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Physico-Chemical Properties of Groundwater In The Kabul Basin, Afghanistan

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Abstracts

The Kabul Basin groundwater physic-chemical parameters are variable from place to place. In Shomali, Deh Sabz, eastern front and eastern front subbasins and source areas, the chemical compositions of the groundwater are approximately similar with surface water. The temperature, pH specific conductivity, hardness and concentration of the total dissolved solids (TDS) measured in the Central Kabul subbasin groundwater were significantly greater than all groundwater samples collected from all other subbasins. Therefore, there is no upland area in the Central Kabul regions to help recharge through lateral groundwater inflows. Beside on the no upland area, rapid increase in population, sewage, agricultural fertilizers, and climate change, no systematic sewage treatment or refuse collection are the main factors which raise the groundwater impurity. The shallow groundwater generally has a weakly oxidising redox environment with oxygen depletion, which is probably caused by the sewage.

Keywords: Kabul Basin, Groundwater, Physico-chemical Properties, Hydrogeology,

Introduction

Absolutely pure water is never found in nature and indeed it is increasingly scarce to face a source of surface or groundwater that requires no treatment before being used for potable-water. Groundwater is the most important drinking water resource for the inhabitants in Afghanistan and particularly in the Kabul City. Kabul, with a population of more than 4 million, is the capital city of the country. It is located in a narrow valley, wedged between mountains between 34° 30′ latitude and 69° 18′ longitude with 1800 m above the sea level. Relief of the basin is variable, the north area is rugged by high mountains and the low flat area is around Jalalabad in the east. The highest point in Hindu Kush is more 6000 m above sea level.

The Kabul metropolitan area is situated in the northern end of the Kabul block which is tectonically active with having a high risk of damaging seismic and other natural hazards (Shnizai et al., 2020; Shnizai and Tsutsumi, 2020). The block is

bounded on the east, west and south by major active strike-slip faults (Fig. 1a). Kabul is the largest city of the country, and one of the most rapidly growing cities on earth due to the influx of refugees and people from the countryside. Beside on the rapid increase in population, sewage, agricultural fertilizers, and climate change are the main factors which raise the impure groundwater, because there is no systematic sewage treatment or refuse collection.

The quality of water resources is seen as a vital requirement to help and raise the standard of living of the people. Therefore, the main purpose of this paper is to study the correlation between climatic parameters and physico-chemical parameters of the groundwater in the Kabul City. Other factors that affect the quality of groundwater such as geology, climatology and surface water quality have also been studied. This study should be to the detail format necessary for submission to governmental and national development organizations for implementation, which could help to manage groundwater quality. The groundwater quality development will also increase livestock well-being, agriculture productions and industrial capacity in the study area.

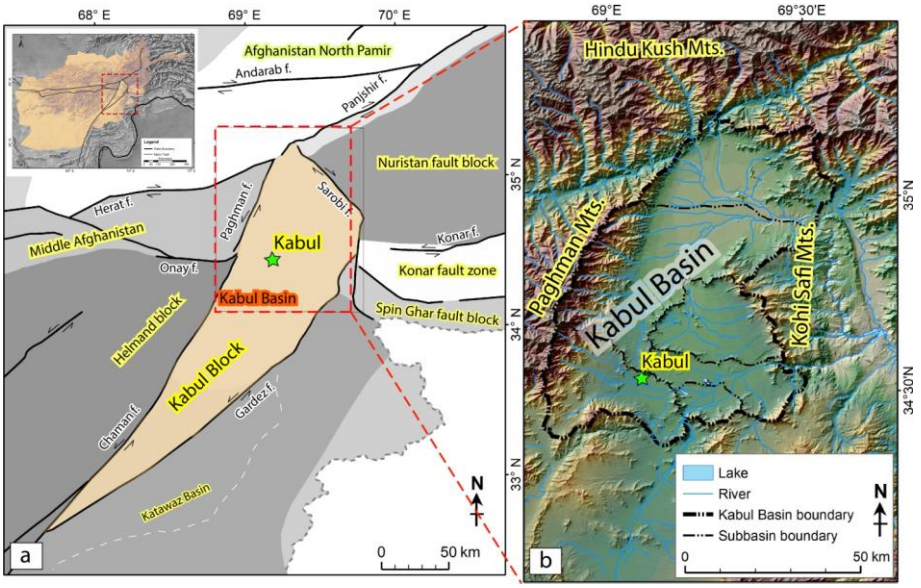


Figure 1. a) Location of the Kabul Block, which is bounded by active faults. This map is modified from Shnizai and Tsutsumi (2020). b) Geomorphic location of the Kabul Basin and subbasins.

Geologic Setting of the study area

2.1. Geology of the area

The geology of the Kabul basin is very complex, which is consisted of various metamorphosed, sedimentary and volcanogenic rocks. These rocks have different stratigraphic ages that belong to Lower Proterozoic up to Quaternary. The basin sediments mainly comprise of Tertiary and Quaternary terrestrial and lacustrine, primarily consisting of marls and interbedded sand and gravel horizons (Fig. 2). The sediments can be subdivided at the molasse-type Butkhak series of the Upper Miocene, the Pliocene Kabul series, the Quaternary terrace sediments of middle and younger Pleistocene and the Youngest Formations (Abdullah et al., 2008). The total thickness of sediments is approximately 600 m (Houben et al., 2009; Tünnermeier and Houben, 2005). The mountain ranges are composed of uplifted metamorphic bedrock. A variety of rocks such as granites, gneisses, schist, quartzite, slates through to soft limestone, travertine, and boulder beds are exposed in the basin.

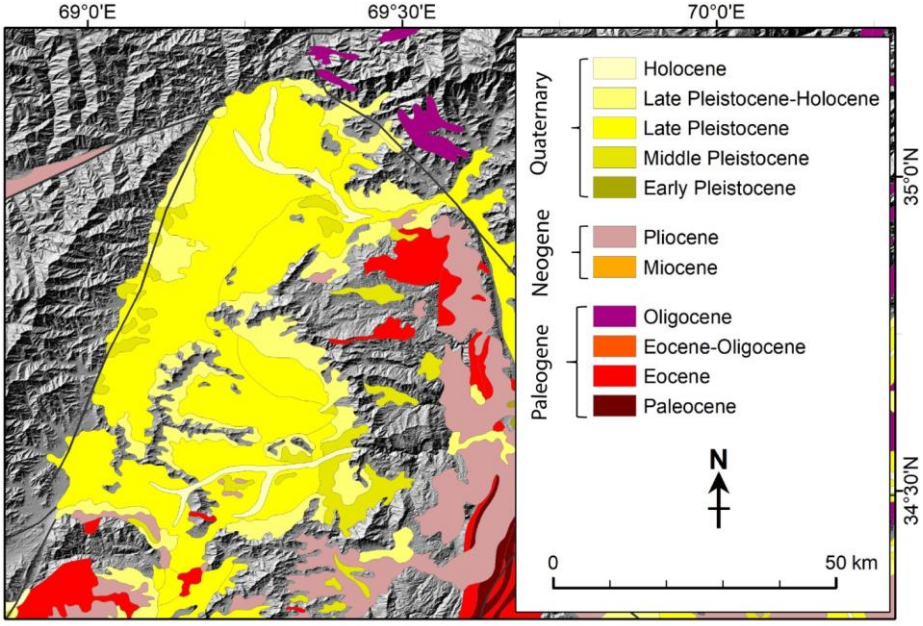


Figure 2. Geological map of the Kabul Basin simplified from Doebrich et al., (2006).

The geomorphology of the Kabul Basin and surrounding regions are strongly influenced by regional and local tectonic activities as well as fluvial processes. The basin is located at the northern end of the Kabul Block, where the Chaman and

Paghman faults bound the western margin of the Block. The Gardiz fault is located in the southern margin, while the Sarobi fault bounds the eastern margin of the Kabul Block (Fig. 1a). Also the primarily motion of the Chaman fault changes from left-lateral strike-slip into left-lateral oblique-thrust motion on the Paghman fault (e.g., Ruleman et al., 2007; Shnizai, 2020; Shnizai et al., 2020; Shnizai and Tsutsumi, 2020).

The Kabul Basin is bounded by high mountain ranges. The Hindu Kush Mountains Ranges bound the northern margin of the basin, while the southern margin is bounded by the Qoh-e Quragh Mountains. The Paghman Mountains are located to the west reaching more than 4400 m in altitude. These mountains are the primary source of sediments deposited in the basin. The central plains of the subbasins are nearly flat and rising gradually to the surrounding bedrock outcrops. The Kabul subbasins formed by interbasin ridges and river drainages include Central Kabul, Paghman and Upper Kabul, Logar, Deh Sabz, Shomali, and Panjsher (Fig. 3a). The interbasin ridges raise ~200-00 m above the valley floors (Mack et al., 2010; Shnizai and Tsutsumi, 2020).

2.3. Hydrogeology of the Kabul Basin

According to the Myslil et al. (1982) and Saffi (2011), the Kabul Basin groundwater can be characterized by three hydrogeologic units; 1) Crystalline rocks; 2) Neogene (Upper Tertiary) aquifer and aquitard system; and 3) Quaternary deposits. Due to faulting and weathering, secondary fractures in crystalline rocks make these rocks to have potential for water bearing systems. Upper Tertiary aquifer and aquitard systems consist of clay and interbedded slit, sand and gravel, which are not considered a major aquifer in the Kabul Basin. The Quaternary deposit consists of sand, gravel and conglomerates with loam and sandy-loam on the surface (e.g., Abdullah et al., 2008; Shnizai and Tsutsumi, 2020). The coarse grained sediments are usually present along the rivers that run southeast. The groundwater resources are mainly related to Quaternary deposits (Fig. 2).

The existing of mountains in the Kabul basin has considerable effects on the surface and groundwater (e.g., Fig. 1b). Analysis of climate data also shows that the elevation and orientation of the mountains are the main factors in the basin which determines the climate (Houben et al., 2009; Mack et al., 2010; Saffi, 2011). The central range of the Hindu Kush Mountains is drained in the south by the left-edge tributaries of the Kabul River (Fig. 1b). The Kabul City area has four main aquifers: The two aquifers lying along the Paghman River and the upper direction of the Kabul River. The other two aquifers follow the course of the Logar River and lower

Kabul River. The upper aquifer consists of very permeable gravels and sands, it is a primary aquifer and has a thickness less than 80 metres. The upper aquifer is underlain by a secondary aquifer which is less permeable; it is composed by, densely compacted gravels and clays. This aquifer has about 1000 metres thickness (Mack et al., 2010).

The infiltration of domestic and industrial sewage has some effects on the quality of groundwater, but does not have any special impact on the groundwater balance therefore most of the water is normally extracted for the aquifers. Only 27% of the direct precipitation infiltrate into the ground (Tünnermeier and Houben, 2005).

Broshears et al. (2005) stated that in the Kabul basin groundwater flows through saturated alluvium and other sediments which fill the basin. Some groundwater should flow through weathered bedrock and also through fractures in the bedrocks, but this amount of flow is less than which flow through alluvium. In the Kabul Basin the water table altitudes are from 2279 m to 1466 m above sea level. In central area the water level ranges from 1785 m to 1775 m above sea level (Fig. 1b). In the basin, groundwater generally flows in the direction of surface-water discharge. Water levels have been measured since 1980. In the upper area the decline is more than 10 m.

3. Data and Method

A total of 285 water samples were collected from various areas of the Kabul Basin, from 7/31/2004 to 7/15/2007 (Table 1). These samples were collected from wells, Kariz, springs and surface. The data for 31 various substances were collected from the research undertaken by United State Geological Survey (USGS) throughout the Kabul basin, which involved the extraction and analysis of 195 groundwater samples (Fig. 3a). The wells depth and samples water level in meter were also measured (Fig. 3a, b). Only, the groundwater data from the aforementioned research was used as primary data in this paper, in order to investigate the effect of climate on groundwater quality and to specify the level of contamination in different parts of the basin (Mack et al., 2010).

Table 1: Location and numbers of the collected samples from the Kabul Basin

Sort of sample / Subbasin Name		Groundwater samples	Surface water samples	Springs samples	Kariz Samples	Total of the samples
Western Front Source Area	**Kabul Basin**	20		1		21
Shomali		23	34	3		60
Paghman and Upper Kabul		35	22		1	58
Eastern Front Source Area		7		1	3	11
Logar		26	11	1		38
Central Kabul		65	12	1		78
Deh Sabz		19				19
Total		195	79	7	4	285

The most recent groundwater sampling campaign has been conducted since 2004 throughout the Kabul (e.g., Broshears et al., 2005; JICA, 2007; Mack et al., 2010; Saffi, 2011; Tünnermeier and Houben, 2005). In this paper groundwater quality analysis was carried out for five physico-chemical parameters such as; groundwater temperature, pH, specific conductivity, hardness and total dissolved solids (TDS) (Table 2). To visualize the results, ArcMap, Golden Surfer, Illustrator softwares were used together with Microsoft Excel for graphical representation of the undertaken analysis.

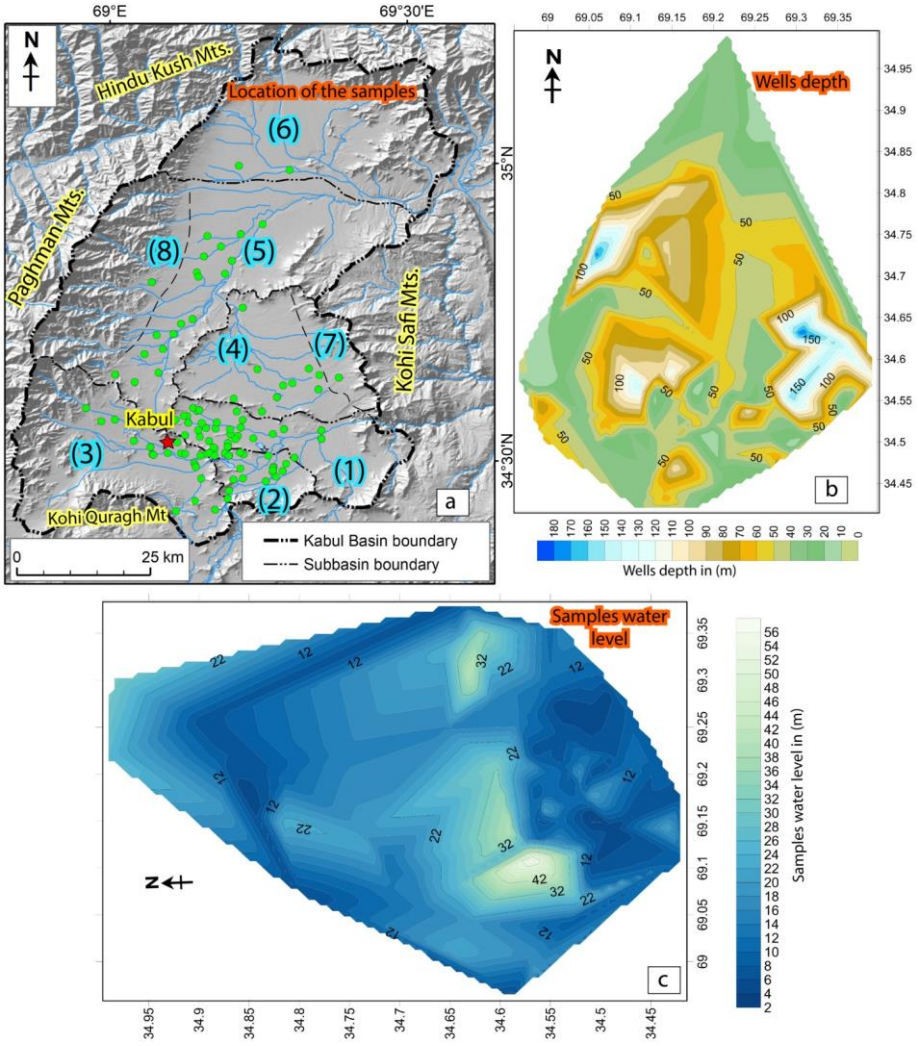


Figure 3. a) Study area with major geographic features. The subbasins and groundwater samples location are shown around the Kabul Basin. The number shows subbasins; (1) Central Kabul; (2) Logar; (3) Paghman and Upper Kabul; (4) Deh Sabz; (5) Shomali; (6) Panjshir; (7) Western Front Source Area; and (8) Eastern Front Source Area. The green dots show the location of the groundwater samples. b) Wells depth in meter. c) Samples water level in meter.

4. Result and discussion

The samples water level shows the distribution of the groundwater in the Kabul Basin, which can be also used as a water table (Figs. 3a, b). The groundwater physic-chemical parameters in the Kabul Basin are variable from place to place. In some areas, the groundwater quality is very good with low dissolved solids and any problematic components. But in some other areas, the quality of groundwater is very poor with high concentration of constituents. The shallow groundwater generally has a weakly oxidising redox environment with oxygen depletion, which is probably caused by the sewage. However, in subbasin regions such as Shomali, Eastern front and Western front source area and Deh Sabz, the chemical compositions of groundwater are approximately similar with surface water. But, in city regions particularly in the Central Kabul the concentration of chemical compositions are very high.

Table 2: Statistical normal distribution of physic-chemical parameters in the Kabul Basin (n=195)

	Temperature °C	pH field	pH lab	Hardness (mg/L)	Specific conductivity (µS/cm)	Specific conductivity lab (µS/cm)	TDS (g/L)
Mean	15.85	7.57	7.75	473.81	1312.5798	936.59	0.542
Maximum	22.5	8.99	8.2	3263.9	15290	5060	3.7
Minimum	10.9	5.88	7.3	34.3	248	287	0.11
SD	2.03	0.35	0.204	492.47	1862.8511	826.23	0.529
Median	15.5	7.56	7.8	357.85	906	754.5	0.445
Mode	15.4	7.55	7.6	357.9	672	524	0.45
WHO Guidelines			6.5-8	<500 ppm			<1 (g/L)

4.1. Temperature

The groundwater temperature is important because of the amount of heavier isotopes increases with increasing temperatures (Tünnermeier and Houben, 2005). In the Kabul basin, the average groundwater is ~16° C, which is much higher than annual average temperature (13° C). The figure 4a shows that the higher temperature (21° C) is present in the north and central part of the Kabul City. Drainage pits, rapid increase of population, heating system are additional sources that have impact of groundwater temperature.

4.2. pH

Neutral water has a pH of 7. If the pH of water is more than 7 it is called alkalinity and if the pH is less than 7 it is acidic. The mean pH of the studied samples of groundwater was 7.6 with standard deviation of 0.4 (Table 2). Among the 195 samples, only 1% was not agreed with the WHO guidelines (Fig. 4b). The WHO limit for pH is 6.5-8 (Table 2). It is a very important parameter for numerous hydro-chemical reactions and assessing the usability of water in a technical system. The pH is also one of the importance on determining the corrosiveness of water because generally the lower the pH, the higher the level of corrosion (WHO, 1986). Cautious attention to pH is necessary at all stages of water treatment before distribution to ensure satisfactory clarification and disinfection to minimise the corrosion of water. Exposure to extreme (pH>11) results in irritation in eyes, skin and mucous membrane and also cause hair fibbers to swell in human. Similarly, low pH also results in same effects with the severity of which increases with decreasing pH (WHO, 1986). According to the WHO (1999, 1984) guidelines, the taste of drinking water should be non-objectionable or acceptable to consumers. Generally, in the Kabul Basin, pH of the groundwater is close to neutral. The northeast, southwest and central region of the Kabul have the highest pH value (8.9, 9 and 8.5), which could be from strong acid emissions in the densely populated region (Fig. 4b). The hydro-chemical process that can have major impact on the groundwater pH, includes of: 1) carbonate equilibrium; 2) solubility of calcium, magnesium, iron, manganese and aluminium minerals; and 3) surface recharge with numerous adsorbed minerals.

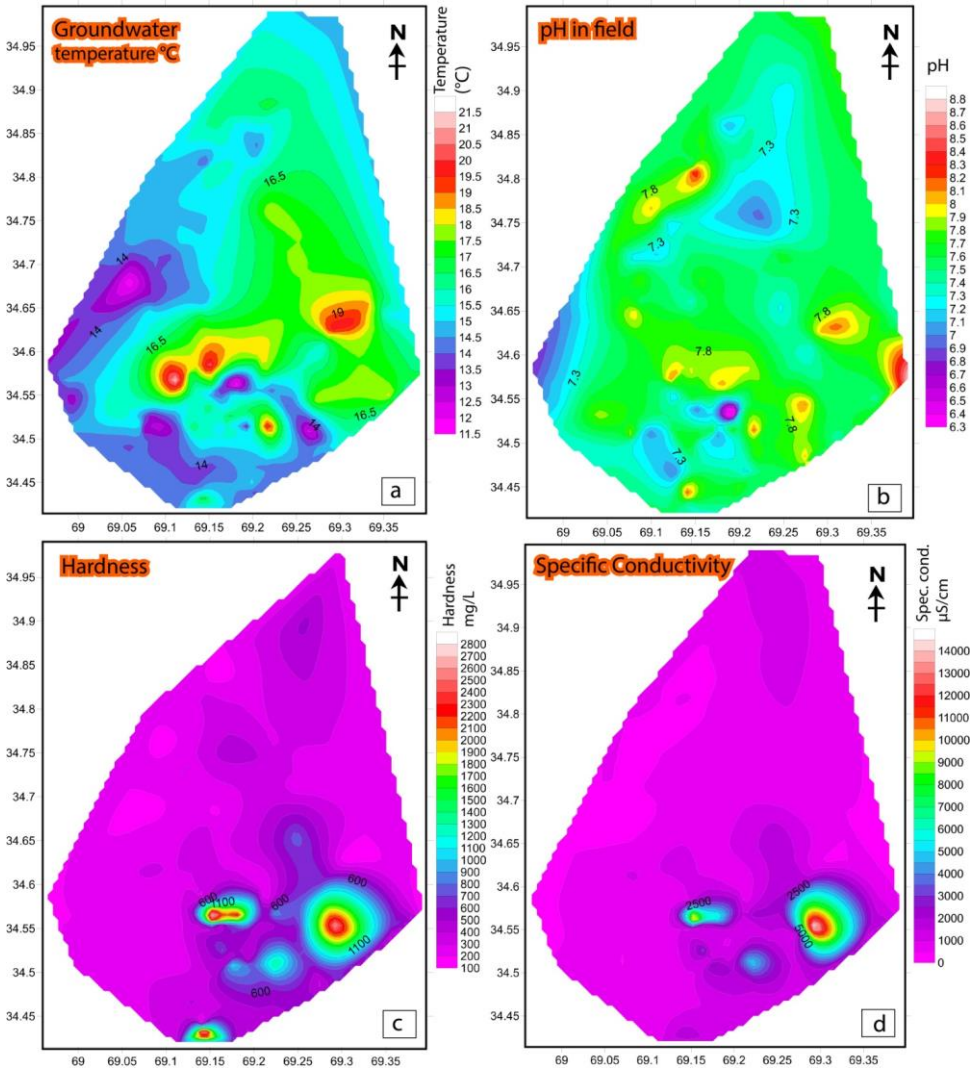


Figure 4. This figure shows physico-chemical parameters distribution around the Kabul Basin. a) Groundwater temperature. b) pH of the groundwater in field. c) Groundwater hardness. d) Specific conductivity of the groundwater measured by micro second per centimetre.

4.3. Hardness

The water hardness is related to the carbonate ($CaCO_3$) equilibrium. Hard water has high concentrations of Ca, Mg, Fe and Mn ions (Asadullah et al., 2013; Saffi, 2011). In the Kabul basin all the samples show very hard degree except two samples which values are 34.3 mg/l and 86.5 mg/l, which makes 0.71% of all the collected samples (Figs. 4c and 5).

The hardness is associated with high carbonate concentrations. This may origin from biomass mineralisation or the dissolution of carbonate minerals. The calcite, aragonite and dolomite minerals cause hardness in water leach from sediments such as limestone. In the Kabul Basin the hardness of the groundwater is directly related to the mineralization of biomass from sewage, and in few cases might be related to carbonate minerals dissolutions.

The south and south-eastern area has the highest (3263.9 mg/l) hardness values (Fig. 4c). Figure 4c also shows that the south-eastern region is more hardness than any region in the basin. This is area is called the central Kabul subbasin. On the other hand, the north-western edge has lower values (34.3 mg/l), indeed this area is sparsely populated area. Hardness can be reduced by using ion exchange. According to the U.S. Department of Interior and the Water Quality Association, water hardness is classified in five groups (Table 3) (Oram, n.d.).

Table 3. Classification of water hardness according to the U.S. Department of Interior and the Water Quality Association.

Classification	**mg/L**
Soft	0-17.1
Slightly hard	17.1 – 60
Moderately hard	60 – 120
Hard	120 – 180
Very hard	≥180

Saffi (2011) stated that 92 percent of water samples from drinking water points are classified as hard or very hard. According to the Niard (2003) and Tünnermeier and Houben (2005) report, in the Kabul Basin from drinking water points approximately 84 percent of the samples are calcified as hard or very hard (Fig. 5). On the other hand, this study shows that 97.85 percent of the groundwater samples from wells are classified hard or very hard. This major hardness gives the water a very high capacity against acid emission.

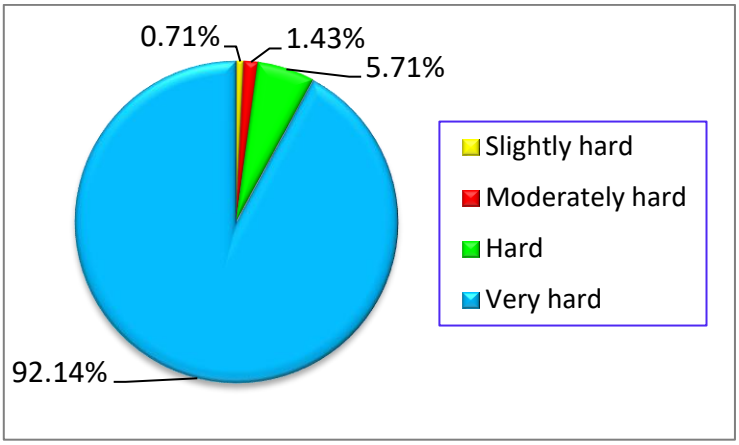


Figure 5. Distribution of groundwater hardness in the Kabul Basin.

4.4. Conductivity

Specific conductivity is an indirect measure of waters' ability to conduct electricity or may be for finding total dissolved solids in water. Also dissolved minerals in water have a positive or negative charge, and the electrical conductivity is a measure of charge. The electric conductivity of the groundwater in the Kabul Basin varies from 248 to ~15300 µS/cm with 1312.58 mean and standard deviation of 1862.85 (Table 2). Large number of samples (124 from 195) has more than 1300 µS/cm specific conductivity.

According to the WHO guideline, specific conductivity is 1500 µS/cm (Table 2). About 55% of the collected samples have more than 1500 µS/cm specific conductivity (Fig. 6). The specific conductivity has association with calcium, magnesium, sodium, chloride and sulphate ions. In the Kabul Basin, the densely populated south-east and central parts have more specific conductivity, because of the strong evaporation (Fig. 4d). Therefore, when the evaporation increases the concentrations of total dissolve solids also increase. In recharge areas, the electrical conductivity value range is small, while in the middle part of the basin especially in Kabul City the electrical conductivity value have progressively increased (Fig. 4d). In the recharge regions, the hydraulic gradient is high and lower solubility takes place, therefore the electrical conductivity is lower than the central region (e.g., Fig. 1b). Also, in summer due to the acute water shortage in the Kabul Basin, the specific electrical conductivity value can be increased. The highest value of specific conductivity is 15290µS/cm (Table 2).

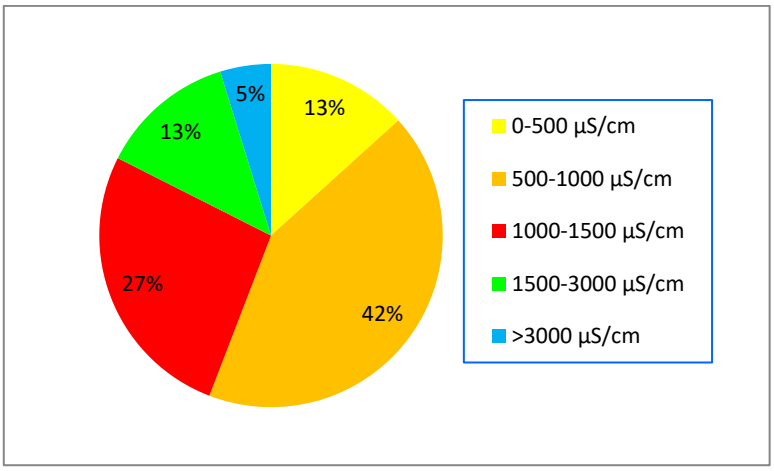


Figure 6. Percentage of specific conductivity of the groundwater around the Kabul Basin.

4.4. Total Dissolved Solids

The Total Dissolved Solids (TDS) refer any organic and inorganic substances in water. These materials can be suspended or dissolved in water. Dissolved solids include materials which are dissolved in water such as, bicarbonate, sulphate, nitrate, calcium, magnesium, sodium, organic and other ions, which are mostly found in industrial or sewage water. The WHO standard for drinking is less than 1000 ppm (~1 mg/L). In this research, the observed total dissolved solids vary from 0.54 to 3.7 g/L with mean 0.54 g/L and standard deviation of 0.53 g/L (Table 2). Out of the entire groundwater samples only 6.25 % of the samples were not able to follow the WHO standard for total dissolved solids. On the other hand, 93.76% of the collected samples were pursuing the WHO standard (Fig. 7). The total dissolved solids primary sources are agricultural and residential runoff, leaching of soil contamination and water pollution. The standard values for TDS in the Kabul Basin groundwater are shown in the Figure 7.

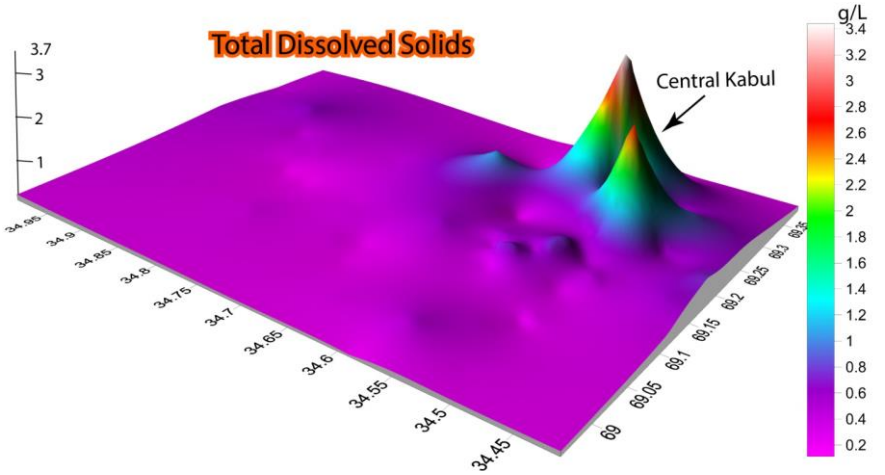


Figure 7. Distribution of the total dissolved solids (TDS) in Kabul Basin. The highest concentration is present in Central Kabul.

In the Kabul basin, the highest total dissolved solids are present in the south-east part, which is more than 2.5 g/L (2500ppm) (Fig. 7). According to the TDS standard, this indicates the maximum contamination level of TDS. The average TDS value in throughout the basin is 0.514 g/L, which is also representing the maximum contamination level (Table 2).

The recorded TDS and Conductivity were correlated by linear regression (R^2 = 0.9703) and electrical conductivity of groundwater directly related to the concentration of the total dissolved solids (TDS) in the groundwater (Fig. 8). Moreover, the specific conductivity (µS/cm) was found the multiple of multiple of 0.0005 (y = 0.0005x - 0.0102). Ions from dissolved solids in water can cause to conduct electrical current. Singh and Karla (1975) stated that the electrical conductivity has been used to estimate total dissolved in mountain streams and rivers.

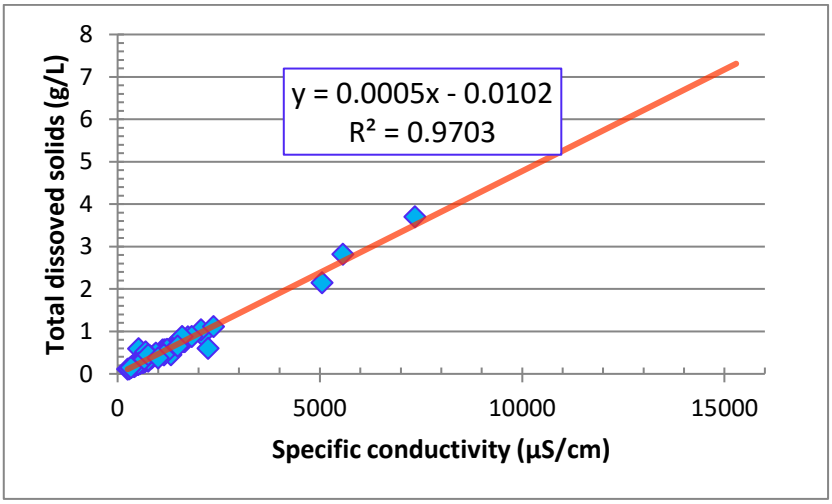


Figure 8. Linear regression shows correlation between TDS and specific conductivity. Specific conductivity of the groundwater is directly related to the concentration of total dissolved solids. (n = 80).

Conclusion

The Kabul Basin is located at the northern end of the Kabul Block, which is strongly influenced by regional and local tectonic activities and fluvial processes. The basin groundwater is characterized by crystalline rocks, Neogene aquifer system and Quaternary deposits hydrogeologic units. Most of the groundwater resources are mainly related to quaternary deposits and few to Neogene aquifer and aquitard systems. In crystalline rocks, secondary fractures due to faulting and weathering make these rocks to have potential for water bearing systems too.

In order to investigate the effect of climate on groundwater quality and to specify the level of contamination in different parts of the basin, a total of 195 groundwater samples were collected from various areas of the Kabul Basin, which was used as primary data in this paper. In the basin, the groundwater physic-chemical parameters vary from place to place. The central part of the Kabul City has the highest temperature (21°C). But, overall the average groundwater temperature is ~16°C, much higher than annual average temperature (13°C). The mean pH of the groundwater collected samples is 7.6. Only 1% of the samples have higher pH than standard value 8.

Almost 97.85 percent of the collected samples are classified hard or very hard. This major hardness is directly related to the mineralisation of biomass from

sewage, and in few cases might be related to carbonate minerals dissolutions. The electric conductivity varies from 248 to 15290 μS/cm. From the collected samples 55% of has >1500 μS/cm specific conductivity. In the Basin, the densely populated south-east and central parts have more specific conductivity, because of the strong evaporation. the observed TDS varies from 0.54 to 3.7 g/L. Out of the entire groundwater samples only 6.25 % of the samples were not able to pursue the WHO standard for total dissolved solids. The TDS primary sources are agricultural and residential runoff, leaching of soil contamination and water pollution. The specific conductivity is directly related to the concentration of the total dissolved solids (TDS) in the groundwater. Ions from dissolved solids in water can cause to conduct electrical current.

Acknowledgment

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