. All of these basins are divided by different heights of mountain ranges, which serves in the role of the border separating groundwater [7–9]. These mountains primarily consist of gneisses, which are crystalline, and in Kabul, it is from the Archaean and Proterozoic periods [10–12]. The sizes of sediments occur due to the slopes of the valleys, and the valley beds. In the skirt and sloppy areas, we can find bigger sizes of sediments, in the middle slopes we can find medium sizes, and in the plain areas, we can find smaller sizes of clay, silt, and sand. Also, in the Paghman region, we can find Granite, which shows the remnants of pre-historic geothermal activities [13]. Among the basins, we can find different types of gravel such as boulders, cobbles, pebbles, granules, sands, silts, and clay [14–16]. These thin sediments occur due to the slope of the area so soil layers in these areas may be thinner than in flood plains, where it tends to accumulate [17,18]. Groundwater is collected with wells and pumps, or it can flow naturally to the surface via seepage or springs [19–21]. In the Kabul basins, we can find different types of geological formations of groundwater such as aquifers, aquiclude, aquifuge, fractures, and Karst's aquifers [22,23]. As the Paghman mountain range has the highest altitude in the Kabul province and hence, there is more snow during the winter season, which melts during the spring season forming different types of streams at different velocities between valleys, which get divided into three separate courses such as upper, middle, and lower [24,25]. In the upper course, the velocity is much higher in the form of turbulent flows, the stream beds have more friction, and the type of erosion is only downcutting [26]. In the middle courses, the slopes of valley beds are somewhat less resulting in a mixture of laminar and turbulent types of streams. While the middle parts of valleys are generally turbulent, near the banks laminar flows are observed [27,28]. In the lower parts of valleys, the flow is primarily laminar, and it only transports smaller sizes of sediments [29–31].

1.1 Geological map of Kabul

In Kabul province, there are different types of mountain ranges and also different types of geological structures such as Anticline, and Syncline. The ranges of mountains in Kabul, which lie within the Kabul Block may be separated by different kinds of faults (**Figure 1a**). In Nuristan Block, there are different types of rocks, sediments, and formations [32,33], such as Oligocene Granite, Paleocene Ultramafics [34,35], Cenozoic sediments, Khotagai series, Carboniferous-Permian sediments, Walayati-Kharog formations, and Sherdarwaza (Khair Khana) formations (**Figure 1a**). In Khair Khana, Kabul airport, and central Kabul mountains, there are different types of minerals, rocks, and formations (Sherdarwaza formations and Gneiss, Amphibolite, marble, Meta-Gabbro, and Mata-Granite). In Walayati mountain formations, there are various types of rocks such as Schist and Amphibolite, and also faults that allow certain rivers to flow [36–38], roads, and other different structures (**Figure 1b**).

1.2 Research objectives

The objective of this investigation stems from our ongoing investigation of several regions of Afghanistan. The region has been in conflict for a long period. This prevented any systematic study of water and soil quality. Due to the increasing population and arid conditions of the region, partially resulting from climate change and anthropogenic activities, a thorough grid investigation of the

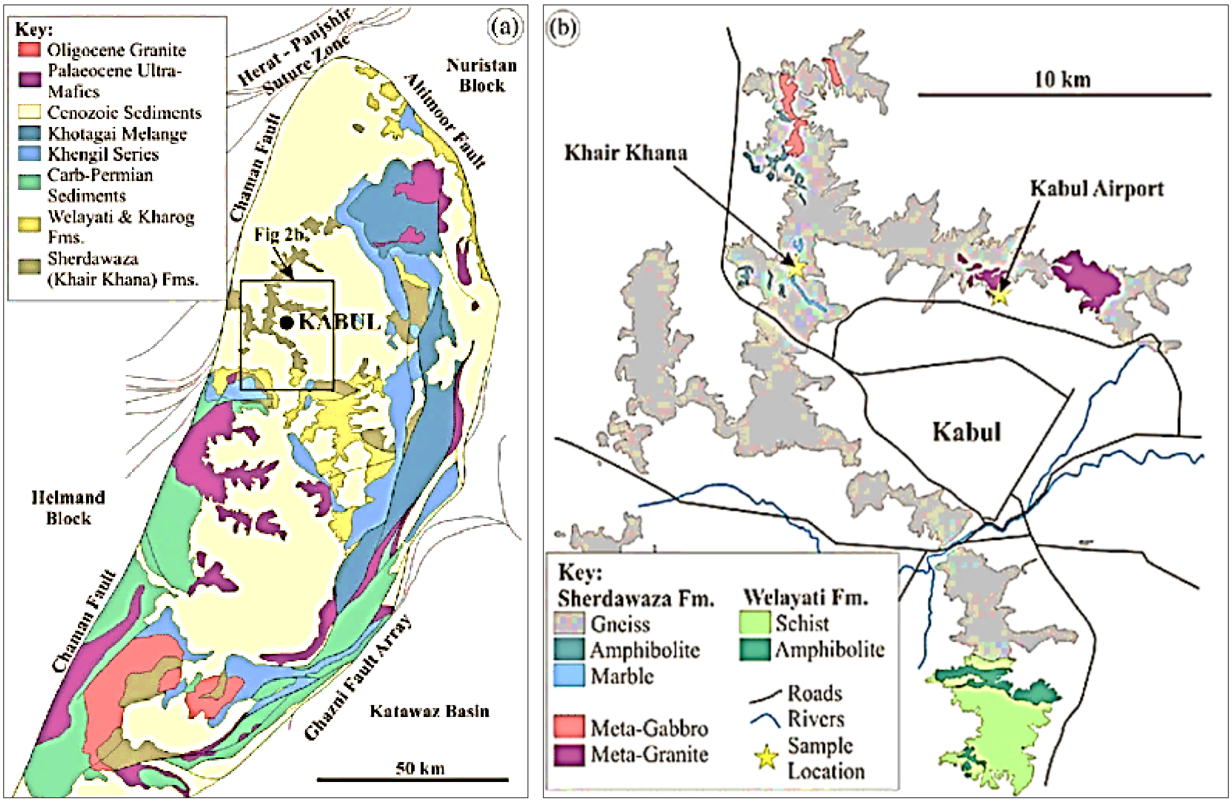

Figure 1. Geological map of Kabul Mountain ranges, Afghanistan. (a): Kabul province blocks, (b): Different types of rocks (near Khair Khana, Kabul airport, and central Kabul mountains).

region must be conducted. Hence, the overall objective of this scientific investigation is to characterize and analyze different rocks, sediments, and soil in Paghman valleys, Kabul (Afghanistan) through petrographic, tectonic, gravel and sieving, geochemical analysis to identify different valley types, nature of river streams, heavy and light minerals, concentrations of Calcium Carbonate $CaCO_3$ ($CaCO_3$ found in some of these areas may affect agricultural), pH (indicates the amount of acidity and alkalinity of soil), electroconductivity (EC) (shows the amount of salinity in soil which may affect animals and plants), and its effects on water quality. Quantifying different parameters that impact water quality [39] (soil quality, agriculture, and groundwater resources) may cause risks to human health and wildlife (contaminated sediments present short and long-term toxic) [39–41]. As we conduct similar investigations in other regions of Afghanistan, we are developing a database to exchange information with other research groups to generate a comprehensive water and soil quality map of the entire country.

2. Method and materials

The focus of this paper is two-fold; the first is the study area research: determination of types of valleys, petrography study of rocks, tectonic activities, and different types of gravel. The second approach is laboratory analysis at the Paghman valleys, Kabul: Sieve analysis or a gradation test is an important method for assessing the particle size distribution of granular material (heavy and light minerals), mechanical analysis, $CaCO_3$, pH, and electrical conductivity (EC).

For the assessment to conduct this research, different samples are collected for analytical techniques including (1) granulometric analysis, (2) heavy mineral analysis, (3) mechanical analysis, and (4) hydro-geochemistry of sediments; calcium carbonate ($CaCO_3$), pH, and electrical conductivity (EC), and then submitted to the laboratory for analysis through the sieving analysis method which is carried out to separate a sample according to its particle sizes by submitting it to mechanical force and thus, the determination of mixed smaller sizes (1 mg sample for determination of mechanical analysis).

3. Results

3.1 Types of valleys

In the Paghman mountain range, **Figure 2** shows different types of valleys such as longitudinal, transverse, diagonal, and parallel (2D model).

The longitudinal valley is an elongated valley found between two almost-parallel Paghman mountain ranges. The depth of this type of valley depends on the slope of the mountain area. From the viewpoint of slopes, the longitudinal valley is divided into three types of courses:

1) **The upper course**, the velocity of the river is much higher, and the type of flow is turbulent. Common features found at this level are lakes, waterfalls, potholes, and gorges. Additionally, in the upper course, there is mostly vertical erosion. This creates its V-shaped valleys. In the riverbed, we can find bigger sizes of sediments such as a boulder, cobbles, pebbles, and granules.

2) **The middle course**, the velocity of the river is middle. Lateral erosion turns the once steep-sided valley into flood plains and the types of sediments are fine gravel granules and sands. Meanders and river cliffs will also form. Water from different sources enters the channel, and the channel widens.

3) **The lower course** is closest to the mouth of the river where the land is low-lying. Erosion is confined to lateral erosion at meanders. The gradient is almost flat due to the lack of vertical erosion. In the lower course of the river, there is little erosion with smaller sizes of silts, and clays. In these areas, the river flows in a meandering pattern and has different types of caving banks depositional banks, and oxbow or dead channels.

The transverse valleys are located vertically (90°) on the Paghman mountain ranges and are long and very sloppy. The form of erosion is downcutting where the bigger sizes of sediments such as boulders, cobbles are deposited in the valley beds.

The diagonal valleys are located at one angle (30°, 40°) and are very short. They are located in the very sloppy areas of the Paghman mountain ranges and consist of bigger sizes of sediments. The type of erosion is downcutting.

The parallel valleys are generally parallel with the layer of rock strikes and the slopes of these types of valleys are different in some places and are as plain in other places at 35°, 40°, and 90° (almost vertical) slopes. The sizes of sediments are larger in the valley beds and are smaller in its plain areas, particularly at the bottom of it.

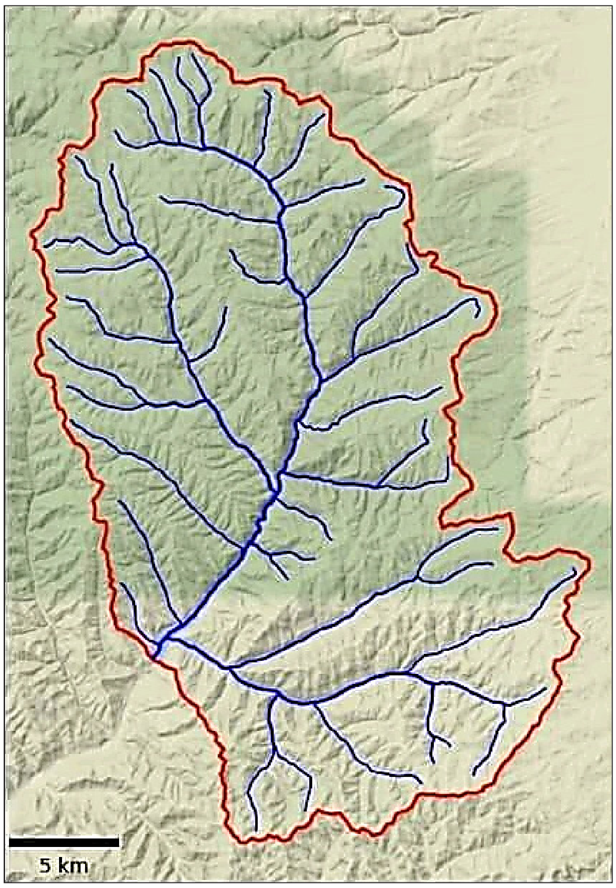

Figure 2. The 2D-model of Paghman valleys, different types of valleys.

The Paghman valleys play a very important role in the Kabul province because the Paghman Mountains have the most snow in winter and spring seasons. Snowmelt provides a great source of fresh water for a lot of communities in Kabul. In addition, the Paghman

Valley streams are also vital for recharging the nation's groundwater supply. When the underground water of the Paghman aquifers finds an exit point, water starts flowing on the surface as springs which can be depressions, valleys, cliffs, or subsurface faults and fractures extending to the surface (**Figure 3**). Furthermore, the Banda Qargha Dam was constructed in the Paghman Valley Kabul in Afghanistan and its peripheral areas provide recreation facilities such as boating, surfing, golfing, etc.

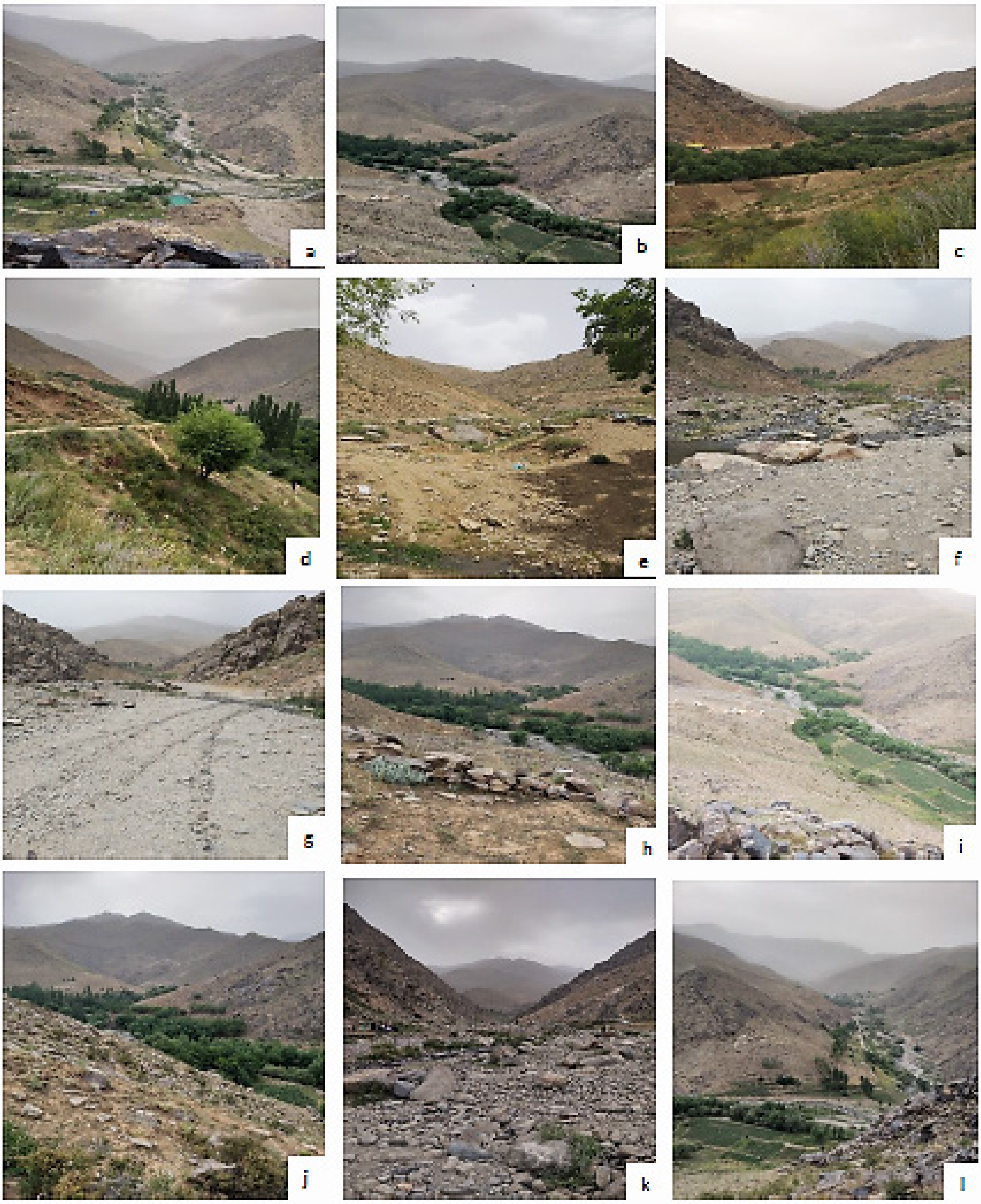

Figure 3. The different types of valleys (a) diagonal and transverse, (b) diagonal, transverse, (c) transverse (d) longitudinal (e) transverse, (f) diagonal, (g) diagonal, (h) longitudinal, paralleled and transverse (i) longitudinal and diagonal, (j) longitudinal and transverse (k) longitudinal, (l) longitudinal and paralleled in Paghman Mountain Ranges, Kabul, Afghanistan.

3.2 Tectonic activities

The Paghman Mountains in the Kabul region are tectonically active areas where there are several structural remnants, viz. epeirogeny and orogeny movements. In these mountain valleys, there are several tectonic structures such as joints, cracks (dip, longitudinal, diagonal, and parallel), domes, basins, and faults (strike-slip faults, normal faults, reverse faults, thrust faults, and oblique-slip faults). Indeed, the presence of numerous major faults in the region (convergent, divergent, and transforms) (**Figure 4**) are the places where earthquakes can occur and can trigger volcanic eruptions through the severe movement of tectonic plates with a variety of symmetrical and asymmetrical folds (zigzag, mushroom, and vergence).

3.3 Petrography

The study area presents different types of sedimentary rocks including breccia, sandstones, siltstone, gravels, and conglomerates. The sediments are coarsest near the Paghman Mountains, the main source area for the Kabul Basin. The conglomerate is a clastic sedimentary rock that is composed of a substantial fraction of rounded to subangular gravel-size clasts and has a particularly good filtration capacity. The conglomerates originate in alluvial environments on both sides of Paghman valleys streams and comprise mainly braided stream and mass flow sequences. However, because of more slopes of valley walls in the Paghman mountains, more gravels are transported by gravity, and near the valley walls, various angular gravel materials are disposed of and cemented by carbonates, clay, SiO_2, and make breccia.

The Paghman Mountains also have several metamorphic rocks such as amphibolite, slate, schist, quartzite, granite (light-colored plutonic rock (igneous rocks that solidified from a melt at great depth)), and gneiss (**Figure 5**). In the Paghman Valley, there are different sizes of Quartzite in river paths. Granite-gneiss in the Paghman Valley has a very wide distribution. Granite is a widely recognized

Figure 4. Tectonic activities and different geological structures, (a) cracks, joints, normal faults, (b) diagonal valley with complex tectonic activities (c) amphibolite with complex tectonic activities (d) transverse valley, cretonne in gneiss with complex tectonics, (e) granite with complex tectonic activities, (f) amphibolite with joints and cracks in Paghman valleys, Kabul, Afghanistan.

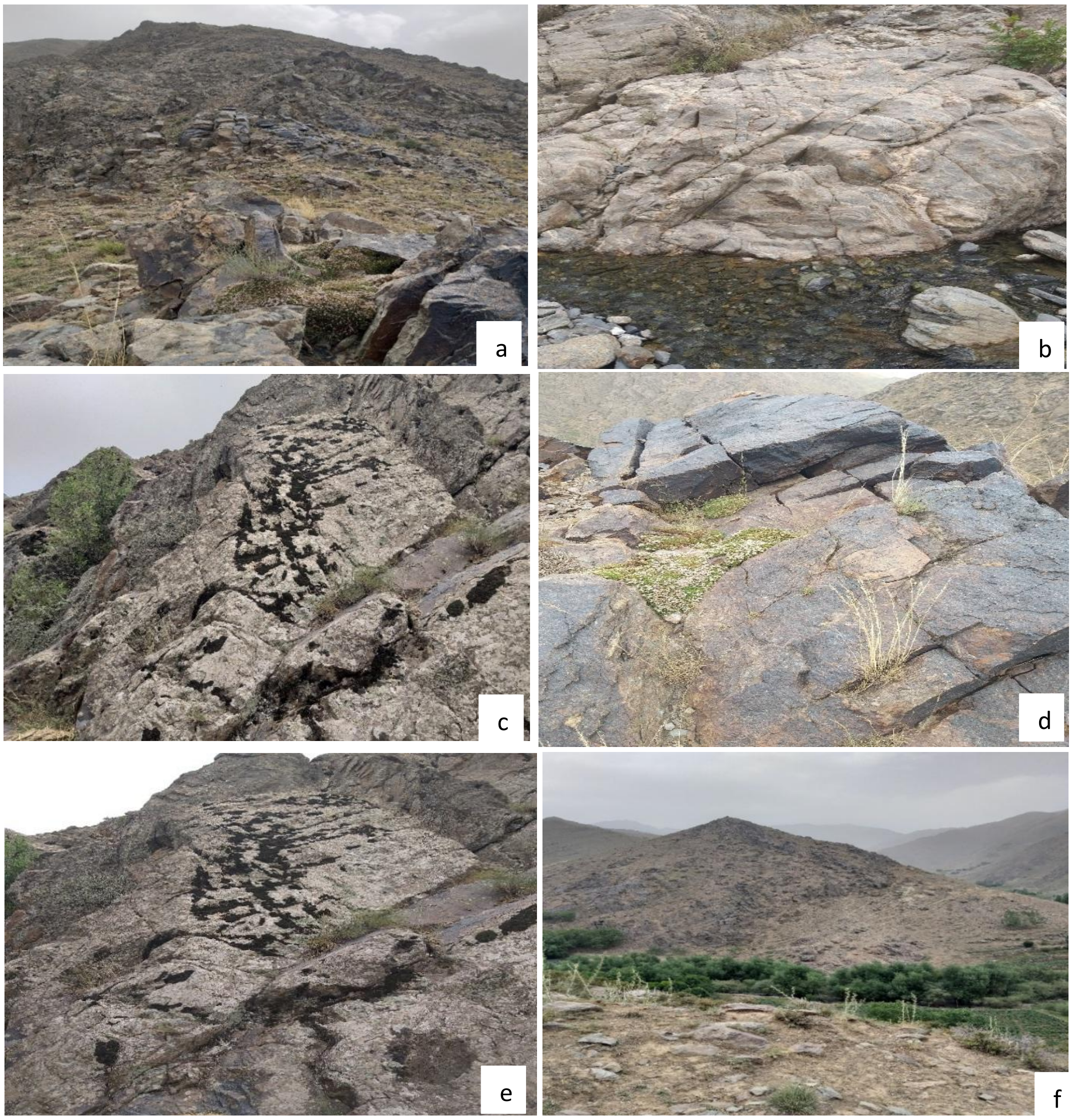

Figure 5. Petrography (a) Amphibolite, (b) Gneiss, (c) Granite, (d) Amphibole with gneiss, (e) Granite with gneiss, (f) Amphibolite with gneiss of Paghman valleys, Kabul, Afghanistan.

igneous rock material in the region because it is a strong, impermeable, and the most suitable rock for the foundation of a dam. Metamorphic gneiss has many uses as a building material including flooring, ornamental stones, gravestones, facing stones on buildings, and work surfaces. These types of rock (granite-gneiss) provide a stable base and help prevent water from seeping through the foundation.

3.4 Types of streams

In the Paghman mountain ranges, stream valleys are characterized by a stream valley plain enclosed by higher ground, with a stream bed and riverbanks in between. The resultant stream types are often associated with tectonically uplifted valleys. A stream's velocity depends on the position in the stream channel, irregularities in the valley, there is a sudden decrease in gradient and velocity.

In the upper course of Paghman valleys (higher altitudes), the stream will have a high velocity where the river has a larger bed load, more roughness, turbulence, and friction; bigger sizes of sediments such as boulders, cobbles, pebbles, granules, sands. At the stream beds water infiltrated between gravel and made different types of springs between different valley beds.

In the middle course of Paghman valleys, the gradient decreases and the discharge increases, but near the banks Laminar or turbulent flow occurs and water moves in parallel layers. The water erodes, transports, and deposits soil and other materials such as granules and sands, and some of the water may infiltrate deeper into the gravels thus recharging groundwater aquifers.

In the lower course of the Paghman valleys (plain), the velocity of the river is very slow as the water doesn't have enough energy to carry material, and the type of streams is laminar. Meandering and braided streams are typical of the lower course which are located on flat terrain that reduces the flow speed of water. These plain areas are very sightseeing places (**Figure 6**).

3.5 River courses

Paghman has different types of streams: the smaller streams consisting of gulley which is a large grove, or channel, in the water that carries runoff after a rainstorm. These gullies join together to form a larger channel known as a stream. These streams result in a bed morphology that is stable at all but the largest flows and manifest at low flow as a longitudinal valley (an elongated valley found between two almost-parallel mountain chains in geologically young fold mountains), as a transverse valley (a valley which cuts at right angles across a ridge or, in mountainous terrain a valley that generally runs at right angles to the line of the main mountain chain or crest). As streams start to flow into each other, they join and start to make larger and larger bodies of flowing water. Usually, a large stream is called a river **(Figure 7**). The farming in the Paghman region is concentrated in the lower-middle course where predominantly farmed various types of trees such as apples, apricots, a variety of peaches, and nuts.

Figure 6. Types of streams (a and c): Turbulent flows in the upper course, (b): Turbulent and laminar flows in the middle course, (d): Meandering and braided streams in the lower course in the Paghman valleys, Kabul, Afghanistan.

Figure 7. River courses (a) longitudinal valley, (b) transverse valley, (c) lower course, (d) middle course in Paghman valleys, Kabul, Afghanistan.

3.6 Types of gravels

In the paths of Paghman River streams, there are different types of gravel and sediments such as boulders, cobbles, pebbles, granules, sands, silts, and clays. The sizes of gravel depend on the slopes and velocity of rivers. As the flow velocity increases, only larger particles will be deposited. Also, near the slope areas, some bigger sizes of sediments are transported by gravity and different types of talus materials consolidated and unconsolidated materials (like gravel, sand, and even silt) are deposited. Generally, the area of gravel sediments makes a good aquifer because it is extremely permeable and porous. At the river paths, conglomerates and breccia are deposited (**Figure 8**).

3.7 Imbricate bedding

Imbricate bedding is an elongated and commonly flattened pebbles and cobbles in gravelly sediment that are deposited so that they overlap with one another like roofing shingles. These structures form in the upper course where high-velocity currents move over a streambed or where strong currents and waves break over a gradually sloping beach, thereby forming a beach shingle. In the Paghman valleys, the slope angle ranges from 15 to 45° of the gravel, as shown in **Figures 8c, 8e, 8g, 8h, 8i, and 8j**.

3.8 Agriculture and crops

Paghman Valley is a very good area for agricultural production (major crops are potatoes, wheat, legume, mulberry, and corn). This agricultural production provides food not only to people living in Paghman but also to people living in different parts of Kabul and Afghanistan. As well as these agricultural lands are good places for sightseeing for Afghanistan's population (**Figure 9**).

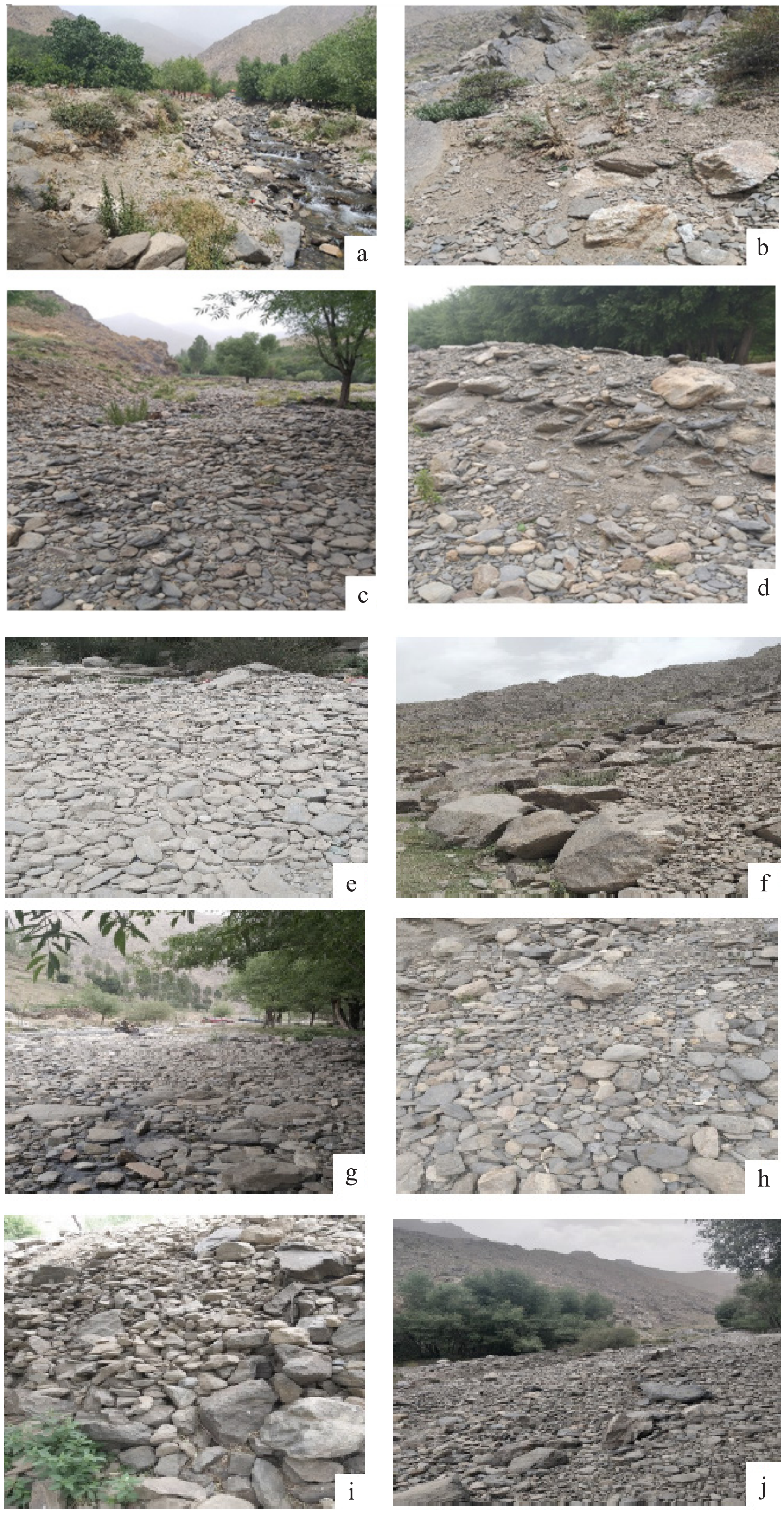

Figure 8. Kinds of gravels; (a): Rounded and homogeny gravels, (b): Talus angular and heterogeny gravels, (c): Rounded and angular gravels transported by streams and gravity, (d): Boulder clay and angular gravels, (e): Rounded gravels transported by streams, (f): Talus boulder with different sizes of gravels, (g): Plate and long gravels, (h): Rounded and angular gravels those transported by water and gravity, (i): Angular gravels transported by gravity, and (j): Angular and rounded gravels transported gravity and streams, in Paghman valleys, Kabul, Afghanistan.

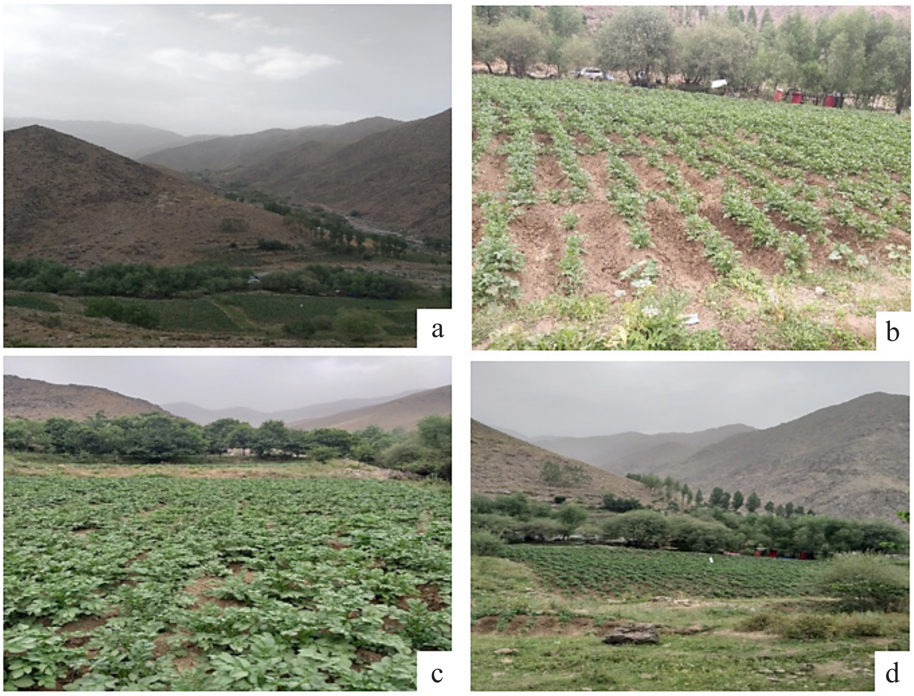

Figure 9. Agricultural lands (a, b, c, d) show different types of crops such as potatoes, wheat, mulberry, apples, apricots, almonds, legumes, and black cherries in Paghman valleys, Kabul, Afghanistan.

3.9 Gravel analysis methods

The gravel analysis method is one of the most important methods of sedimentology rocks. It is a method that is used to determine the grain size distribution of soils. In this study, the gravel is from different places along the river (big sizes and smaller ones). It is possible to obtain the grain size distribution by; getting samples, recording different size materials, and from the percentage, finding the different types of gravel transported from source areas. Selected three points are important, and at every point, determine the weight of different types of gravel. The size used in this study is 30 × 80 cm for a boulder and the smaller sizes are for sand and silt. The gravel is a mixture of different-sized pieces of rock fragments including Garnet, Quartzite, Gneisses, Schist, Amphibolite, Slate, Conglomerates, Breccia, and Limestone. These rocks are deposited in the surrounding mountains of the Paghman Mountains range, and it's transported by different factors of exogenetic forces such as alluvial, colluvial, prolluvial and delluvial. Among these sediments, some are more rounded and others are angular. **Figures 10–12** show the roundness and angularity of sediments belonging to the consolidation of rocks.

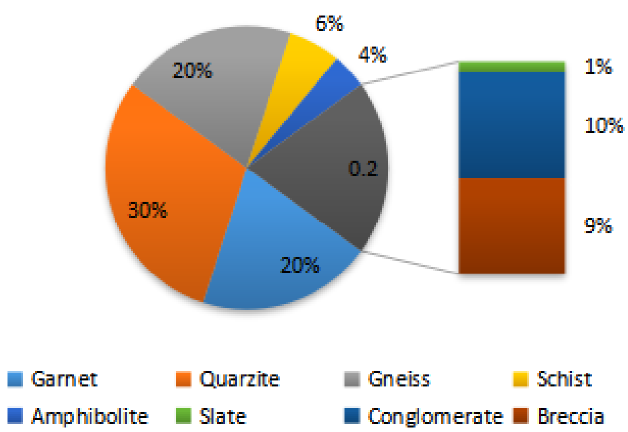

Figure 10. The gravels analyzed in point 1, Paghman valleys, Kabul, Afghanistan.

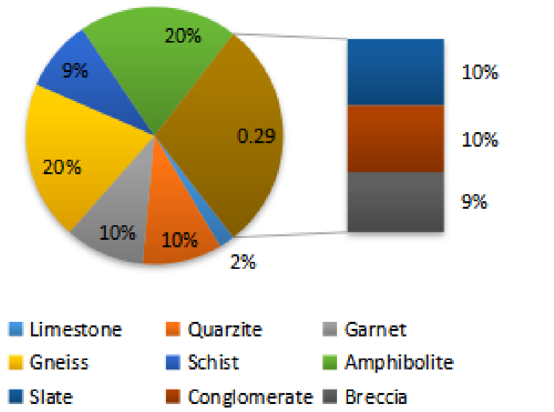

Figure 11. The gravels analyzed in point 2, Paghman, Kabul, Afghanistan.

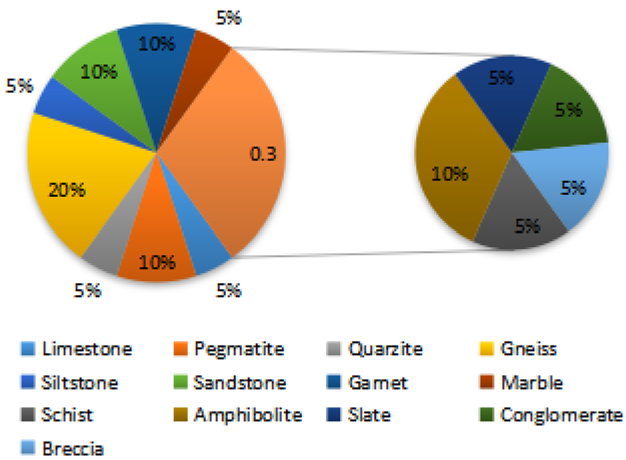

Figure 12. The gravels analyzed in point 3, Paghman valleys, Kabul, Afghanistan.

3.10 Sieving analysis method

The sieving analysis method is a mechanical technique used to separate particles of different sizes by allowing the material to pass through a series of sieves of progressively smaller mesh size and weighing the amount of material that is stopped by each sieve as a fraction of the whole mass. This work is aimed at grading the particle sizes of 1 kg samples from three points and transporting them to the laboratory. After drying the samples using the sizes of sieved mesh such as 6.3 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, and 6.3 µm, then analyzing the samples by sieved mesh. This can be interpreted by analyzing the retention of particles throughout a sieve stack or the amount of material that passes through each sieve; the percentage individually of every sieved size and the present histogram with cumulative distribution curves (**Figure 13**). The sieving analysis method can be used not only to determine different types of soils and different types of flows but also it is a good method used in construction sites to separate pebbles and stones from sand.

3.11 Sedimentological analysis of heavy and light minerals

After the sieving analysis method was done using this current method of sedimentological analysis of heavy and light minerals based on the smaller sizes of mesh sediments (sieving analysis method) samples weighed 5 mg in 3 different points. Separation of heavy minerals from the samples

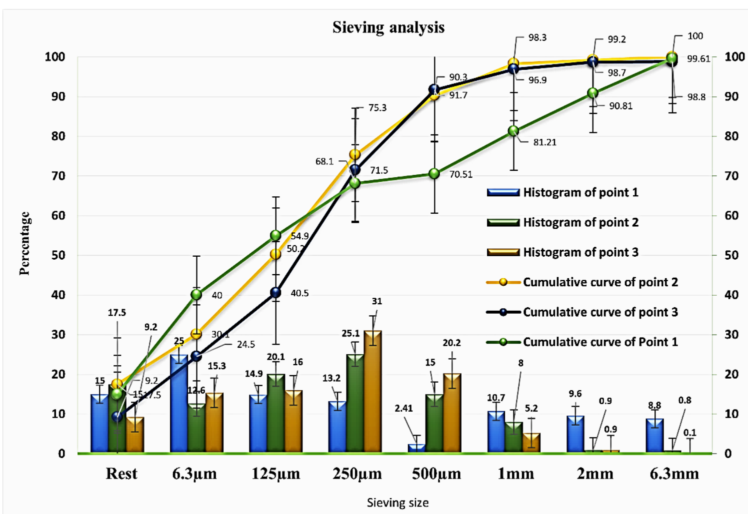

Figure 13. The sieving analysis in point 1, point 2, and point 3, Paghman valleys, Kabul, Afghanistan.

was done with the aid of bromoform to enable petrographic. First, the heavy minerals precipitated in this solution, dried then made a thin slide of heavy minerals. Second, after 24 hours there were the light minerals precipitated, dried then made a thin slide of light minerals. Third, an analysis of the heavy and light mineral suite, under the polarising microscope. The data obtained from the grain size analysis are presented in **Figures 14–19**.

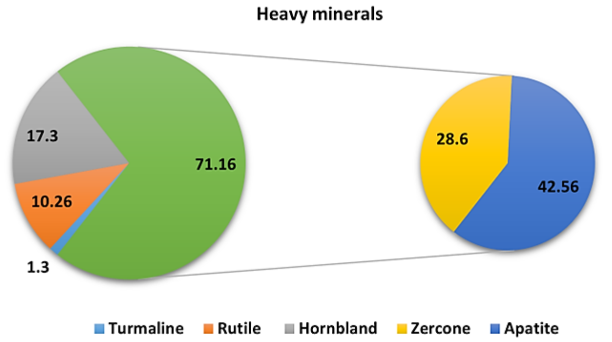

Figure 14. The heavy minerals in point 1, Paghman valleys, Kabul, Afghanistan.

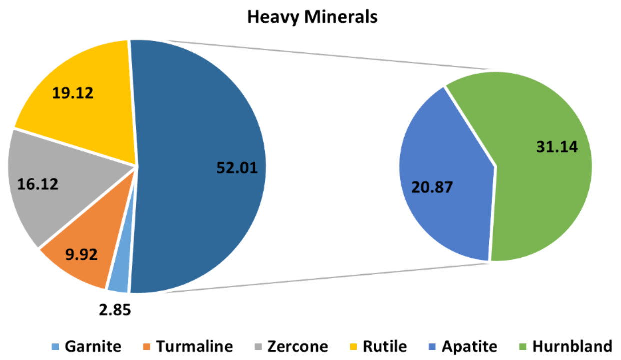

Figure 15. The gravels analyzed in point 2, Paghman valleys, Kabul, Afghanistan.

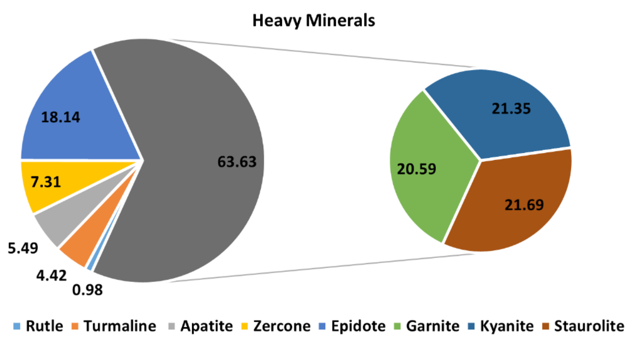

Figure 16. The gravels analyzed in point 3, Paghman valleys, Kabul, Afghanistan.

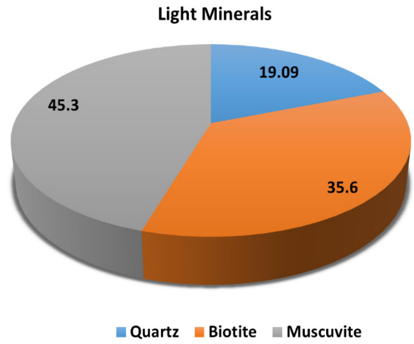

Figure 17. The light minerals in point 1, Paghman valleys, Kabul, Afghanistan.

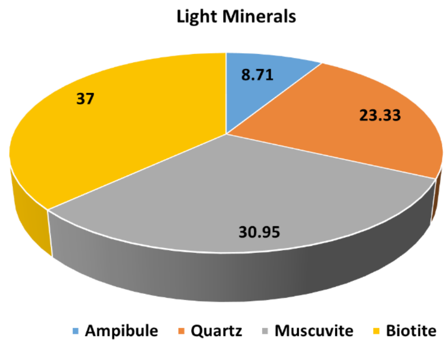

Figure 18. The light minerals in point 2, Paghman valleys, Kabul, Afghanistan.

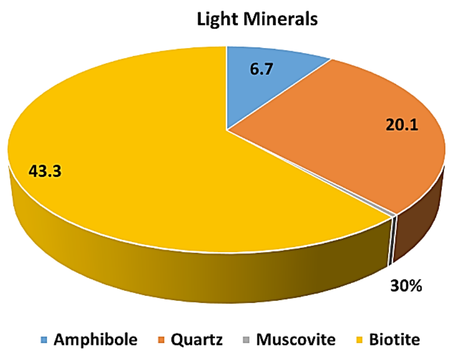

Figure 19. The light minerals in point 3, Paghman valleys, Kabul, Afghanistan.

3.12 Mechanical analysis

Mechanical soil testing refers to the use of mechanical devices or tools to assess the physical properties of soil. Mechanical analysis is the determination of the size range of particles present in the soil, expressed as a percentage of the total dry weight. This method is based on smaller sizes of mesh:

- Place a soil sample of 5 mg (in 3 different points prepared) about ¾ full in a sample jar and add distilled water (1000 L) to cover the soil.

- Set the jar where it will not be disturbed for 2 to 3 days.
- Then measure the percentage of sand and silts.
- Soil particles will settle out according to size. After 1 minute, mark the jar the depth of the sand.
- After 2 hours, mark on the jar the depth of the silt.
- When the water clears mark on the jar the clay level. This typically takes 1 to 3 days, but with some soils, it may take weeks.
- Measure the thickness of the sand, silt, and clay layers.
- Calculate the percentage of sand, silt, and clay.
- Finally, determine the different types of soil by using the Texture Triangle (place any soil sample into one of 12 different soil texture categories).

Thus, in this investigation, the types of soil are loam, sandy loam, and silty loam (**Figures 20–22**).

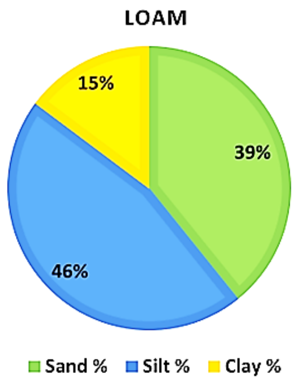

Figure 20. The mechanical analysis in point 1, Paghman valleys, Kabul, Afghanistan.

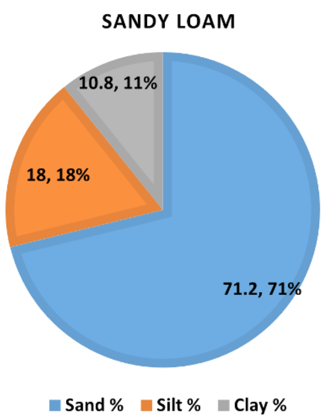

Figure 21. The mechanical analysis in point 2, Paghman valleys, Kabul, Afghanistan.

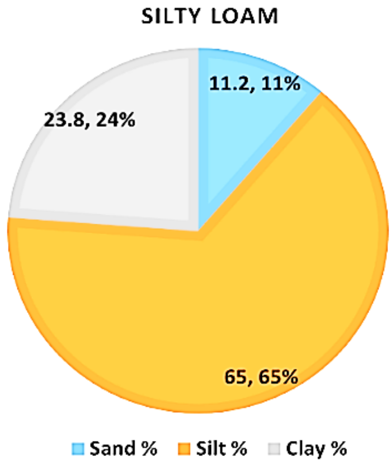

Figure 22. The mechanical analysis in point 3, Paghman valleys, Kabul, Afghanistan.

3.13 Calcium carbonates ($CaCO_3$)

Calcimeter is the method used in this study to determine the Carbonate content $CaCO_3$ in agricultural soils at 3 different points. A determination of the carbonate content in the soil based on a volumetric method. **Figure 23** shows the amount of calcium carbonates in 3 points 0.44%, 0.44%, and 0.33%, respectively. Calcium carbonate is used for different purposes such as construction and medicinal industries.

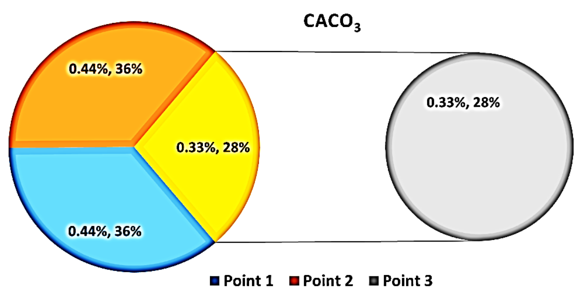

Figure 23. The amount of $CaCO_3$ in point 1, point 2, point 3, Paghman valleys, Kabul, Afghanistan.

3.14 pH

The pH measurement is used in this hydrogeological study in Paghman Valleys in Kabul, Afghanistan. **Figure 24** shows that pH was measured in 3 points: 7.66, 7.96, and 8.02, respectively. This shows that the soil is alkaline which may result from receiving water that contains highly alkaline substances (i.e., calcium carbonate, $CaCO_3$).

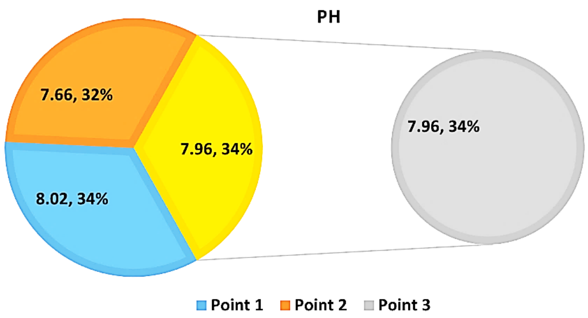

Figure 24. The amount of pH in point 1, point 2, point 3, Paghman valleys, Kabul, Afghanistan.

3.15 Electrical conductivity (EC)

Electrical conductivity (EC) is the measure of the "total salts" concentration in the nutrient solution. In this research, the EC is measured by EC-meter (It is expressed in milliSiemens per linear centimeter (mS/cm) or micro siemens per linear centimeter (mS/cm) where 1 mS = 1000 μS) and it is normal in 3 different points as EC values were observed are 798.30, 877.34, and 950.36 (μs/cm), respectively (**Figure 25**). Therefore, the water characterizing this study area may be used for certain agricultural uses and other purposes but may affect the growth of many different crops in the region and cause.

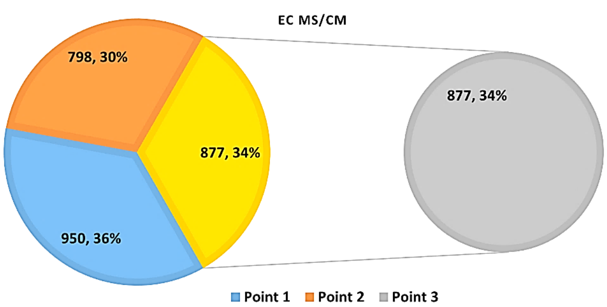

Figure 25. The amount of EC in point 1, point 2, point 3, Paghman valleys, Kabul, Afghanistan.

3.16 Assessment of groundwater quality using Piper trilinear techniques

In the study described above, groundwater sampling was conducted to assess the groundwater chemistry and water types using Piper trilinear plots [42]. As a result, the groundwater chemistry was assessed, and processes, natural and anthropogenic, were identified as the controlling factors for hydrochemistry. A Piper plot for data observed from 50 stations is shown in **Figure 26**.

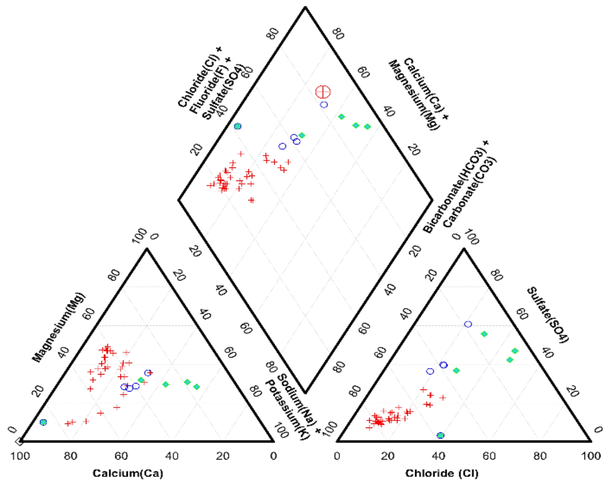

Figure 26. Piper trilinear plot using data from 50 collection stations.

In Piper diagram, the projections of the cations and anions are in the regions 5, 6, and 9 in the diamond shape, where the prominent types are Magnesium bicarbonate, Calcium Chloride, and mixed Ca-Mg-Cl types. However, a slight variation was observed in the Na-Cl type of water. Results of the hydrochemistry suggest that all the water samples are alkaline. This is also consistent with our pH measurements. Major processes controlling the water quality are mineral dissolution, Cation exchange, and inverse cation exchange processes, and anthropogenic activities such as wastewater discharge from laundry, carwash, and other residential and small-scale industrial operations.

4. Policy recommendations

Water is the key to sustainable development and is crucial for socio-economic and human survival itself [39,41]. Freshwater is becoming increasingly scarce, which is rapidly becoming one of the world's biggest problems [41]. People in water-scarce areas will increasingly depend on groundwater [35,36,41,43–45]. The vast majority of the people in Afghanistan particularly Paghman region (Kabul) drink unsafe water, often contaminated by sewage and deadly pathogens. This research and different previous studies (physicochemical analysis) illustrate that groundwater in the majority of areas of the Kabul Basin is not generally suitable for human consumption. Because, in some cases such as the Paghman region, the concentrations of many contaminants are higher than accepted health standards. Despite its water pollution, the downstream community of the Paghman basin still used water contaminated for agricultural purposes (cereals, vegetables, fruits…), livestock watering, washing, cooking, and other domestic needs. This means there is exposure to these potentially toxic substances via different pathways. In the long run, these pollutants pose health risks to humans and even damage to the environment. To contain and avoid this dangerous situation, the municipalities, and local and national health authorities need to take the necessary regulatory and preventive measures to control the discharge of untreated wastes into water bodies. Also, industry owners and operators and local communities must sustain their responsibility to safeguard the aquatic and even terrestrial environments and respective residents' rights to live in healthy environments. The average concentrations for most of the analyzed parameters exceeded the recommended limits of drinking and irrigation water quality guidelines. Given the potential health implications of the toxic substances, the following measures should be sought as a matter of urgency.

- Restrict and monitor discharge from polluting industries. In Kabul and nearby provinces, over 90% of the industries discharge waste to nearby rivers and streams without proper treatment, polluting the rivers and local environments with heavy metals and other contaminants. Therefore, there is an imminent need for regulatory measures to ensure adequate enforcement of the pertinent provisions on environmental protection and social sustainability of industrial investments. For example, demanding existing industries to install and use waste treatment plants is urgently needed.
- Support polluters and the community to minimize their wastewater discharge. Rather than closing the established industries, it is better to equip them, with continuous/regular capacity-building training, with environmental health and safety measures, and demand them to install treatment plants and treat their wastewater before discharging it into the environment. The industries should install and upgrade their treatment plants together with proper management of their waste. The new industries must fulfil the environmental impact assessment criteria before establishment. Also, local communities deserve to be empowered to exercise environmental stewardship.
- Establish centralized ISO-certified laboratories and databases. As a nation, we should have an advanced centralized environmental protection laboratory. The government should update the currently applicable environmental quality standards and empower such laboratories and their capability to enforce regulations for water pollution. We are very poor in data sharing and database management. Hence, as a nation, we have to have a centralized database management system to enable the generation of quality data, minimize/avoid mandate overlapping between government agencies, and improve data sharing using a robust database management system.
- Clear distinction of mandates between different government bodies. There is an overlapping of mandates between government agencies concerned with environmental protection. Hence, there should be clear lines of mandates consistently applied both vertically along the ties of a given agency and horizontally across agencies. Establishing and effectuating a platform to coordinate inter and cross-sectoral environmental issues and share analysis of existing successful techniques is needed.
- Regulatory agencies need to enforce the implementation of laws, rules, and regulations.

Even if there are laws, regulations, and standards at federal and regional levels, their implementation and enforcement of pollution control are very weak. Therefore, the regulatory agencies need to ensure adequate implementation of laws, rules, and regulations that provide for environmental protection. Also encouraging and incentivizing eco-friendly investments avoids grappling with polluting sectors.

- Design new approaches and strategies for waste management. We recommend that the government introduce new initiatives such as water stewardship to use water socially, culturally, economically, and environmentally in a sustainable manner. Such a method should be achieved through a stakeholder-inclusive approach in the catchment and basin development projects.
- Integrate water issues in urban and regional planning. To reduce the negative impacts of urbanization and industrialization and to enhance water quality, the government should incorporate water in its urban and regional development plans. Hence, the government should include water-sensitive urban design before implementing the urban development plan.

Furthermore, this study has not covered micro/nano plastics, which are now found in significant quantities in household products, cosmetics, and clothing. These products are discharged into the water streams and are difficult to filter, especially when the plastics are disintegrated to reduced dimensions. The current water filtration systems are not designed to separate micro/nano plastics and pose significant health risks [46,47]. However, knowing the impending health risks and also knowing that water supplies in the areas under investigation do not have significant amounts of micro/nano plastics, it is prudent to put a policy framework for Plastic Pollution Prevention (PPP), proposed by the authors.

5. Conclusions

This geological investigation is conducted at different locations (points) in Paghman valleys to highlight different types of rocks, sediments, and soil in Kabul, Afghanistan, and to correlate with types of valleys, petrographic analysis, tectonic activities, types of river streams, river courses, types of gravel and gravel analysis. Using different methods to analyze the quality of water and soils in Paghman is critically important for human, animal, and crop health and to optimize crop production to protect the environment from contamination by runoff. The methods used here include gravel and sieving analysis methods, quantification of heavy and light minerals, mechanical analysis, pH determination, electro-conductivity, and Cation and Anion concentrations. It is observed using pH values that the water is alkaline in nature. This is also confirmed by the Pipe trilinear plot, observed from Cation and Anion concentrations from 50 different sites. The pH is adequate for many plants, especially those adapted to arid climates. The EC value levels indicate an excess of nutrients which may cause poor water quality and may also be detrimental to plant growth. Thus far, the values are within a range that allows water to be used for many basic purposes. Hence, the studied soils are loam, sandy loam, and silty loam. These soils with their pH and EC are generally safe and suitable for cultivating many crops and fruit trees. However, air pollution, limited water resources, population growth, improper management of wastewater, and waste disposal are all combined factors affecting the Paghman region. However, with the increasing population and with the current use of new and emerging chemicals, including the excess use of plastic for everyday use, there is growing concern that will impact water quality. Given that, several policy recommendations are proposed in the previous section. It is worth mentioning that years of regional conflict have not severely impacted the water quality in this region, however, it still requires extensive research to identify ammunition residues and other chemicals that may have been used during that period. Overall, this investigation provides an effective Hydrogeological overview of the Paghman Valleys in Kabul, Afghanistan and it serves as a policy recommendation for a range of mitigation measures.

Author Contributions

Hafizullah Rasouli (H.R.), Kaltoum Belhassan (K.B.), Ashok Vaseashta (A.V.), Conceptualization: H.R., A.V., K.B., Methodology: H.R.; Software: H.R., A.V.; Validation, H.R., A.V., K.B., Formal analysis, H.R., A.V., K.B., Investigation, H.R.; Resources, H.R, A.V.; Data curation, H.R., A.V.; Writing-original and draft preparation, H.R., A.V., K.B., Visualization, H.R., A.V., K.B.

Conflicts of Interest

The authors declare no conflicts of interest-financial or otherwise.

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