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Evaluation of Groundwater Quality for Drinking Water by Using Physico-Chemical Analysis in the City of Ibb, Yemen

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Abstract: The current study was conducted to evaluate the quality of groundwater around Ibb in the Republic of Yemen. Groundwater samples were collected from ten different boreholes. The physico-chemical parameters of groundwater samples, as major anions and nitrogenous compound which include fluoride (F^-), chloride (Cl^-), nitrites (NO_2), nitrates (NO_3), ammonia-N (NH_3-N), major cations which include (Mg^{2+}, Ca^{2+}, K^+, Fe^{2+}) and heavy metals (Zn^{2+}, Cu^{2+}) were analyzed in the laboratory using the standards physicochemical methods. Furthermore, pH, temperature, electrical conductivity (EC), total dissolved solids (TDS) was measured in-situ. The results of this study revealed that the groundwater around wastewater treatment plant (WWTP) in the boreholes (BH5, BH9 and BH10) was not potable and thus not suitable for drinking, since most of the physical and chemical parameters results such as TDS, NH_3-N, Mg^{2+}, Ca^{2+}, T.H and Cu^{2+} exceeded the permissible limits given by Yemen's Ministry of Water and Environment. While the results of the others boreholes revealed that, the suitability of these boreholes for drinking. This study concluded that the effluent of the existing WWTP was the main reason causing this groundwater pollution. Therefore, it is suggested that the (WWTP) is either closed or its effluent is transferred further beyond the groundwater aquifer 20 km. Furthermore, the groundwater in the boreholes should be continuously monitored in order to prevent further ecological contamination and to guarantee public health.

Key words: Wastewater treatment plant · Groundwater · Cations · Heavy metals

INTRODUCTION

Groundwater is a vital source for drinking and irrigation all over the world. The use of groundwater is expected to increase because of the growing of population, irrigation and industrialization. This vital resource of drinking water can be easily depleted due to the fact that it is renewed at a very slow rate. Groundwater contamination can be considered permanent [1]. Generally, Ibb city population relies on groundwater for all of their demands source. Basically, the main source of groundwater for Ibb population is situated in the south west of the city. At the present time, more than twenty wells are in operation, ten of which feed directly into the network and ten feed the high level reservoir. The depth of the wells ranges from 135 up to 333m [2]. Geographically, Ibb is located between Dhamar and Taiz governorates. It is about 193 km south of Sana'a, the capital of Yemen. It has an area of about 5383 km^2. 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 Zabid valley with an elevation of about 2000 m 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 falls under the tropical highland types, characterized by two pronounced seasons. The greatest quantities of rainfall in the Republic of Yemen occur in Ibb. Sewage treatment plant of the city is located in Mitm area. Its height is between 1870 – 1880-m above the sea level. The existing plant has a capacity of 5,000 m^3/day. The incoming flow is about 10,500 m^3/day [2]. There are several boreholes which are distributed around the Ibb Sewage Treatment Plant and the effluent of the plant is used for irrigation purposes. The population of Ibb has

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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. Therefore, the main objective of this study is to evaluate the suitability of groundwater around Ibb for drinking purposes throughout the Physico-chemical parameters analyses.

Geology of the Study Area: The formations of Ibb 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.

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

MATERIALS AND METHODS

Collecting Samples: The groundwater samples were collected from ten different boreholes around Ibb City as shown 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 a suitable temperature until the time of analysis. After that, the groundwater samples were analyzed in the lab of Ibb Water and Sanitation Local Corporation (IWSLC).

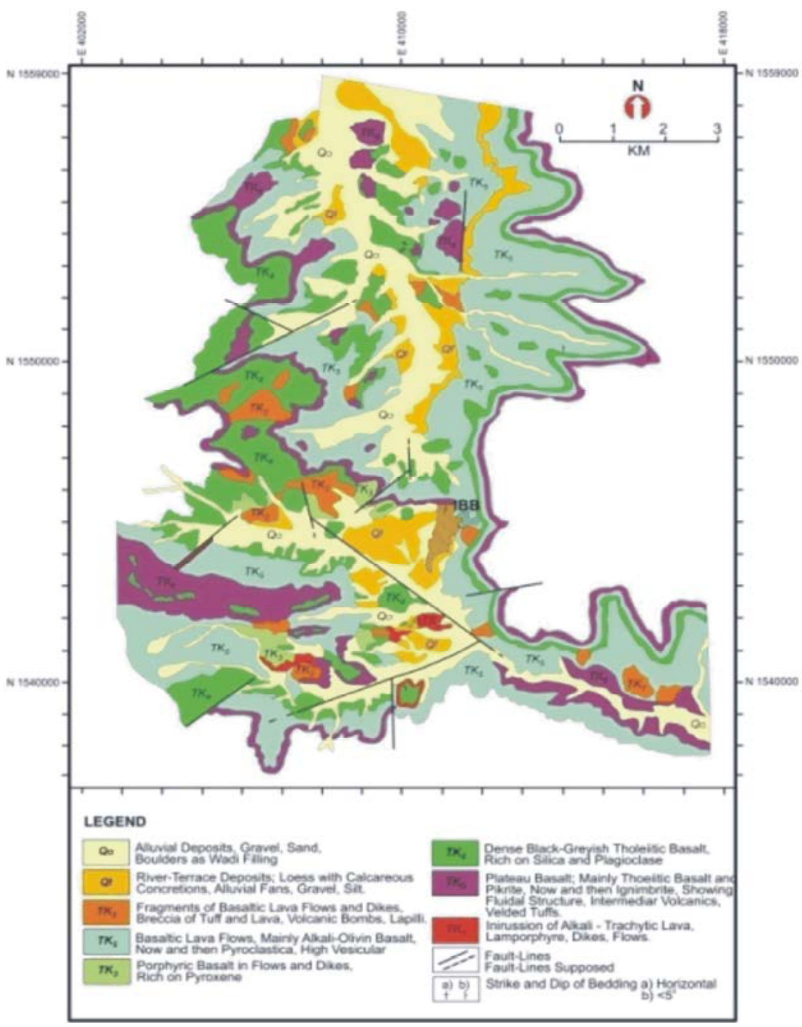

Fig 1: Geological map of Study area
Source: [3]

Table 1: Geological formations of Ibb

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.

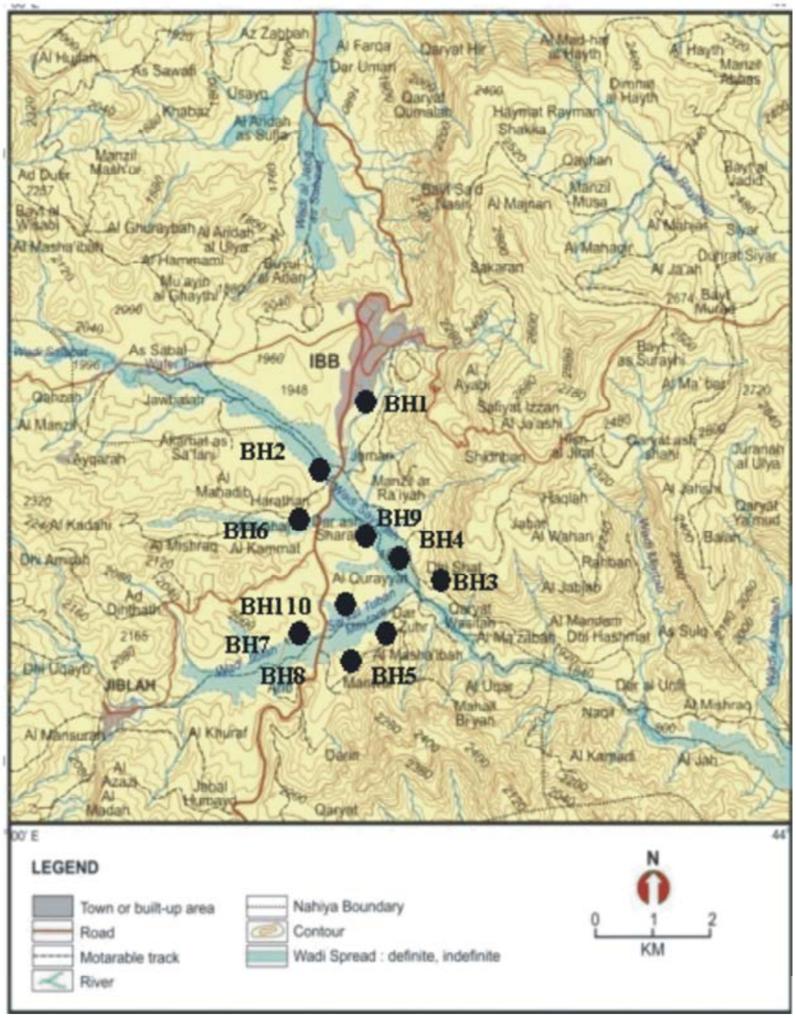

Fig 2: Topography map of the study area and the location of boreholes

The Measurements of Physico-chemical Parameters: In-situ parameters, that were 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 (µS/cm), whereas, total dissolved solid (TDS) were measured by using the factor 0.65 multiplied by the EC reading [4]. The measurements were taken three times and the average was recorded.

Fluoride (F^-) was measured by using the Portable Data logging Spectrophotometer HACHDR/4000 Method 8029 (SPADNS Method). Chloride was measured by the Mercuric Nitrate Titrimetric Method. A 25ml water samples was placed in an Erlenmeyer flask and then Diphenylcarbazone regent was added to the sample. The solution was blue-green, when the Mercuric Nitrate was added as a titrant, the solution turned to purple and made the end point of the titrant [4].

Cl=(M × M.Wt × 1000 × Number of ml of Hg (NO3)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 the Cadmium Reduction Method (Method 8039). The method used 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 the Nessler Method (Method 8038). Iron was measured by the Portable Datalogging Spectrophotometer HACH R/4000 and the method used was the FerroVer Method (Method 8008). Calcium was measured by the (EDTA) titrimetric method which involves the use of solutions of ethylene diamintitra acetic acid. A 25ml 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 turned from wine red to blue and made the end point of the titrant. The equation below gives the calculation of calcium [4].

Calcium= (M ×Wt× 1000×40 ×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 calculating the difference between the total hardness and the calcium hardness as follows:

Total hardness (as $CaCO_3$) = 2.497 [Ca^{2+}, mg/L] + 4.118 [$Mg^{2+,}$ mg/L].

Then:

4.118 [Mg^{2+}, mg/L] = Total hardness (as $CaCO_3$) - 2.497 [Ca^{2+}, mg/L] [4].

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

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

RESULTS AND DISCUSSION

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

pH: the pH mean values were statistically different among the boreholes (BH) as shown in Figure 3. The highest value of 7.4 was measured in BH8 whereas the lowest value of 7 was measured in BH5. [5] stated that the pH of natural water generally ranged from 5.5 to 8.6. Water with lower pH tended to cause corrosion and in many cases an upward adjustment to the neutral range (pH = 7.0) was necessary. Yet with all the discrepancies between pH readings, these results comply with the range values set by Yemen's Ministry of Water and Environment [6] and [7].

Electrical conductivity (EC) values showed significant differences (*P<0.05*) among all water samples. The highest value was recorded in BH10 (1198 µS/cm) whereas the lowest value was recorded in BH2 (827 µS/cm). According to [8], the importance of electrical conductivity is its measure of salinity, which greatly affects the taste and thus has a significant impact on

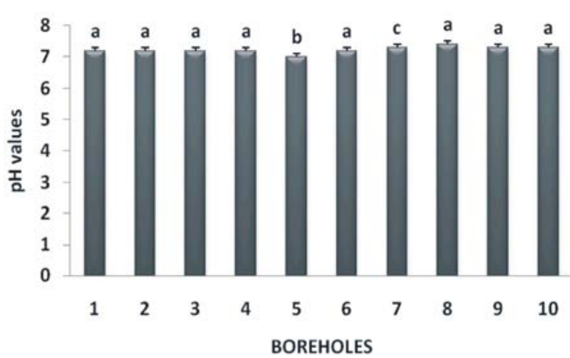

Fig 3: Mean values ± S.Dof pH in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

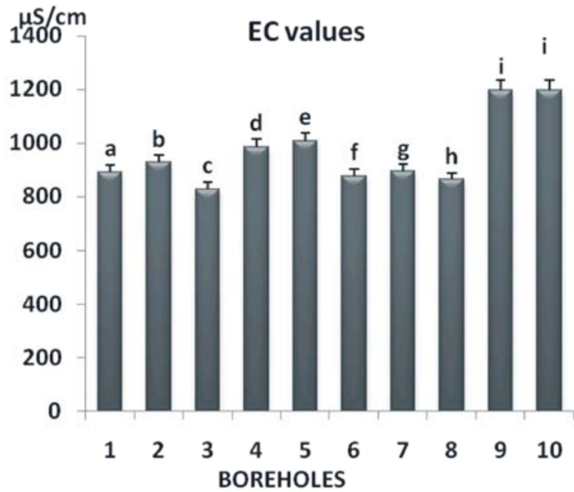

Fig 4: Mean values ± S.D of EC in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

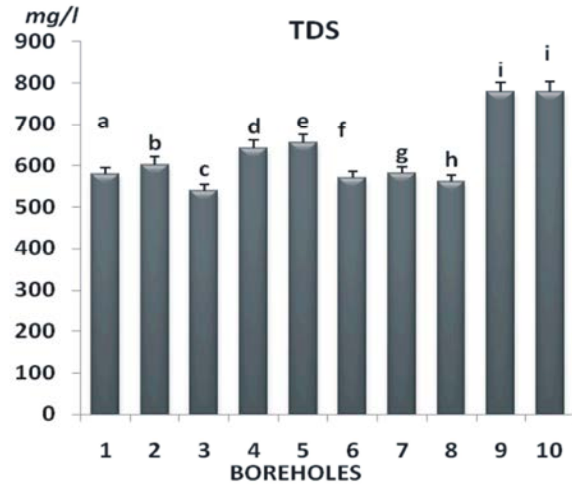

Fig 5: Mean values ± S.D of TDS in groundwater boreholes. Boreholes with different letters differ significantly.

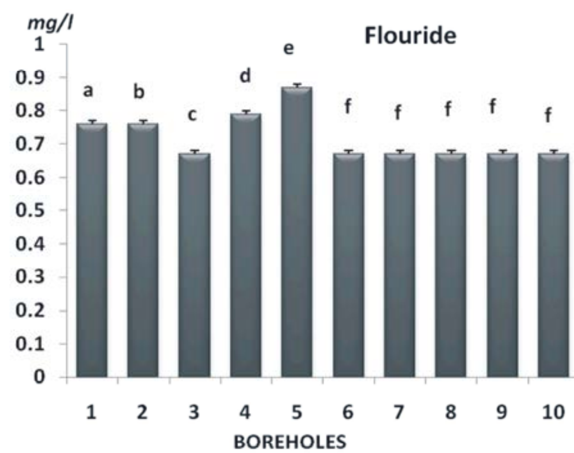

Fig 6: Mean values ± S.Dof F^- in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

user's acceptance of the water as potable. The high values of EC in BH 5, BH 9 and BH 10 were not within the range values of 450 to 1000µS/cm set by Yemen's Ministry of Water and Environment [6]. While, EC values in the other boreholes were within the Yemen standard value which is required for drinking water.

Total Dissolved Solids (TDS) Statistically were significant differences (*p<0.05*) among 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 were higher than the results 5005.5mg/l obtained by [9]. 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 [6] and [7] for drinking water. Due to the absence of pollution in this area (except 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, rocks and the depth of the boreholes.

Flouride Ion (F^-): Statistically, there were significant differences (*p<0.05*) in the concentrations of Fluoride ion among all boreholes, except 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 were normally recommended, although the actual amount in specific circumstances depended upon the air temperature, since air temperature influences the consumption [10]. In general, the values of F^- in all boreholes are in agreement with the acceptable standards of drinking water set by [6] and [7].

Chloride Ion (Cl^-): the results of Chloride ion analysis showed significant differences (*P<0.05*) among all water samples. These were lower than the acceptable standards of drinking water set by [6] and [7].for drinking water.

NO_2, NO_3 and NH_3-N: the concentrations of NO_2, NO_3 and NH_3-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 [6] and [7] standards

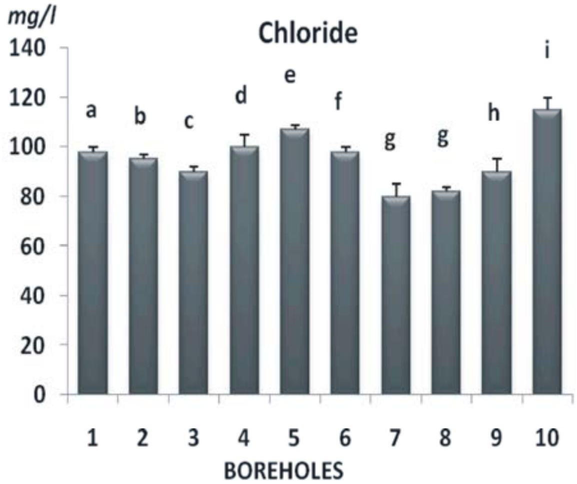

Fig 7: Mean values ± S.D of Cl^- in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

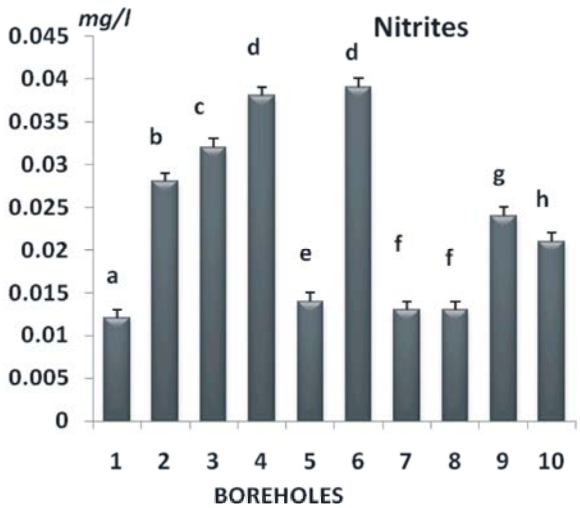

Fig 8: Mean values ± S.D of NO_2 in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

(0.1mg/l for NO_2, 50mg/l for NO_3 and 0.5mg/l for NH_3-N). It can be said that the concentrations of major anions and nitrogenous compounds at the studied area were below the acceptable standards of drinking water set by [6] and [7]. This indicates the absence 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.

Iron ion (Fe^{+2}): the obtained results of Iron concentration showed significant differences (*P<0.05*) for all analyzed water 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.

Calcium ion (Ca^{+2}): the obtained results of the calcium analysis showed significant differences (*P<0.05*) among all water samples and were in the range of (104 – 152 mg/l). By comparing these results with [6] and [7] guidelines, all water samples were within the [6] and [7] guidelines.

Magnesium ion (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 in all studied boreholes and were in quite low levels in relation with reported values by [6] and [7]. Moreover, they did not show any signs of pollution in the groundwater.

Total Hardness (TH): the concentrations of total hardness of 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 [6] and [7] guidelines (500mg/l), BH10 value was over the accepted standards.

According to [11], 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

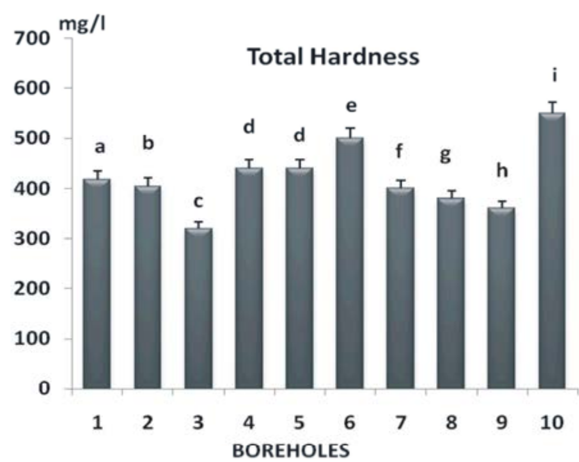

Fig 9: Mean values ± S.D of T.H in groundwater boreholes. Boreholes with different letters differ significantly, while boreholes with same letters do not differ significantly.

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: [11]

the cations pass over rocks containing sulphate ions. It means that water in all studied boreholes was very hard. 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.

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 [6] and [7] standards. BH 5 (1.12 mg/l) and BH10 (1.7 mg/l) showed the highest concentration of Copper (Cu) compared to the standards (1 mg/l) set by [6] and [7] and by contrast, these results were higher than the results obtained by [9].

CONCLUSIONS

This study has chemically and physically analyzed ten groundwater boreholes samples from Ibb. We have concluded 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 set by YMWE (1999) and WHO (2004) standards (1000 mg/l). These results were higher than the results 505.5mg/l obtained by Al-sabahi *et al*. (2008).

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

The highest concentration of cupper 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, rocks and the depth of the boreholes. Moreover, BH5, BH9 and BH10 are affected by the effluent of the wastewater treatment plant in Ibb City. This study concluded the effluent of the existing WWTP was the main reason causing this groundwater pollution. Therefore, it is suggested that the (WWTP) is either closed or its effluent is transferred further beyond the groundwater aquifer 20 km. Furthermore, the groundwater in the boreholes should be continuously monitored in order to prevent further ecological contamination and to guarantee public health.

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