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ARTICLE

Groundwater Quality Assessment in Pul-e-Charkhi Region, Kabul, Afghanistan

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ABSTRACT

We present the results of studies conducted on the assessment of groundwater quality observed on several water samples taken from water supply sources in the Pul-e-Charkhi region, which is located near the eastern part of Kabul and has seen steady growth in population after the U.S. completed its withdrawal from Afghanistan on 30 August 2021. The water in the basin serves as the main source of water supply and it consists of water discharge from nearby local industries, automobile repair and wash, Osman House, Gradation Place, International Standards Region, and many other regional sources that create a mix of contaminants in discharge to the basin. We collected several samples from each groundwater source for this investigation and transported them carefully to the research laboratory, maintaining the integrity of the samples. The main objective of this study is to assess groundwater quality for the determination of contaminants in groundwater to see what limitations it may pose for recycling and reuse. Such a study is necessary since the region requires persistent sources of water due to a steady increase in population and an associated shortage of water supply due to arid conditions. Furthermore, there is unavailability of similar data since the region served to support military operations since 2001. The samples were analyzed for temperature, electro-conductivity, dissolved oxygen, total dissolved solids, salinity, pH, color, turbidity, hardness, chemicals, and heavy metals. The results obtained suggest that the parameters can be used efficiently to design filtration strategies based on region-specific contamination for the specific catchments located in and around the Kabul Basin. An effort to add additional characterization techniques is described to detect micro/nano plastics and new and emerging contaminants. The efforts reported here are consistent with the 2030 agenda for Sustainable Development Goals.

Keywords: Groundwater; Water quality; Chemical parameter; Physical parameter; Geology

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1. Introduction

This study concerns the assessment of the groundwater quality in the Pul-e-Charkhi region located near the eastern part of Kabul. The region has a lot of historical and political context. Historically, the region is on an Indian tectonic plate, formed by tectonic activities of the Gondwana since almost ~140 million years ago, and moving at a speed of ~20 cm/year toward the Asian plate. Generally, the east side of Kabul was separated along a fault line in the Tertiary (geological period) ~90 million years ago. The forming of the Himalayan Mountain occurred due to the movement of ~2000 miles over approximately 50 million years, following the collision of the Indian plate with the Asian plate in the Alpine orogeny [1]. The Kabul Basin can be described as a valley filled with different sizes of sedimentary materials or regolith and surrounded by crystalline mountains (metamorphic) rocks [2]. The ranges consist of different elevations of crystalline and sedimentary rocks [3,4]. Quaternary sediments are > 100 m thick and are dispersed around Kabul [5]. Underlying tertiary sediments in Kabul are estimated to be between 1500-2000 m thick, depending upon the area location of the valley [6,7]. The adjoining mountains are predominantly comprised of Paleo-Proterozoic gneiss and Late Permian and Late Triassic sedimentary rocks [7]. The gravel and sand in the river channels were deposited by the Lata-band formation as Quaternary terrace sediments of middle and younger Pleistocene age overlay these conglomerates. The Khengal and basement rocks are over-thrusted by schist mélange, which is termed the Cottagay Series in the northern Kohe-Safi range [8], and are under-thrusted by mélange in the Kabul River valley [9]. The eastern part of the Kabul Basin is exhibited by a few isolated yet linear faults and cliffs that exhibit normal dip-slip movement [10]. The Granite in Paghman, Kabul spans from Precambrian [11] and Khengal series. To further characterize the basin, it is important to note that Kabul is surrounded by different fault systems including Chamman-moqure [12], Sarobi, and Mahi-par faults [13]. The Kabul Basin is tectonically active in the transpressional deformation plate-boundary region in the areas under investigation [14,15]. The inter-basin ridges [16,17] are accumulated from metamorphic core-complex rocks, consisting of Paleoproterozoic gneiss [18]. The sediments of Khengal series were initiated since the Jurassic period [19] and are situated in the Thythes Ocean in Afghanistan [20].

The Pul-e-Charkhi Basin dates to the Quaternary (Pleistocene) and Neogen geological periods. The Pul-e-Charkhi sedimentary basin is situated on the east side of Kabul City and covers an area of ~580 km^2 [21,22]. Most regolith and sediments are transported to this basin from different points of Loger and Asmayey mountains, formed by flashfloods and accumulation occurring in the Kabul River at different thicknesses and in different locations of this basin. Various sediments accumulate sequentially and form a morphology, which can be seen at different release points [23]. Sediment types correspond to the nature of rocks located in the surrounding mountains, as we observe Garnete, Biotite, and Muscovite mineral particles. The surrounding mountains of this basin are formed from metamorphic rocks like Schist, Gneiss, and Slate. The Chelsaton Mountains are a series of Loger Mountain ranges, which are located from Southwest to Northeast, called Walayati and Khengal series [24]. In these mountains, different kinds of rocks such as slate, Gneisses, Granite mica schist, and gravel for construction material [25] are found. Further analysis reveals that there are additional sediments than Quartzite, Gneisses, and Schist. As per the morphology of Pul-e-Charkhi, there are three relief kinds, viz. high (upper course) in the mountain slopes, middle relief (middle course) in the hills, and plains (lower course) in the agricultural lands. Furthermore, Pul-e-Charkhi Basin is located between mountain ranges which are called intermountain backing basins, with the plain areas passing the Kabul River and its two laterals located on agricultural lands [26]. Furthermore, Pul-e-Charkhi houses a military airfield nearby. Various strategic locations such as Pul-e-Charkhi prison, camp warehouse, and salt pit are all located nearby. However, since the 2021 withdrawal of U.S. forces from the region, there has been a lot of commercial interest and hence subsequent pollution resulting from industrial activities. The discharge water also ends up in the basin. Hence, the main objective of this investigation is to assess the groundwater quality which is extracted for selection for different types of usage, such as drinking water, agriculture, and industries. As proposed by the authors, an efficient water filtration strategy is to filter out region-specific contaminants [27]. The thickness, and sizes of soil and sediment vary year-to-year in hydro-meteorological conditions of the basin thus impacting groundwater percolation, surface, and groundwater pollution [28].

The Pul-e-Charkhi region has experienced significant industrial growth ranging from pharmaceuticals, metals, auto-repair, construction, and even bakeries—all producing CO and CO_2 emissions as well as a mixture of waste discharge in the water basin including micro/nano plastics, metals, volatile organic compounds, and new and emerging contaminants. Several of these contaminants are emitted into the environment and remain suspended locally due to the high mountains in the region. The suspended particles get mixed with precipitation by absorption and leaching and contaminate the surface waters and the earth's surface and soil. Some of these factories use metals such as Arsenic (As), Cadmium (Cd), and Lead (Pb), which have severe consequences, should they be discharged into the water basin. Several health centers in the region also pose concerns about the likelihood of medical waste being released into the water basin. Lastly, the ubiquitous presence of plastics from single-use plastic bottles and grocery bags is a major concern as most of the plastic waste ends up in landfills and subsequently in surface waters through estuaries and rivers. Therefore, geological and pedogenic research for the future of this region is critically important for the efficient management and planning of groundwater. This research is essential to studying groundwater quality, with almost no previous research available pertaining to this basin [29].

1.1 Geology of Kabul

First, we present a brief overview of the geology of the Kabul Basin which dates to the Quaternary (Pleistocene) period [30,16]. Sediments to this basin come from Aliabad, Asmayie, Paghman, Qorugh, and Logger mountains. These mountains are in the surrounding areas of Kabul Basin and these sediments are carried by water at varied periods of time and form different thicknesses. The upper and middle parts of Kabul Basin terraces accumulate some heavy and light minerals, which originate from the mother rocks located in the surrounding mountain areas of Kabul Basin. For example, Epidote, Cyanite, and Granite can be found in some terraces of the Kabul River Basin as they arise from Metamorphic (Crystalline) rocks. Also, there are some other minerals, such as Rutile and Zircon which come from igneous rocks of the Paghman Mountains range [17,31]. In addition, there are some other minerals such as Muscovite and Biotite, as metamorphic rocks from the surrounding mountains of Kabul Basin. Biotite and Rutile minerals in the middle and lower terraces of the Paghman River also come from igneous rocks of the Paghman Mountain range, and all sediments are carried by water and accumulate in terraces [32,18]. All rivers of Kabul Basin conjoin at different locations, and all run about from west to east, and sediments of Kabul Basin belong to Tertiary (Eocene and Oligocene), and the age of sediments between the upper and middle parts of Kabul is ~ (20-45) million years, called Tertiary formations [19]. The upper part of these sediments is covered by younger sediments of lower Quaternary (Pleistocene) sediments, and it consists of the terraces above. It has different complexes, altitudes, and locations. For example, the upper part of the Kabul River Basin originated from the Quaternary, as we observe combined and dispersed gravel sediments, as compared with the middle part of the Kabul River Basin, which comes from the Tertiary. All mountains surrounding Kabul Province are made of metamorphic rocks, while the Paghman Mountains change of metamorphic rocks arises from some pyrogenous rocks. The radiometry method found that the lifetime of these metamorphic rocks of approximately (928 ± 8) million years [21,34]. The older of the two is located in the Khair Khana

Mountains while the younger one is in the Shawaky and Qorugh Mountains range [12,36,37] (**Figure 1**).

Figure 1. The geological map of Pul-e-Charkhi, Kabul, Afghanistan.

1.2 Geographical location

The Pul-e-Charkhi (lat: 34.54132°, long: 69.36764°) is one of the bigger areas of Kabul province and is located in the east part of Kabul province (**Figure 2**). It has a total area of ~48,800,000 km^2, agricultural land of ~4800 ha, an urban area is ~15,800,000 km^2, and an unplanned area is approximately 3,300,000 km^2. The surrounding areas consist of the Loger River located at the west side [38,22], with south and east sides Botkhak and Bagrami, and the Kabul River flows at the north side [22,39,40]. The total population living in these areas is ~325000 [22,41].

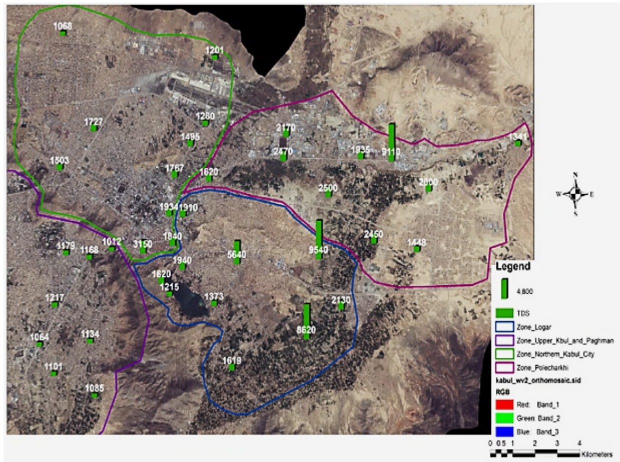

Figure 2. The location map of Pul-e-Charkhi.

2. Methods and materials

The area under investigation consists of the Pul-e-Charkhi region, a province of Kabul, where we identified water sources from 10 ring wells. The samples were collected, transported to the laboratory, and then subsequently analyzed at the laboratory of the Department of Geology, Kabul University. The results of various characterizations are provided below. **Tables 1 and 2** list various parameters that were characterized and instrumentation used for the measurements.

Table 1. Physical parameters of groundwater in Pul-e-Charkhi regions.

No	Name	Formula	Unite	The device of measurement	Location of analysis
1	Color	Col	DOS	Color test kit, Model#: CO-1, HACH	Laboratory
2	Temperature	T	°C	Potable groundwater temperature Multi 341 Instrument	Laboratory
3	Electroconductivity	EC	µs/cm	Potable groundwater Conductivity meter, Model#: Multi 340i	Laboratory
4	Solutions	TDS	mg/L	Potable groundwater temperature Conductivity meter, Model#: Multi 340i	Laboratory
5	Saline	Sal	mg/L	Potable groundwater temperature Conductivity meter, Model#: Multi 340i	Laboratory
6	Solution of Oxygen	DO	mg/L	Dissolved Oxygen Sensor, Model#: Multi 340i	Laboratory

Table 2. Chemical parameters of groundwater in Pul-e-Charkhi regions.

No	Name	Symbol	Unite	Measurement Instrument	Location of analyzed
1	Calcium	Na	mg/L	Spectra photometer # DR3900	Laboratory
2	Magnesium	Mg	mg/L	Spectra photometer # DR3900	Laboratory
3	Sodium	Na	mg/L	Spectra photometer # DR3900	Laboratory
4	Hydroxide	OH	mg/L	Spectra photometer # DR3900	Laboratory
5	Carbonates	CO_3	mg/L	Spectra photometer # DR3900	Laboratory
6	Bicarbonate	HCO_3	mg/L	Spectra photometer # DR3900	Laboratory
7	Chloride	Cl_2	mg/L	Spectra photometer # DR3900	Laboratory
8	Fluorides	F	mg/L	Spectra photometer # DR3900	Laboratory
9	Sulfite	SO_4	mg/L	Spectra photometer # DR3900	Laboratory
10	Phosphate	PO_4	mg/L	Spectra photometer # DR3900	Laboratory
11	Potassium	K	mg/L	Spectra photometer # DR3900	Laboratory
12	Nitride	NO_3	mg/L	Spectra photometer # DR3900	Laboratory
13	Nitrite	NO_4	mg/L	Spectra photometer # DR3900	Laboratory
14	Ammonia	NH_3	mg/L	Spectra photometer # DR3900	Laboratory
15	Iron	Fe	mg/L	Spectra photometer # DR3900	Laboratory
16	Manganese	Mn	mg/L	Spectra photometer # DR3900	Laboratory
17	Copper	Cu	mg/L	Spectra photometer # DR3900	Laboratory
18	Aluminum	Al	mg/L	Spectra photometer # DR3900	Laboratory
19	Arsenic	Ar	mg/L	Spectra photometer # DR3900	Laboratory
20	Cyanides	CN	mg/L	Spectra photometer # DR3900	Laboratory

3. Results and discussions

In this study, we used physical and chemical limitations at the groundwater of Pul-e-Charkhi regions, of Kabul Province, Afghanistan. Here, we collected different groundwater samples from the general water supply, Bricks center, Washing of Cars, Osman House, Gradation place, International Standards, etc. regions of Kabul. These measurement parameters include temperature, electro-conductivity, dissolved oxygen, total dissolved solids, salinity, pH, color, turbidity, T hardness from $CaCO_3$, calcium, magnesium, sodium, alkalinity, passphrase, OH, CO_3, HCO_3, chlorides, florid, sulfate, phosphate, potassium, nitrite, nitrate, ammonia, iron, manganese, copper, aluminium, arsenic, and cyanide, as described in **Table 3**.

It should be noted that water passing through the tables of gravel continues to be filtered through a variety of mechanisms. On the other hand, there are old practices of burying waste in the ground, which over a period of time leaches into water tables with high acidic contents due to decomposition. Hence, regular monitoring of these contaminants is essential in providing guidance to the local municipalities on water purification strategies. From this investigation, our objective is to establish in-field testing as well as laboratory-based testing of water samples to consistently monitor different types of pollutants in water, such as organic materials, micro/nano plastics, metals from industrial discharge, raw sewage, and other new and emerging contaminants. We have also studied temperature dependence which tends to dissolve more chemicals causing changes in electroconductivity. In addition, we studied the redox process for self-purification of water due to catalysis. Likewise, characterization of TDS (total dissolved solids) provides turbidity due to soluble and salty rocks and salinity, while pH provides data on salinity. In the following section, we describe several methods that are used to characterize these contaminants. In parallel, we continue to develop additional capabilities to characterize new and emerging contaminants using Atomic Absorption Spectroscopy, Raman, and Fourier Transform Infrared (FTIR) spectrophotometer.

Table 3. Groundwater physical and chemical parameters in Pul-e-Charkhi regions.

Parameters	Units	Well locations					
		Water supply	**Bricks center**	**Washing of cars**	**Osman house**	**Gradation place**	**International standards**
Temperature	°C	25	24	15	30	20	25-30
EC	µs/cm	1619	2150	2470	1942	9140	1500 (WHO2006)
pH		7.18	7.35	7.89	8.208	8.186	6.5-8.5
DO	mg/L	25	39	37	35	26	
TDS	mg/L	1445.22	1645.02	1288.12	6067.26	3075.20	1000
Salinity	mg/L	0.8	1.1	1.2	0.9	5.1	
Color	APHA	0	0	0	0	0	No acceptable
Turbidity	NTU	0	0	0	0	0	5 NTU
T hardness as $CaCO_3$	mg/L	800	1000	1140	750	2050	500
Calcium	mg/L	24	76	18.4	72.1	120.2	75
Magnesium	mg/L	478.9	599.9	721.3	357.8	153.8	30
Sodium	mg/L	6	0	32	27	140	200
T Alkalinity	mg/L	475	650	575	350	150	NGVS
Phosphorus	mg/L	0	0	0	0	0	NGVS
OH	mg/L	0	0	0	0	0	NGVS
CO_3	mg/L	0	0	0	0	0	NGVS
HCO_3	mg/L	475	650	575	350	150	NGVS
Chlorides	mg/L	0	0	0	0	0.02	250
Florid	mg/L	0	0	0	0	1.21	1.5
Sulfate	mg/L	95	92	116	127	1000	250
Phosphate	mg/L	0.19	0.59	0.44	0.33	2.12	NGVS
Potassium	mg/L	11.1	8.5	7.1	6	33.9	NGVS
Nitrite	mg/L	0.001	0.001	0.021	0.022	0.121	3
Nitrate	mg/L	1.2	0.4	2.2	0.15	1.2	50
Ammonia	mg/L	0.19	0.17	0.15	0.08	0.16	NGVS
Iron	mg/L	0.16	0.61	0	0	0.07	0.3
Manganese	mg/L	0.8	0.9	1	0.8	1	0.3
Copper	mg/L	0.05	0.06	0.05	0.05	0.22	0.2
Aluminum	mg/L	0.03	0.011	0.027	0	0.036	0.2
Arsenic	mg/L	0	0	0	0	0	0.05
Cyanide	mg/L	0	0.001	0.002	0.002	0.002	0.05

3.1 Temperature

The temperature of groundwater is generally between 5-15 °C, which is normally colder than surface water. At the location of the brick center, the water temperature is generally lower than the Kabul River. The temperature of the water near the well of the washing area is higher than the regional standard, which results in lower water quality for the villagers, due to a decrease in the amount of oxygen. Furthermore, it results in decomposition due to an increase in bacterial formation bacteria (**Figure 3**). The temperature of groundwater varies with the depth of groundwater, volcanic eruptions, and geographical locations. From the viewpoint of temperature, the ground is divided into six categories as it consists of very cold (5 °C), less cold (10 °C), warm water (18 °C), almost warm (25 °C), warm (37 °C), and very warm (more than 40 °C). In this investigation, all groundwater temperature is around 22 °C, which is suitable for drinking and most all other usages [42].

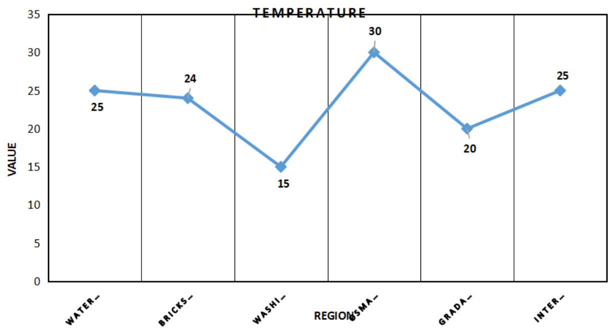

Figure 3. Groundwater temperature in Pul-e-Charkhi regions.

3.2 Electro-conductivity (EC)

Conductivity is the measurement of the primary current in any solution, and it shows the quantity of salt dissolved in water. The electro-conductivity is also dependent on the temperature of the water temperature during the measurement. Using a WTW GmbH, Weilheim Multi 340i pH/Dissolved Oxygen/Conductivity Measuring Instrument, the investigation could easily be conducted at the site, although samples were transported to the laboratory for assessment. To obtain an accurate value, it was necessary to measure the electro-conductivity at least three times for each sampling. The EC was higher at the Gradation place (9140 µs/cm) as compared to the international standard (1500 µs/cm) (**Figure 4**). Conforming to the norms of Afghanistan the EC, the World Health Organization (WHO), and Asian countries the electro-conductivity is 1500 µs/cm [43].

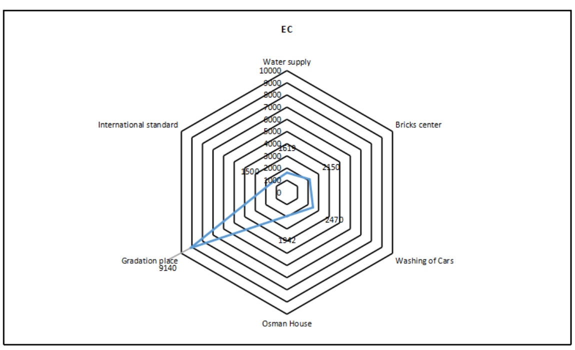

Figure 4. Groundwater electro-conductivity in Pul-e-Charkhi region.

3.3 pH

pH stands for the "power of hydrogen". The numerical value of pH is determined by the molar concentration of hydrogen ions (H^+). The pH determination is because of hydrogen ions (H^+) and hydroxyl ions (OH^-) on pH. The higher the H^+ concentration, the lower the pH, and the higher the OH^- concentration, the higher the pH. At a neutral pH of 7 (pure water), the concentration of both H^+ ions and OH^- ions is 10^{-7} M. Thus, the ions H^+ and OH^- are always paired—as the concentration of one increases, the other will decrease; regardless of pH. For this investigation, the pH of groundwater was measured and was observed to be between (6.5 to 8.5). As per WHO, the water can be used for drinking and irrigation water (**Figure 5**). Generally, a WTW GmbH, Weilheim Multi 340i pH/Dissolved Oxygen/Conductivity Measuring Instrument was used for the determination of pH for measuring the acidic and basic nature of water samples. We determined that the pH of water is within the range agreement with WHO guidelines of 6.5-8.5, and also for the Asian countries [44]. The hydroxyl group (OH) is due to the alkalinity of water. When the pH is higher than 7, the water displays a higher OH group.

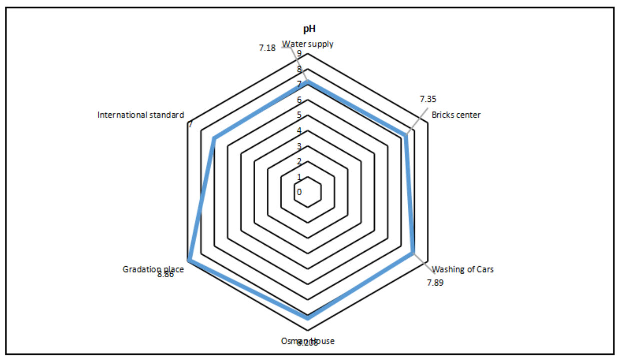

Figure 5. Groundwater pH in Pul-e-Charkhi regions.

3.4. Dissolved oxygen (DO)

The DO (dissolved oxygen), in Asiab regions is attributed to the location. For the measured samples, it was found to be more than recommended by WHO. Usually, from the observed values, we can find the main reason, which generally is due to the location and the height of the well with respect to the mean sea level (**Figure 6**).

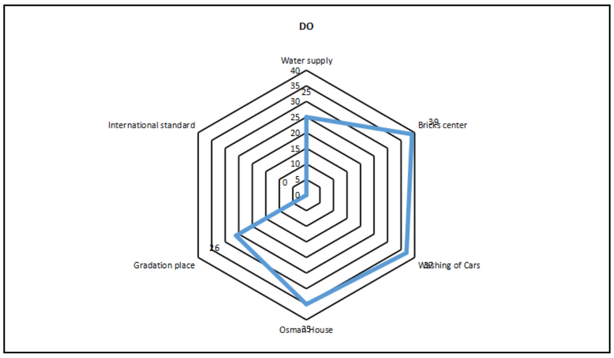

Figure 6. Groundwater DO in Pul-e-Charkhi regions.

3.5 TDS

For this part of the investigation, the TDS (total dissolved solid) shows the concentration of the solution (dissolved) material in water, such as salts, carbonates, and gypsum. The measured value of TDS is higher than the WHO standard (~1000 mg/L) [45]. From this measurement, we can estimate that the main reason for higher TDS will be due to the limestone coming from the surrounding mountains. Furthermore, since the surrounding mountains have more carbonates and limestones, the solids leach from different layers of aquifers producing higher TDS (**Figure 7**).

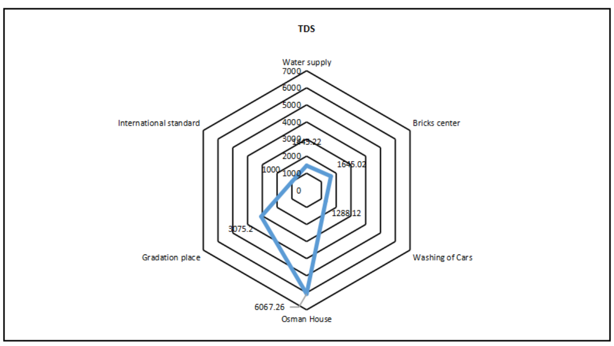

Figure 7. Groundwater DO in Pul-e-Charkhi regions.

3.6 Salinity

Generally, in groundwater, we can find some amount of salinity, and the type and concentration of salt pertain to the source and the layers that infiltrate the groundwater. Generally, the amount of salt in the groundwater is more than the surface water. The main sources of salinity are due to the compositions of saline lithology in groundwater layers, that come in contact and are attributed to the duration of salt percolation to surface water as well. The concentration of salt is also due to the composition of minerals and rocks that come in contact with the groundwater. Also, the amount of salinity is due to the evaporation, because Afghanistan is one the countries where we have more evapotranspiration than precipitation. Arising due to arid- the semi-arid climate of Afghanistan, there is more evaporation than precipitation, hence the amount of salinity in some places is due to the amount of salts from the igneous rocks, as such rocks contain Na, and Ca elements as compositional elements. Additionally, in this region, we also find some granite (**Figure 8**).

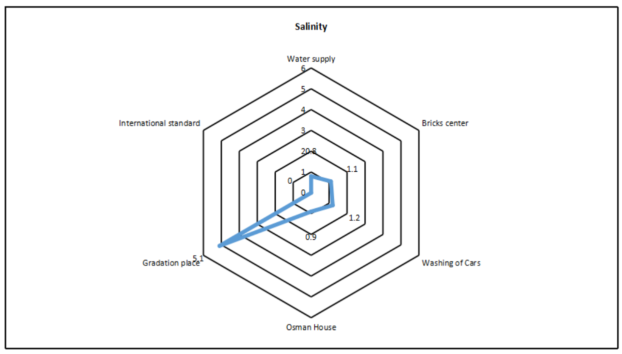

Figure 8. Groundwater total dissolved solids (TDS) in Pul-e-Charkhi regions.

3.7 Color

The groundwater color for this investigation is measured as per the WHO standard. In general, color is a great indication of the quality and contents of water, which generally has a slight green color, while every other color arises due to the existence of organic and inorganic materials in soluble forms. The existence of organic materials is typically displayed as brown, while the organic acidic dissolved solids have a yellow color. The existence of iron and hydrogen sulfides is shown by the red color, and the manganese shows a black color [46]. Generally, the color of groundwater is divided into five separate categories, viz: blue, green, yellow, red, and colored. While the blue color of the water is desirable, care must be taken for use for drinking water and all other uses. In general, green color is also good but it may have some negative effects, due to bacteria, algae, and uncertainty being unstable. To mitigate the negative effects of coloration, it is necessary to measure color and we used Color Test Kit, Model CO-1, Product #: 223400 (HACH, Colorado, USA). The sample measurements and their comparison to local and international standards are shown in **Figure 9**.

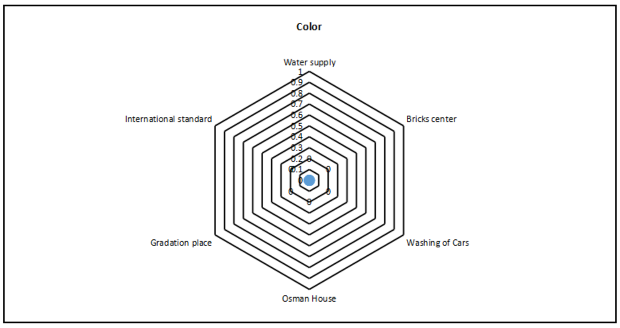

Figure 9. Groundwater color in Pul-e-Charkhi regions.

3.8 Turbidity

The turbidity in this study was measured by a turbidity meter since it measures the soluble solid materials in the water, but the turbidity cannot sum up in the watercolor. Generally, the turbidity is created by non-soluble materials in which the amount is lower in terms of high quantity that caused turbidity of water. The standard units for turbidity are ppm of non-soluble materials. According to WHO standards, the turbidity of water must be lower than 5. In this study, all the points are between 4 to 3 [47], as shown in **Figure 10**.

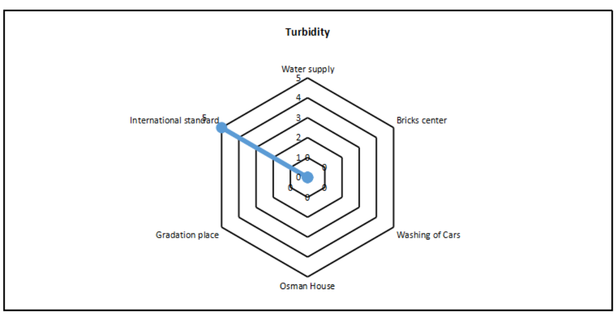

Figure 10. Groundwater turbidity in Pul-e-Charkhi regions.

3.9 Hardness as $CaCO_3$

The amount of carbonates results in varying pH (acid and basic) conditions, and it plays a very important role in the solution of soluble materials. Generally, in surface water, the amount of CO_2 should be fewer than 10 mg/L, but in groundwater, the amount is far more than 100 mg/L. In this study, the amount of carbonates is more than the recommended WHO standard (500 mg/L). The main reason is due to the existence of carbonate rocks in the surrounding mountains (**Figure 11**).

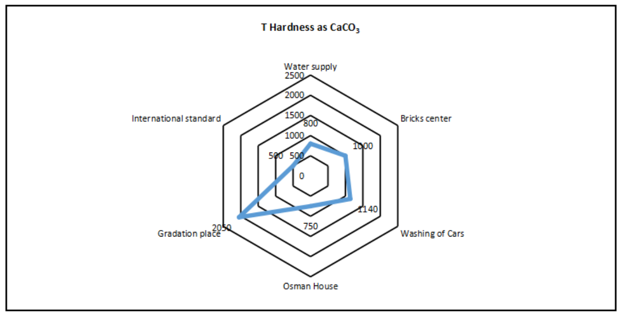

Figure 11. Groundwater T hardness as $CaCO_3$ in Pul-e-Charkhi regions.

3.10 Calcium

Calcium is one of the basic metals of the earth, and during reaction with water, it makes calcium hydroxides. Calcium is one of the important elements for the vertebral column bone, and the existence of calcium in water is good for the protection of human bone. We can find calcium in water, as it comes from certain rock formations in nature, and generally, it is found in the forms of calcium carbonates, carbonates, and sulfides. Although beneficial, a higher amount of calcium causes the hardness of the water. According to the WHO standard, the amount of calcium is 75 mg/L. The samples show that the amount of calcium in groundwater is near the WHO limit, as shown in **Figure 12**. However, after normal filtration, the water can be used for general purposes. Only in the Alishang region the amount of calcium was observed to be very high (~120 mg/L), which is due to the igneous rocks in that specific location [48].

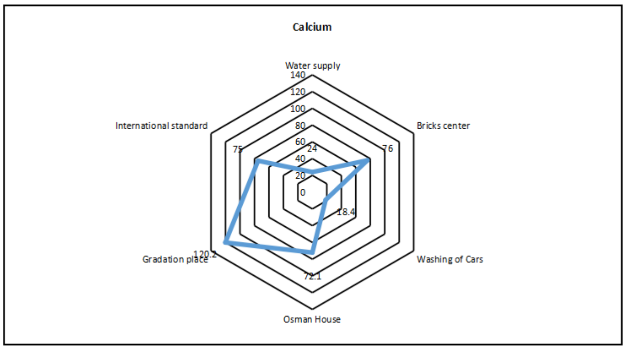

Figure 12. Groundwater calcium in Pul-e-Charkhi regions.

3.11 Magnesium

Magnesium is also one the basic metals of the earth, and with the fire having bright light and made magnesium oxides. Magnesium is used for normal activities of muscles and as an anti-acid for digestive tracks. The usage in water is ~250 mg/24 h. Magnesium is one the very important cations of water, which makes different soluble salts in water. In this study, the amount of Mg is observed to be more than recommended by WHO standard (30 mg/L), the main reason will be the mother rocks having Mg in the composition (**Figure 13**). A higher amount of Mg in water can induce a diarrheal response in humans.

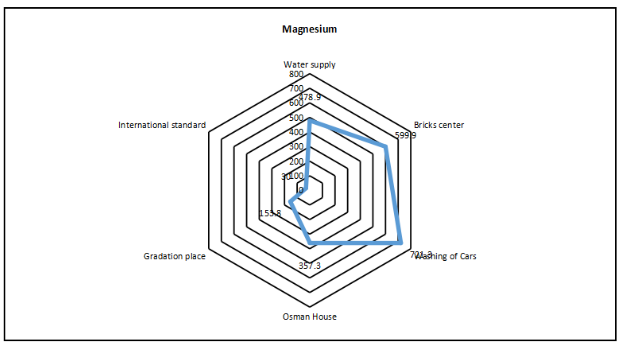

Figure 13. Groundwater magnesium in Pul-e-Charkhi regions.

3.12 Sodium

Sodium is one the important constituents of NaCl, which serves as an important part of our diet, as it is used for pH balance for the human body. The concentration of Na is due to the location and composition of rocks. The concentration of Na in freshwater is ~500 mg/L. For those places where there is no precipitation, the concentration exceeds 500 mg/L. In ocean waters, the concentration of Na is up to 1100 mg/L, since Na is one of the soluble elements [49], and in saline water, the amount is approx. 1-100 mg/L. In this study, the amount of Na is lower than the WHO standard (200 mg/L), hence the water can be used for drinking and other usages (**Figure 14**), following standard municipality water cleaning procedures.

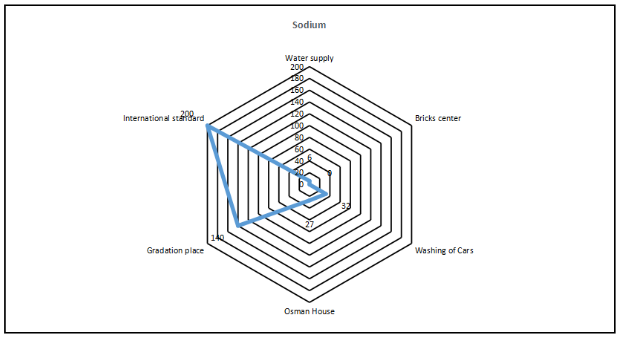

Figure 14. Groundwater sodium in Pul-e-Charkhi regions.

3.13 Alkalinity

Alkalinity is the buffering capacity of a water body; a measure of the ability of the water body to neutralize acids to maintain a fairly stable pH level. The ions that contribute to alkalinity are carbonate, bicarbonate, and hydroxide. Alkalinity may also include contributions from borates, phosphates, silicates, or other bases. When the pH is higher than 7, the solution is more alkaline in nature. Some of the pollutants, such as soap solution in urban areas and water from canals, etc. can also raise the pH. For the area under investigation, the alkalinity is found to be more than the WHO standard and the main reason is due to the composition of surrounding rocks from mountains (**Figure 15**). In general, pH electrodes are used for alkalinity titration using the preset endpoint technique. It is very important to calibrate the pH electrode before the analysis when using the preset end-point titration method. Interferences for the titration method are soaps, oily matter, suspended solids, or precipitates, which may coat the glass electrode and cause a sluggish response.

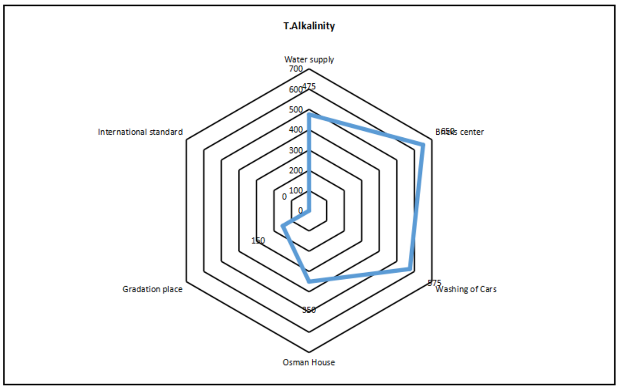

Figure 15. Groundwater alkalinity in Pul-e-Charkhi regions.

3.14 Phosphorus

Phosphorus results from several industrial activities, agricultural feed, and fertilizers since a vast majority of phosphorus compounds mined are consumed as fertilizers. Additionally, phosphate mines contain fossils because phosphate is present in the fossilized deposits of animal remains and excreta. Low phosphate levels are an important limit to growth in several plant ecosystems. Phosphate is needed to replace the phosphorus that plants remove from the soil and with increasing population its annual demand is rising. As per this study, the amount of phosphorus observed is consistent with limits established by the WHO standards and hence can be used for drinking water and other usages after standard water cleaning at the local municipality.

3.15 $CaCO_3$

Carbonates are one of the very important components of rock formations, found as minerals calcite and aragonite, most remarkably in chalk and limestone, eggshells, shellfish skeletons, gastropod shells, and pearls. Materials containing a lot of calcium carbonate are termed calcareous. Calcium carbonate is the active component in agricultural lime and is generated when calcium ions in hard water react with carbonate ions to create limescale. It has medical use as a calcium supplement or as an antacid, but excessive consumption can be hazardous and cause hypercalcemia and digestive issues. However, for the region under investigation, the observed value of $CaCO_3$ is within the WHO range. Chemically, it is represented as follows [50].

$$CO_3^{-2} + HOH \quad HCO_3^- + OH^-$$

$$HCO_3^- + HOH \; H_2CO_3 + OH^-$$

In the titration of the carbonate ions, we can find in the two steps, as it changes to the acids in the first stage as HCO_3, an intermediate form in the deprotonation of carbonic acid. It is a polyatomic anion with the chemical formula HCO_3^-. Bicarbonate serves a crucial biochemical role in the physiological pH buffering system. When acids are added to water, the amount of CO_3 decreases, and it changes to HCO_3. In this study, the amount of HCO_3 is higher than the WHO standard and the main reason for this is the composition of lithology and surrounding mountain rocks (**Figure 16**).

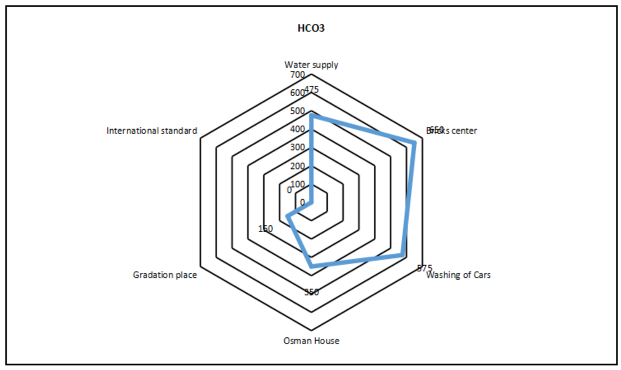

Figure 16. Groundwater calcium carbonates in Pul-e-Charkhi regions.

3.16 Chloride

Chloride refers either to a negatively charged (Cl^-) chlorine atom, or a non-charged chlorine atom covalently bonded to the rest of the molecule by a single bond (^-Cl). It is an essential electrolyte in body fluids responsible for maintaining acid/base balance, transmitting nerve impulses, and regulating liquid flow in and out of cells. Due to high reactivity, it also has corrosive characteristics and increased concentrations of chloride can cause a variety of ecological effects in both aquatic and terrestrial environments. The concentration of chlorides in groundwater under observation is 10 mg/L. The concentration of chlorides in such places is due to salts, and seawater infiltration. For this investigation, the quantity of chlorides is much lower than WHO standard (250 mg/L), and hence the water can be used for daily consumption following standard municipality filtration methods (**Figure 17**).

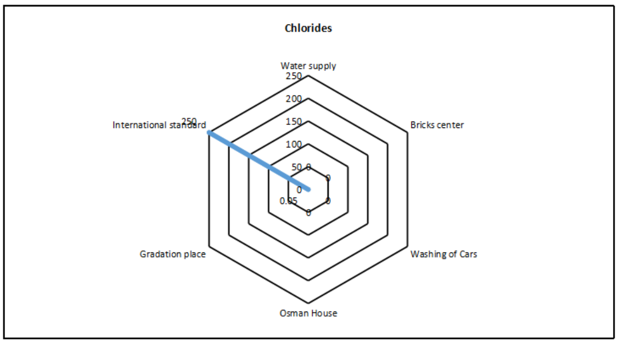

Figure 17. Groundwater chlorides in Pul-e-Charkhi regions.

3.17 Fluoride

Fluoride, a mineral, is naturally present in many foods and available as a dietary supplement. Generally, soil, water, plants, and foods contain trace amounts of fluoride. Most of the fluoride that people consume comes from fluoridated water, foods, and beverages prepared with such water, and use of toothpaste and other dental products. Fluoride in its ionic form of the element fluorine inhibits the initiation and progression of dental decay and stimulates new bone formation. The concentration of fluoride in surface water that is not polluted is about ~0.1-0.3 mg/L [51], but generally in groundwater the concentration is observed to be ~0.1-0.3 mg/L, and in some of the locations is observed to be about 12 mg/L. In most of the areas under investigation, the amount of fluoride is observed to be lower than the WHO standard (1.5 mg/L), hence the water can be used for drinking and all usages following standard municipality cleaning procedures (**Figure 18**).

3.18 Sulfate

Sulfate is an important polyatomic anion with the empirical formula SO_4^{2-}. Salts, acid derivatives, and peroxides of sulfate are widely used in various industries. Sulfates occur as microscopic aerosols resulting from fossil fuel and biomass combustion. They increase the acidity of the atmosphere and form acid rain. In groundwater, it is found in the form of magnesium sulfate (commonly known as Epsom salts), which is used in therapeutic baths. The concentration of sulfate in freshwater is less than 10 mg/L. However, for water directly discharged from mining industries to the groundwater, the amount of sulfate is observed to be ~500 mg/L. The concentration of sulfate in natural water fluctuates from 1-1000 mg/L. For this investigation, the quantity of sulfate is observed to be lower than the WHO standard (250 mg/L), and we can use it for drinking and other usages (**Figure 19**) following standard municipality cleaning procedures.

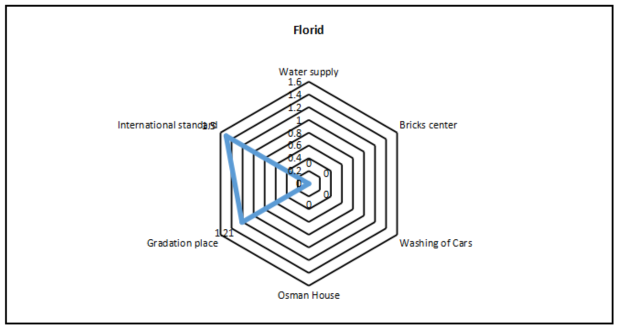

Figure 18. Groundwater fluoride in Pul-e-Charkhi regions.

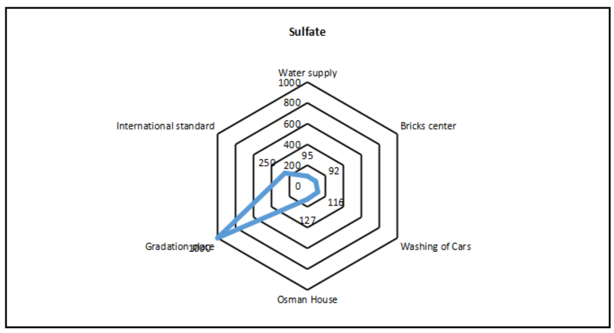

Figure 19. Groundwater sulfate in Pul-e-Charkhi regions.

3.19 Phosphate

Phosphate is another very important element that occurs in groundwater. Phosphate arises from any of numerous chemical compounds related to phosphoric acid (H_3PO_4). Derivatives are composed of salts containing the phosphate ion (PO_4^{3-}), the hydrogen phosphate ion (HPO_4^{2-}), or the dihydrogen phosphate ion ($H_2PO_4^-$), and positively charged ions such as those of sodium or calcium. A second group is composed of esters, in which the hydrogen atoms of phosphoric acid have been replaced by organic combining groups such as ethyl (C_2H_5) or phenyl (C_6H_5). Phosphates are a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent. Furthermore, phosphates are chemicals containing the element phosphorous, and they affect water quality by causing excessive growth of algae. Phosphates in water feed algae, which grow out of control in water ecosystems and create imbalances, which destroy other life forms and produce harmful toxins. For this study, the amount of phosphate is close to the limit of WHO standards. Depending upon location, for the most part, the water can be used for drinking and other usages pending standard cleaning procedures (**Figure 20**).

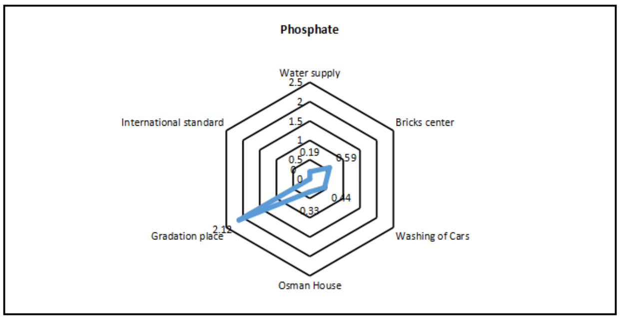

Figure 20. Groundwater phosphate in Pul-e-Charkhi regions.

3.20 Potassium

Potassium (K) is yet another important element in the groundwater. There is a growing movement to use potassium in conjunction with sodium to treat and soften drinking water. This would cause the level of potassium in drinking water to rise. The level of potassium in drinking water depends on the type of treatment used. Water that goes through potassium permanganate has lower levels of potassium than water that uses a potassium-based water softener. The concentration of potassium in clean water is about 2-5 mg/L. Generally, the concentration of K in natural water is 30 mg/L. In this study, the amount of K is observed to be higher than the WHO guidelines and it may cause some issues if consumed untreated beyond standard clean procedures (**Figure 21**).

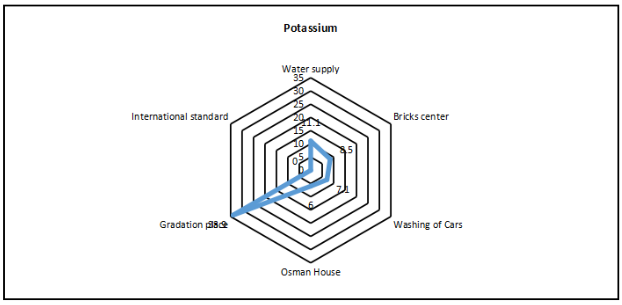

Figure 21. Groundwater potassium in Pul-e-Charkhi regions.

3.21 Nitrite

The nitrite ion has the chemical formula NO_2^- and is widely used throughout chemical and pharmaceutical industries. Nitrite can be reduced to nitric oxide or ammonia by many species of bacteria. Under hypoxic conditions, nitrite may release nitric oxide, which causes potent vasodilation. Sodium nitrite is used to speed up the curing of meat and also impart an attractive color and hence is used by the food industry. However, excess amounts of nitrites are known to be carcinogens. The returned nitrites in water are lower than 2 mg/L. Additionally, the reason for the presence of nitrites is due to the decomposition of sewage and industrial activities, such as dyes. In this study, the presence of NO_2^- is within the limit set by the WHO standard, and hence the water can be used for drinking and other usages following standard municipality cleaning (**Figure 22**).

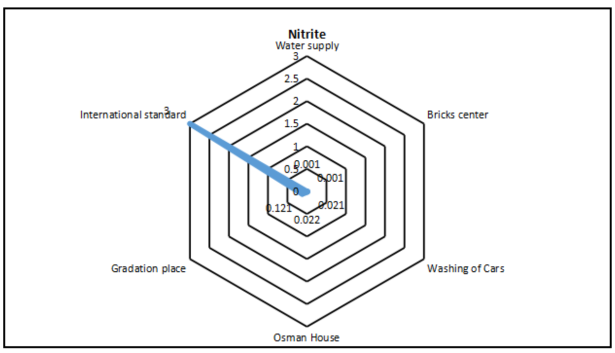

Figure 22. Groundwater nitrate in Pul-e-Charkhi regions.

3.22 Nitrate

Nitrate is a polyatomic ion with the chemical formula NO_3^- and salts containing this ion are called nitrates, which is a common component of fertilizers and explosives. Almost all inorganic nitrates are soluble in water and hence are used in agriculture, firearms, medicine, and even in the food industry. Nitrate salts are found naturally on earth in arid environments as large deposits, particularly of nitratine, a major source of sodium nitrate. Lightning strikes in Earth's nitrogen- and oxygen-rich atmosphere produce a mixture of oxides of nitrogen, which form nitrous ions and nitrate ions, which are washed from the atmosphere by rain or in occult deposition. Nitrates are also produced industrially from nitric acid. In freshwater or estuarine systems close to land, nitrate can reach concentrations that are lethal to fish. While nitrate is much less toxic than ammonia, levels over 30 ppm of nitrate can inhibit growth, impair the immune system, cause stress in aquatic species, and are known to produce methemoglobinemia. In clean water, the amount of NO_3^- is lower than 2 mg/L. In this study, the amount of NO_3^- is within the WHO guidelines of 50 mg/L, and hence water can be used for drinking and other usages following normal filtering and cleaning (**Figure 23**).

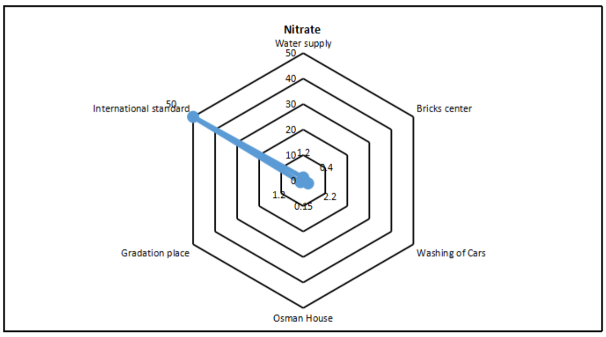

Figure 23. Groundwater nitrate in Pul-e-Charkhi regions.

3.23 Ammonia

Ammonia is an inorganic compound of nitrogen and hydrogen, NH_3, a stable binary hydride, which is a colorless gas with a distinct pungent smell. Biologically, it is a common nitrogenous waste, particularly among aquatic organisms, and it contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to food and fertilizers. Ammonia readily dissolves in water. In an aqueous solution, it can be expelled by boiling. The aqueous solution of ammonia is basic. The maximum concentration of ammonia in water (a saturated solution) has a density of 0.880 g/cm^3. In wells, the quality of water can be improved by decomposing nitrates by suitable catalysts into constituent elements. In this study, the amount of ammonia is within the WHO guidelines and hence water can be used for drinking water purposes pending standard cleaning and filtering (**Figure 24**).

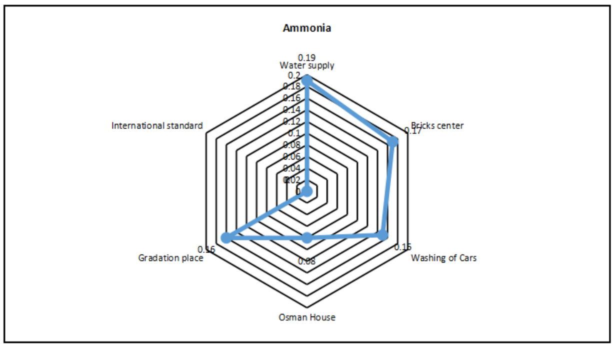

Figure 24. Groundwater ammonia in Pul-e-Charkhi regions.

3.24 Iron

Well waters are generally rich in iron since it exists in different forms, such as in suspended colloidal forms, and in complex forms of organic or inorganic materials. This iron element is not harmful to the human body, but it changes the physical properties of water (including smell) and has a bitter taste. After sedimentation, one can separate iron oxides. In this study, the amount of iron is according to the WHO standard (0.3 mg/L), and we can use it for drinking water (**Figure 25**).

3.25 Manganese

Manganese is an essential human dietary element, important in macronutrient metabolism, bone formation, and free radical defence systems. It is a critical component in dozens of proteins and enzymes. It is found mostly in the bones, but also in the liver, kidneys, and brain. In the human brain, manganese is bound to manganese metalloproteins, most notably glutamine synthetase in astrocytes. Yet, manganese is a common impurity in private well water supplies. Also, manganese is naturally occurring in rocks and soil, so it gets into groundwater that seeps through the earth, collecting minerals. Manganese is used as an additive in gasoline and is released into the environment in exhaust gases. For the water samples in this study, the amount of manganese is within the limits set by the WHO and hence water can be consumed for drinking water and other usages following standard cleaning and filtration procedures (**Figure 26**).

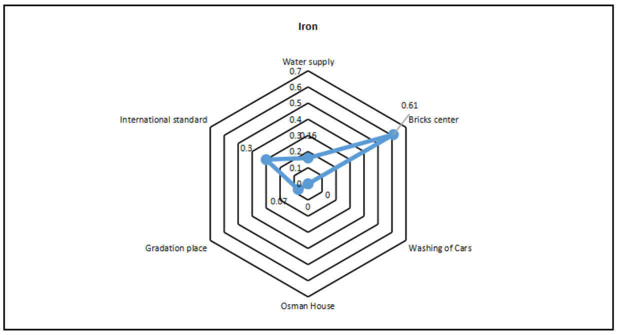

Figure 25. Groundwater iron in Pul-e-Charkhi regions.

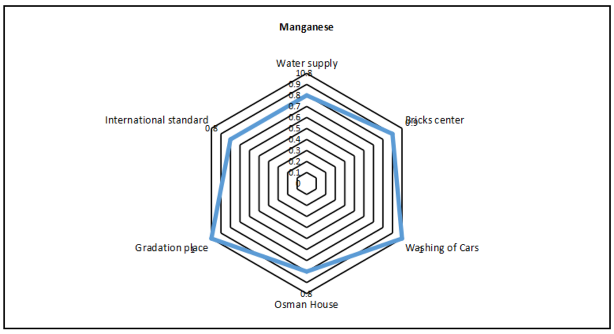

Figure 26. Groundwater manganese in Pul-e-Charkhi regions.

3.26 Copper

Cu is also one of the very important elements in nature. It is located in the rocks and lithology of the earth at varying compositions. In households, copper is used for cooking utensils and also in the plumbing. Copper is a mineral and metallic element that's essential to human health. However, too much copper will have side effects. Copper leaching is especially likely in acidic water with a low pH. In this study, the amount of Cu is at a slightly elevated level than recommended by the WHO standard (0.2 mg/L). However, with some precautions and using standard cleaning and filtration procedures, the water can be used for drinking and other usages (**Figure 27**).

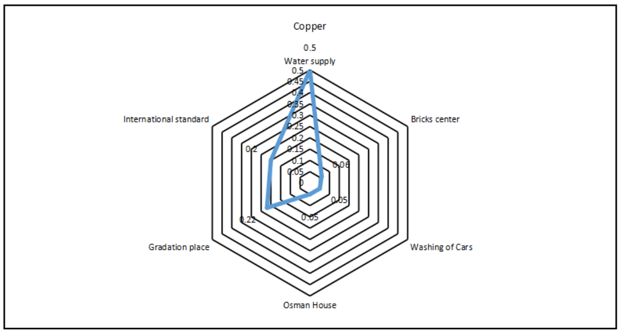

Figure 27. Groundwater copper in Pul-e-Charkhi regions.

3.27 Aluminum

Aluminum is one of the most common heavy metals found in drinking water and is also found abundantly in the earth's crust. This lightweight, silvery-white metal is used in a variety of products, including airplane parts, cans, kitchen utensils, foils, and satellite dishes. Unlike other metals, like iron and zinc, aluminum is non-essential to humans and is considered toxic. There is no recommended daily aluminum intake required by the human body. The most common way that aluminum gets into drinking water is through surface runoff and soil seepage. Water flows over rocks or through soil with high concentrations of aluminum, and traces of the metal dissolve into the water. Acid rain resulting from industrial activity is another common cause of high aluminum concentrations in surface water. In this study, the amount of aluminum was found to be within the WHO standard (0.2 mg/L) and the water can be used for drinking and other usage activities following standard cleaning procedures at the municipality (**Figure 28**).

3.28 Arsenic

Arsenic is one of the most toxic elements in water. It is found in those places near metal mining, and industrial-scale insecticide production with discharge into the groundwater. Another common source of arsenic is water from freeways entering into the groundwater. There has been a substantial amount of research done to address arsenic in groundwater and drinking water supplies around the world. In drinking water supplies, arsenic poses a problem because it is toxic at low levels and is a known carcinogen. Long-term exposure to inorganic arsenic, mainly through drinking water and food, can lead to chronic arsenic poisoning. Skin lesions and skin cancer are the most characteristic effects. In 2001, the USEPA lowered the MCL for arsenic in public water supplies to 10 micrograms per liter (µg/L) from 50 µg/L. In this study, the amount of Arsenic is according to the WHO standard (0.05 mg/L), and we can use the water for drinking water and other usages following standard cleaning procedures (**Figure 29**).

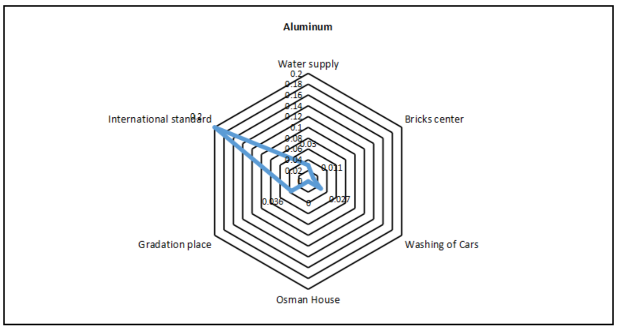

Figure 28. Groundwater ammonium in Pul-e-Charkhi regions.

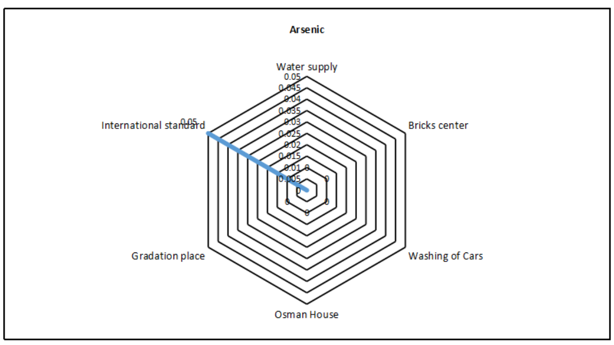

Figure 29. Groundwater arsenic in Pul-e-Charkhi regions.

3.29 Cyanides

HCN and its components are found in industrial and mining waters that contain a chemical compound with the formula HCN and structural formula H−C≡N. It is a colorless, extremely poisonous, and flammable liquid that boils slightly above room temperature. Hydrogen cyanide is a linear molecule, with a triple bond between carbon and nitrogen. The tautomer of HCN is HNC, hydrogen isocyanide. Hydrogen cyanide is weakly acidic, and it partially ionizes in a water solution to give the cyanide anion, CN^-. A solution of hydrogen cyanide in water, represented as HCN, is called hydrocyanic acid. The salts of the cyanide anion are known as cyanides. HCN has a faint bitter almond—like odour, which is difficult to detect, and a volatile compound has been used as inhalation rodenticide and human poison, as well as for killing whales. Furthermore, cyanide ions interfere with iron-containing respiratory enzymes. The lethal dose concentration (LC_{50}) is 501 ppm (for rats, 200 ppm for mammals, and 357 ppm for humans). Using this investigation, we determined the amount of HCN at 0.05 mg/L, which is below the WHO standard and can be used for drinking and other usages (**Figure 30**), after normal municipality cleaning processes.

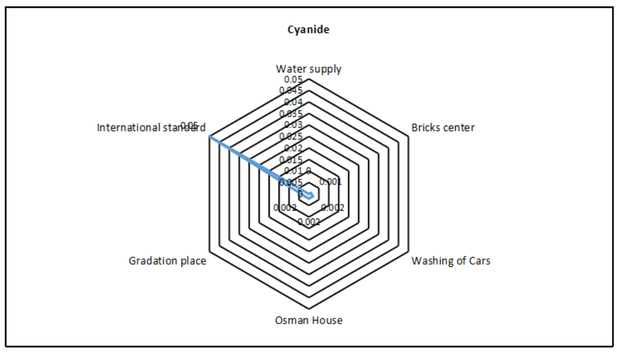

Figure 30. Groundwater cyanides in Pul-e-Charkhi regions.

4. Conclusions and discussion

During this investigation, we assessed the physical and chemical characteristics of the groundwater in the Pul-e-Charkhi region of Kabul Province, Afghanistan. We collected different samples of groundwater from various locations of water supply consisting of discharge from Bricks center, Washing of Cars, Osman House, Gradation Place, International Standards, and other similar regions of Kabul.

Several parameters were measured, such as temperature, EC, DO, TDS, salinity, pH, color, turbidity, T hardness as $CaCO_3$, calcium, magnesium, sodium, alkalinity, phosphorus, OH, CO_3, HCO_3, chlorides, florid, sulfate, phosphate, potassium, nitrite, nitrate, ammonia, iron, manganese, copper, aluminum, arsenic, and cyanide respectively. The groundwater samples and parameters still show good results with national and international standards, indicating that water can be recycled using standard coagulation, flocculation, and bleaching methods. These results also suggest that the groundwater quality can still be used efficiently in the other districts of Kabul and other provinces in Afghanistan. As discharge now consists of new and emergent materials, including nanomaterials, it is necessary to improve the cleaning procedures and study life cycle analysis [52] to assess and remediate new and emergent contaminants, including microplastics [53-55]. One of the primary goals of the World Health Organization (WHO) and its member states is that "all people, whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water." The novelty of this investigation is to initiate a study of this kind that aims to provide comprehensive data on pollutants in this region. The level of contaminants is increasing and soon, the region will need to implement an improved and comprehensive approach to mitigate these contaminants. Also, in view of micro/nano plastics and new and emerging contaminants such as returned pharmaceutics, volatile organic compounds, degreasers containing acetone, trichloroethylene, and other large chain hydrocarbons such as per-and polyfluoroalkyl substances (PFAS), also known as forever chemicals, we need better characterization facilities. Using our international network and with support from our local funding agencies, we would like to keep local municipalities and the general population aware of the contaminants and adverse health impacts that can result from using contaminated water. This is also consistent with the Sustainable Development Goals (SDG). The study conducted here is consistent with SDG-6 to support access to clean water for all.

Author Contributions

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

Conflicts of Interest

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

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