

Evaluation of Groundwater Quality for Drinking water by using physico-chemical analysis in Ibb City, Yemen

ABSTRACT

A study on the evaluation of groundwater composition was carried out around Ibb city, Republic of Yemen. Groundwater in the vicinity of Ibb city is used for drinking. The main objective of this study is to determine the suitability of the groundwater around Ibb city for drinking. Groundwater samples were collected from ten different boreholes. The physico-chemical characteristics of groundwater, included major anions and nitrogenous compound fluoride (F^-), chloride (Cl^-), nitrites (NO_2^-), nitrates (NO_3^-), ammonia-N (NH_3-N), major cations (Mg, Ca, K, Fe) and heavy metals (Zn, Cu) were analyzed in the laboratory using the standards physicochemical methods. Furthermore, pH, temperature, electrical conductivity (EC), total dissolved solids (TDS) were measured in-situ. The results of this study revealed that, the groundwater around wastewater treatment plant in the boreholes (BH5, BH9 and BH10) were not potable and thus not suitable for drinking water, since most of the physical and chemical parameters results such as TDS, NH_3-N , Ca, Mg, T.H and Cu exceeded the permissible limits given by Yemen's Ministry of Water and Environment. Therefore, the current study suggests that water quality should monitor these boreholes and transfer the effluent of the existing WWTP further beyond the groundwater aquifer or close the existing WWTP and build another wastewater treatment plant at 20Km far from the existing one in order to prevent further ecological contamination and guarantee protecting public health

Keywords: Wastewater treatment plant, groundwater, cations, heavy metals, Ibb City.

1. INTRODUCTION

Groundwater is a vital source of water for drinking and irrigation all over the world. The use of groundwater is expected to increase because of increasing of population, irrigation, and industrialization. But this vital resource of drinking water can be easily depleted because it is renewed at a very slow rate. Also, on human time scale, groundwater contamination can be considered permanent (Joseph 2005). Groundwater is generally a very good source of drinking water, because of the purification properties of the soils; it is also used for irrigation and spraying, and for industrial purposes (Tebbutt 1983). Ibb city relies on groundwater for its supply. Its main well field (Salaba-Jibla well field) is situated in the south west of Ibb city. In 1973, two wells were constructed (Salaba and Kennedy wells), 7 new were drilled in 1982, 3 more in 1997, 3 in 2003, and two in 2003-2004. At present, more than 20 wells are in operation, 10 of which feed directly into the network, and 10 feed the high level

reservoir. The depth of the wells ranges between 135 and 333m (Dar Al Handash 2006). The most favorable source of the water supply system in Ibb city is groundwater. The few number of springs in the vicinity have very small discharges, except for some shallow wells which have been drilled in the past surrounding the city, especially in the wadi areas, and which provide a local water supply for irrigation purposes. Apart from a few perennial streams which are alimented from springs and the merging of groundwater in the riverbeds of Wadi Salabat Al- Sayyadah and Wadi Sahool, no wadis with permanent flow exist in Ibb city (Dorsch 1983). The main objective of this study is to evaluate the suitability of these water sources for drinking purposes throughout the Physico-chemical.

2. Study area

Ibb city is located between Dhamar and Taiz governorates. It is about 193 km from the capital of Yemen, with an area of about 5383 km². It is located at latitude 13°58'48" and longitude 44°10'48" and is situated in a fault controlled valley close to the main watershed of the Wadi Zabid at an elevation of about 2000m above sea level. The general drainage direction is towards the south. During and after heavy precipitation, run-off of exceptional force can occur which floods large parts of the alluvial plain of the Mitm valley. The climate of Ibb city falls under the tropical highland types, characterized by two pronounced seasons. It is determined by the geographical position of Yemen, by the intensive relief and the high elevation of the region. From May to September the climate is mainly influenced by the moist air masses of the monsoon circulation system, which flows from the south-west against the Yemen highland and causes heavy precipitation in the mountain area. During dry season from October to April- dry air masses originating in the central Asian anticyclone system are the main reason for the rainless and cold winter. The greatest quantities of rainfall in the Republic of Yemen occur in the Ibb region.

Ibb sewage treatment plant is located in Mitm area. Its height is between 1870 – 1880 m above the sea level. The treatment works comprise of 2 inlet screens, 3 grit channels, 2 aeration tanks, 2 circular final settling tanks, return excess and thickened sludge pumps, circular thickener, sludge drying ponds, drying beds and chlorination. Also the plant includes administrative building comprising the office, the laboratory, the control room, the warehouse, and the workshop. The existing plant has a capacity of 5,000 m³/day. The incoming flow is about 10,500 m³/day (Dar Al Handasah 2006).

There are several boreholes which distributed around Ibb sewage treatment plant and the effluents of the plant are used for irrigation purpose. The population of Ibb city has increased rapidly during the last decade. The preliminary results of the census data of the year 2004 indicate that the population has increased much more than expected. The current population is approximately 374,833 people based on the past census data by the Department of Planning.

2.1 Geology of the study area

The formations of Ibb city are accompanied by widespread volcanism of Tertiary age which covered the major part of the area (Table 1). The rhythmic sequence of the plateau in the district extends over a considerable area. The landscape is typical of "trap volcanism" as a designation for the tremendous succession of volcanic effusions.

Table1. Geological formations of Ibb city

Alluvial Deposits (Qa)	Principally gravel, sand, boulders, and large detritus of volcanic origin as wadi filling.
River – terrace Deposits (Qt)	Loess with calcareous concretions, alluvial fans, gravel, silt, loamy sands as well as sandy loam.
Alkali – trachyte (Tk1)	Dikes and flows of alkali – trachytic lava.
Volcanic breccia (Tk2)	Fragments of basaltic lava flows and dikes, breccia of tuff and pyroclastica, bombs, and lapilli.
Porphyric basalt (Tk3)	Flows and dikes of lava rich in pyroxene.
Tholeiitic basalt (Tk4)	Dense black-greyish basaltic lava, rich in silica and plagioclase.
Alkali – olivine basalt (Tk5)	Lava flows, now and then pyroclastica.
Plateau basalt (Tk6)	Intermediate volcanics, mainly tholeiite and pikrite, velded tuffs, now and then ignimbrite.

The Geological map (in Figure1) shows the whole geological study area from the south to the north of Ibb city. In this connection, the above lithological units were distinguished.

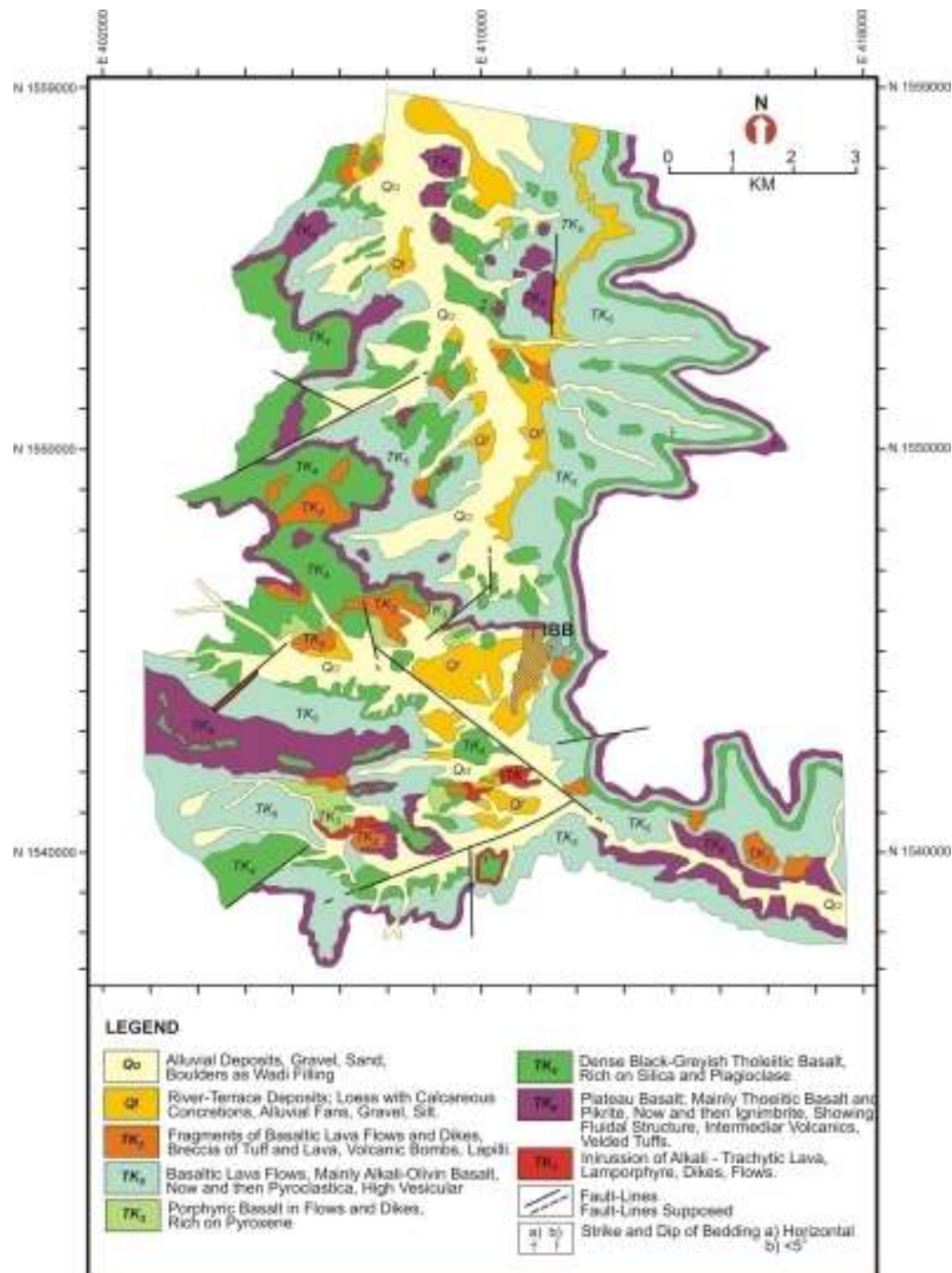


Figure1. Geological map of Study area

Source: Dorsch 1983

3. MATERIALS AND METHODS

The groundwater samples were collected from ten different boreholes around Ibb city as given in Figure 3. Polyethylene bottles covered with aluminum foils were used to collect groundwater samples for chemical analyses. The samples were then transported in a cool box and stored under suitable temperature until analysis. The laboratory of Ibb Water and Sanitation Local Corporation (IWSLC) was used for analyzing of groundwater samples.

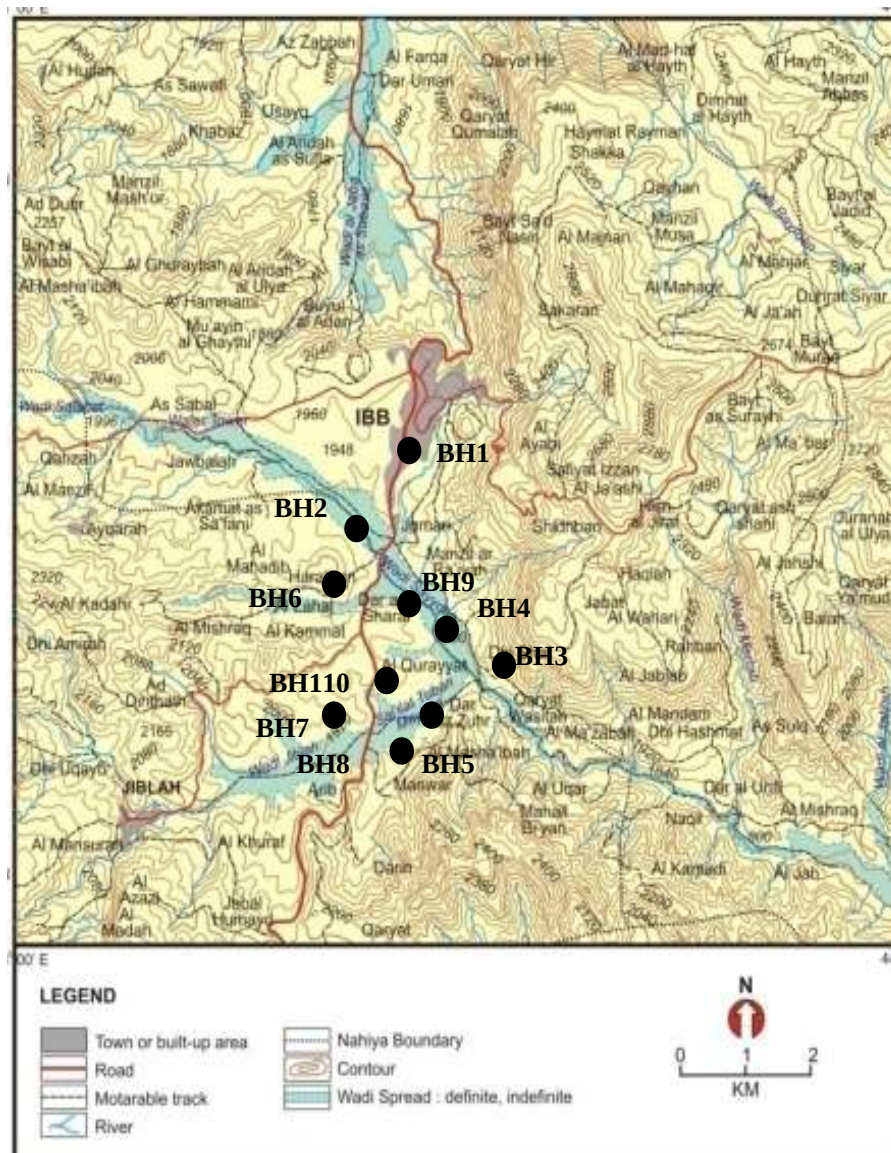


Figure2. Topography map of the study area and the location of boreholes

In-situ parameters that are measured include pH, temperature by using pH meter model 3071, UK. Electrical conductivity (EC) is measured by using EC HACH meter

model LF91 in microsiemen per cm ($\mu\text{S}/\text{cm}$), whereas, total dissolved solid (TDS) is measured by using the factor 0.65 multiplied by the EC reading (5). The reading is performed in triplicate and the average is recorded.

Fluoride (F) was measured by using Portable Data logging Spectrophotometer HACHDR/4000 Method 8029 (SPADNS Method). Chloride was measured by the Mercuric Nitrate Titrimetric Method. 25ml of water samples was placed in Erlenmeyer flask, and then Diphenylcarbazone reagent was added to the sample. The solution was blue-green, when the Mercuric Nitrate was added as a titrant, the solution was turned from blue-green to purple, and making the end point of the titrant (APHA 1998).

$$\text{Cl} = (M \times M. Wt \times 1000 \times \text{Number of ml of Hg (NO}_3)_2) / V$$

Where,

$$M = 0.1$$

Wt = atomic weight of Cl which equal 35.5

V = volume of water sample

Nitrate was measured by the Portable Data logging Spectrophotometer HACHDR/4000 using Cadmium Reduction Method (Method 8039). The method for Nitrite measurement was Diazotization Method (Method 8507) using Portable Data logging Spectrophotometer HACHDR/4000. Ammonia was measured by the Portable Data logging Spectrophotometer HACHDR/4000 using Nessler Method (Method 8038). For Iron measurement by the Portable Datalogging Spectrophotometer HACH R/4000 the method was FerroVer Method (Method 8008). Calcium was measured by the (EDTA) titrimetric methods which involves the use of solutions of ethylene diamintitra acetic acid. 25ml of water sample was placed in a conical flask, and then 2ml of buffer solution was added to the sample. Man Ver 2 Calcium indicator was also added to the sample. The solution was wine red, when EDTA was added as a titrant, the solution was turned from wine red to blue, making the end point of the titrant. The equation below gives the calculation of calcium (5).

$$\text{Calcium} = (M \times Wt \times 1000 \times 40 \times \text{number of ml of EDTA}) / V$$

Where,

$$M = 0.05$$

Wt = atomic weight of Ca which equal 40

V = volume of water sample

Magnesium was measured by calculation as the difference between the total of hardness and the calcium hardness as follows:

$$\text{Total hardness (as CaCO}_3\text{)} = 2.497 [\text{Ca}^{2+}, \text{mg/L}] + 4.118 [\text{Mg}^{2+}, \text{mg/L}].$$

Then:

$$4.118 [\text{Mg}^{2+}, \text{mg/L}] = \text{Total hardness (as CaCO}_3\text{)} - 2.497 [\text{Ca}^{2+}, \text{mg/L}] \quad (5).$$

Flame photometer (PFP 7) is a low temperature, single channel emission flame photometer and has been designed for the routine determination of potassium (K). It is a direct reading digital instrument.

4. Statistical analysis

The quantitative results were expressed as means $\pm$ S.D. Differences between means were tested using one-way analysis of variance (ANOVA) followed by the student-Newman-keuls t-test.

5. RESULTS AND DISCUSSION

The results of physicochemical parameters included in-situ parameters, major anions and nitrogenous compounds, major cations and heavy metals for groundwater:

pH: the pH mean values were statistically different among the boreholes as given in Figure 3. The highest value of 7.4 was measured in BH8 whereas the lowest value of 7 was measured in BH5. Zajic (1971) stated that the pH for natural water generally ranges from 5.5 to 8.6. Water with lower pH tends to cause corrosion, and in many cases an upward adjustment to the neutral range (pH = 7.0) is necessary. Yet with all the discrepancies between pH readings, these results are in agreement with the range values set by Yemen's Ministry of Water and Environment (YMWE 1999) and WHO (2004).



Figure 3 Mean values $\pm$ S.D of pH in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

EC: Electrical conductivity (EC) values showed significant differences ($P < 0.05$) between all water samples. The highest value was recorded in BH10 (1198 $\mu\text{S}/\text{cm}$) whereas the lowest value was recorded in BH2 (827 $\mu\text{S}/\text{cm}$). According to Langenger (1990), the importance of electrical conductivity is its measure of salinity, which greatly affects the taste and thus has a significant impact on user's acceptance of the water as potable. The high values of EC in BH 5, BH 9, and BH 10 are not within the range values of 450 to 1000 $\mu\text{S}/\text{cm}$ set by Yemen's Ministry of Water and Environment (YMWE, 1999). However, EC values in the other boreholes were within the Yemen standard value which is required for drinking water.

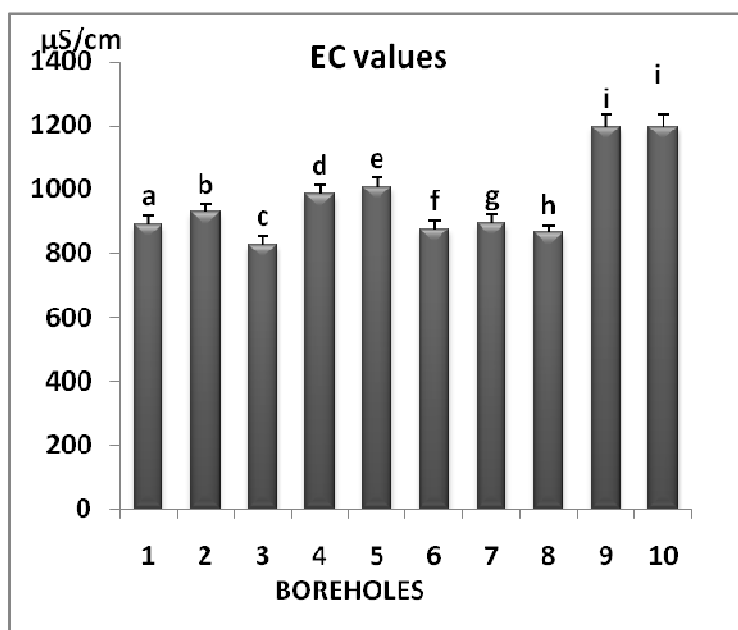


Figure 4 Mean values $\pm$ S.D of EC in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

TDS: Statically, there were significant differences ($p < 0.05$) in the concentrations of total dissolved solids (TDS) between all boreholes. The highest value of 778.7 mg/l was measured in BH10 whereas the lowest value of 538.2 mg/l was measured in BH2. These results are higher than the results 5005.5mg/l obtained by Al-sabahi et al. (2008). Yet, the concentrations of total dissolved solids (TDS) in all boreholes did not pose any water quality problems because these results were in agreement with the range values set by Yemen's Ministry of Water and Environment (YMWE, 1999) and WHO (2004) which are required for drinking water. Due to the absence of pollution in this area (except for BH5, BH9 and BH10), it can be said that the variations in concentrations of these parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, and the dilution of the boreholes.

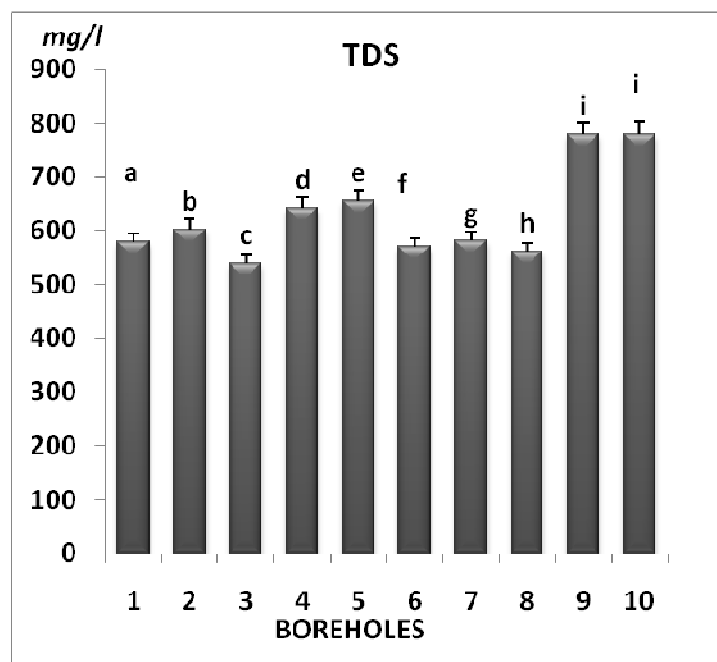


Figure 5 Mean values $\pm$ S.D of TDS in groundwater boreholes. Boreholes with different letters differ significantly.

F⁻: Statistically, there were significant differences ($p < 0.05$) in the concentrations of Fluoride ion between all boreholes, except for BH6 and BH10. The highest concentration of F⁻ was measured in BH5 with the value of 0.87 mg/l. Optimum concentrations of 0.7 to 1.2 mg/l are normally recommended, although the actual amount in specific circumstances depends upon the air temperature, since air temperature influences the amount of water that people drink (Arcadio & Gregoria 2003). In general, the values of F⁻ in all boreholes are in agreement with the standard acceptable levels of drinking water set by YMWE (1999) and WHO (2004).

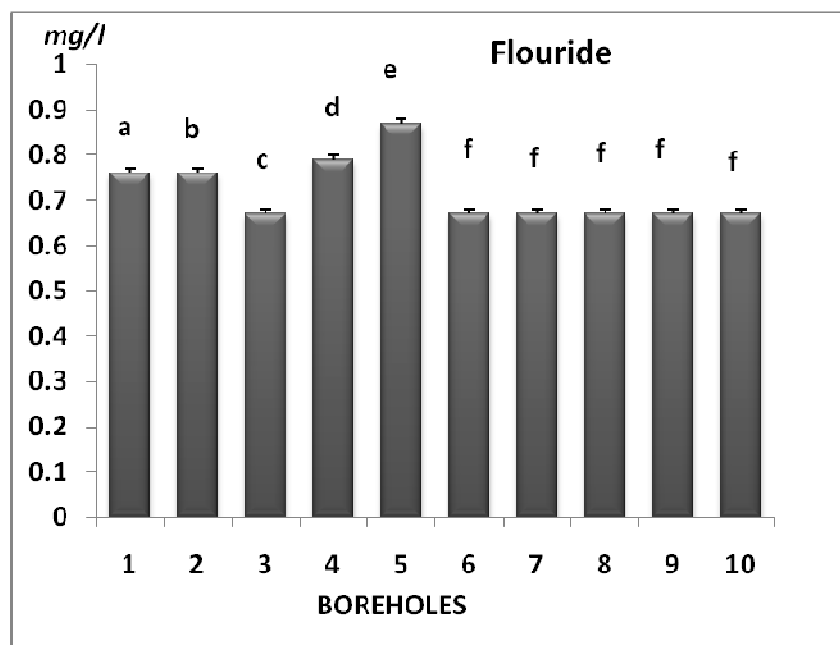


Figure 6 Mean values $\pm$ S.D. of F⁻ in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

Cl⁻ : the results of Chloride ion analysis showed significant differences ($P < 0.05$) between all water samples which were lower than the standard acceptable levels of drinking water set by YMWE (1999) and WHO (2004) which required for drinking water.

NO₂, NO₃ and NH₃-N: the concentrations of NO₂, NO₃ and NH₃-N in the studied boreholes were significantly different ($P < 0.05$) and very low and did not show any water quality problem if compared to YMWE (1999) and WHO (2004) standards (0.1mg/l for NO₂, 50mg/l for NO₃ and 0.5mg/l for NH₃-N). It can be said that the concentrations of major anions and nitrogenous compounds at the study area were below the standard acceptable levels of drinking water set by YMWE (1999) and WHO (2004) which required for drinking water. This indicates the absence of the source of pollution in this area. It can be said that, the variations in concentrations of these parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, and the dilution of the boreholes.

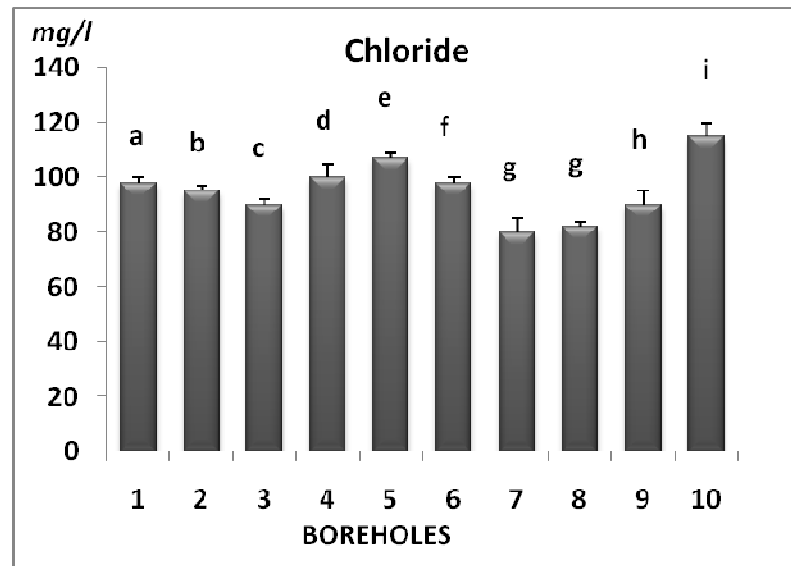


Figure 7 Mean values $\pm$ S.D of Cl^- in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

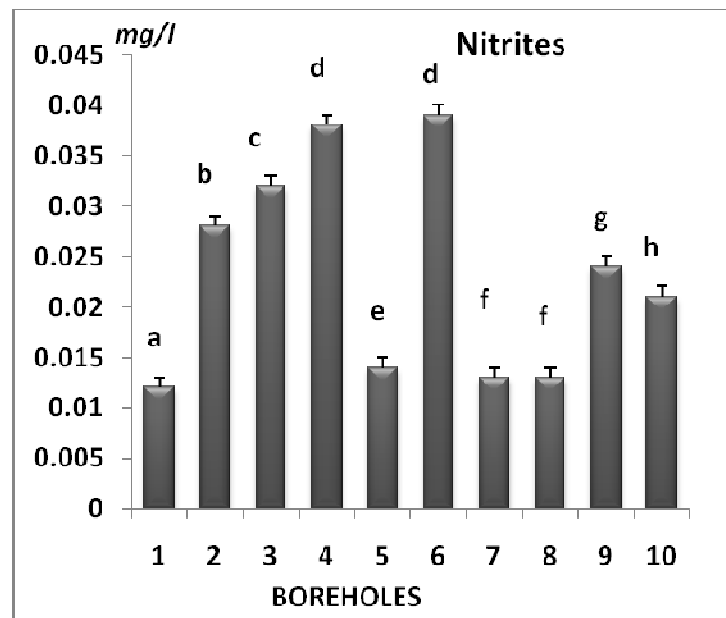


Figure 8 Mean values $\pm$ S.D of NO_2 in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

Fe⁺²: the obtained results of Iron concentration showed significant differences ($P<0.05$) for all the water analyzed samples. The highest result was obtained from BH9 with the value of 0.422mg/l, while the lowest result was obtained from BH10 with the value of 0.032 mg/l.

Ca⁺²: the obtained results of calcium analysis showed significantly differences ($P<0.05$) between all water samples and were in the range of (104 – 152 mg/l). By comparing these results with YMWE (1999) and WHO (2004) guidelines, all water samples were within the YMWE (1999) and WHO (2004) guidelines.

Mg⁺²: the highest concentration of magnesium was found in BH10 with the value of 40.93mg/l, whereas the lowest concentration was found in BH1 with the value of 13.92mg/l. These results showed significant differences between all studied boreholes and were in quite low levels in relation with reported values by YMWE (1999) and WHO (2004) and did not show any signs of pollution in the groundwater.

T.H: the concentrations of total hardness for all boreholes exhibited range values between 320 and 550 mg/l and showed significant differences ($P<0.05$). The highest value was reported from BH10. By comparing these results with YMWE (1999) and WHO (2004) guidelines (500mg/l), BH10 value was above the accepted limit.

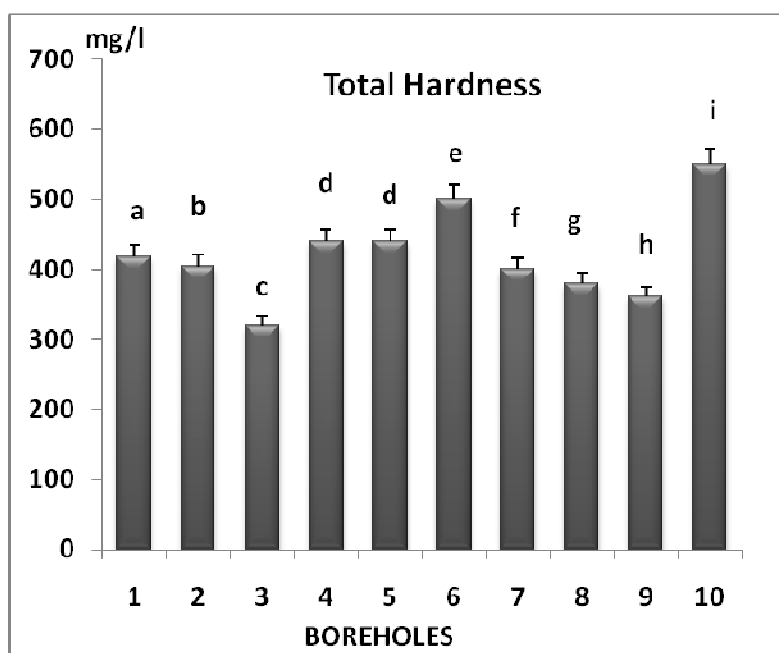


Figure 9 Mean values $\pm$ S.D of T.H in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

According to David (2004), there are two types of water hardness: temporary and permanent. Temporary hardness is removed when the water is boiled this is the process that leaves deposits of calcium carbonate on water heaters and kettles. Permanent hardness is formed as the cations pass over rocks containing sulphate ions. Meaning that water in all studied boreholes was very hard. By comparing the level of hardness and water type in table 2 with our results regarding this area, it can be said that groundwater in this area was very hard.

Table 2: Levels of hardness of water and the type of water

Water type	Equivalent
Soft	< 50 mg/L as CaCO ₃
Moderately hard	50–150 mg/L as CaCO ₃
Hard	150–300 mg/L as CaCO ₃
Very hard	> 300 mg/L as CaCO ₃

Source: David 2004

Copper (Cu) and zinc (Zn) were the heavy metals examined in this study. Concentrations of zinc (Zn) in the studied boreholes were significantly different ($P<0.05$) and very low and did not show any water quality problem if compared to YMWE (1999) and WHO (2004) standards. BH 5 (1.12 mg/l) and BH10 (1.7 mg/l) showed the highest concentration of Copper (Cu) in comparison with the standards (1 mg/l) set by YMWE (1999) and WHO (2004), and by contrast, these results were higher than the results obtained by Al-sabahi et al. (2008).

6. CONCLUSION

The study has carefully examined and analyzed ten groundwater boreholes and came up with the following: the concentration of total dissolved solids in BH9 (778.05 mg/l) and BH10 (778.7mg/l) was high compared to the other boreholes and very close to the upper limit specified by YMWE (1999) and WHO (2004) standards (1000 mg/l). These results were higher than the results 5005.5mg/l obtained by Al-sabahi et al. (2008).

The obtained results of ammonia were high in BH5 and may cause very serious effects on human health. The results of total hardness of groundwater in this area indicated that it was very hard because it had the largest value of both Ca^{+2} and Mg^{+2} . These concentrations in most cases remarkably exceeded the values of safe drinking water which were recommended by YMWE (1999) and WHO (2004).

The highest concentration of copper was found in BH10 with the value of 1.7mg/l followed by BH5 with the value of 1.12mg/l. By comparing these results with YMWE (1999) and WHO (2004) values, water from BH5 and BH10 may cause health hazards. Furthermore, these results are higher than the results obtained by Al-sabahi et al. (2008). It can be said that the variations in concentrations of these parameters can be attributed to the nature of the geological and chemical structure of the soil and rocks, the depth of the boreholes, and the dilution of the boreholes. Moreover, BH5, BH9 and BH10 are affected by the effluent of the wastewater treatment plant in Ibb city. Therefore, the current study suggests that water quality should monitor these boreholes and transfer the effluent of the existing WWTP further beyond the groundwater aquifer or close the existing WWTP and build another wastewater treatment plant at 20Km far from the existing one in order to prevent further ecological contamination and guarantee protecting public health.

7. REFERENCES

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