Groundwater Exploitation and its Relation to the Water Quality Deterioration Conditions of Sana'a Drinking Water Supply

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ABSTRACT :

Yemen such a developing arid country suffers a lot of water-related health problems. The predominant health problems are still the communal diseases, which result from identifiable features of the environment, such as lack of water, lack of a protected water supply, and inadequate waste disposal.

Motivation for this study grew out of concern over groundwater drought and contamination in the Sana'a basin, Republic of Yemen, which have become recently some of the most important problems that require an intensive attention to be studied widely, and properly understood. Our paper is intended to study the chemical qualitative properties of Sana'a drinking water. Studies in this aspect received very little attention.

The analyses of 31 water samples taken from different sources of Sana'a drinking water supply indicate unacceptable levels of various samples concerning the Fluoride, Nitrate, Iron, and Sulphate. This causes serious problems by exceeding the maximum tolerable concentration given by WHO and National guideline values. Meanwhile there are numerous numbers of water samples of different origin, which possesses acceptable levels of the given common parameters shown in tables, which decided the quality of our drinking water in Sana'a. The variations in concentrations of the above four ions may be attributed to the nature of the geological and chemical structure of the rocks and soil for each region, the depth of the wells, as well as the contamination due to the west water disposal.

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NTRODUCTION

Water is the most important element in the nature, required for all living organisms to survive. Water is closely related to human health, man's activities and the environment. In arid countries, groundwater is the most important source of drinking water and agriculture. Pollution can impair the use of water and can create hazards to public health through high mineralization, toxicity or spreading of disease in the human body Water represents more than two thirds of the body weight.

The term, pure water, means ifferent hings o ifferent eople. Households are primarily concerned with domestic water problems related to colour, odour, taste, and safety to family health, as well as the cost of any treatment required for improving the water quality. Chemists and engineers working for industry are concerned with the purity as it relates to scale deposition and pipe corrosion. Regulatory agencies are concerned with setting standards to protect public health. Farmers are interested in the effects of irrigation waters on chemical, physical, and osmotic properties of soils, as they influence crop production. But, purity water means for all humans the water which is free from any substance that may affect human health or even cause unpleasant complaints to consumers. Water exists in nature in many forms; however, strictly speaking, pure water chemically does not exist for any appreciable length of time in nature. Even while falling as rain, water picks up small amounts of gases, ions, dust and particulate matter from the atmosphere. Then, as it flows over through the surface and through layers of the earth, it dissolves and carries with it some of almost every thing it touches, including that which is dumped into it by man. These added substances include industrial and commercial solvents, metal and acid salts, decaying animal and vegetable matter, fertilizers, pesticides, herbicides, radioactive materials and living pathogenic microorganisms. The impurities may give water a bad taste, colour, odour, or cloudy appearance 'turbidity' and cause hardness,

corrosiveness, staining, or frothing. They also may present a dangerous problem to health and may some times cause death (1-3).

The source of drinking water in Sana'a is only groundwater that can be contaminated through many routs. The main routs of ground water contamination are:- Interference of groundwater with sewage system.

- Houses rubbish materials.
- Agricultural fertilizers & pesticides.
- Erosion of tanks & pipeline materials during water distribution.
- Industrial waste materials.
- Water deficiency that increases the concentration of the contaminants.

The study of water pollution is a very wide field, of which we are interested only in the inorganic chemical substances found in our drinking water, particularly the 12 ions that are common in our environment. These are (a) Anions: Including, carbonates (CO_3^{-2}), bicarbonates (HCO_3^-), chloride (Cl^-), sulfate (SO_4^{-2}), nitrate (NO_3^-), and fluoride (F^-). And (b) Cations: Including, sodium (Na^+), potassium (K^+), magnesium (Mg^{+2}), calcium (Ca^{+2}), iron (Fe^{+2}, Fe^{+3}), and copper (Cu^+, Cu^{+2}).

Some of these ions are very essential in our nutrition (4). So, their presence in drinking water is preferable, but in levels below their maximum tolerable concentration, which is the concentration above which, the ion may cause harmful effect to the human body either within short term drinking of water (acute toxicity) or, after long period of water consumption (chronic toxicity). The problems associated with chemical constituents of drinking water arise primarily from their ability to cause adverse health effects after prolonged periods of exposure, of particular concern are those cumulative toxic properties, such as heavy metals, and carcinogenic substances. Cancers, cardiovascular problems, gastrointestinal abnormalities, urinary tract disorders, central nervous system disorders and many other health problems are induced mainly by

water contamination with toxic chemicals (5,6). The maximum tolerable concentration of certain pollutants is determined according to WHO guideline value and in the literatures of the National water resources authority.

MATERIALS AND METHODS

During our research We used the following materials and instruments: HACH DR 2000 Spectrophotometer; pH Digital 520; Eijkel Kamp digimeter L21 Conductometer; Sensitive Electric Balance; Flameno Photometer MDC; Automatic Titrators; and different Metal indicators.
Most of the metal ions are analyzed and determined by using metallochromic indicators, then measured spectrophotometrically, few other were determined by using flame photometer while the remaining ions were analyzed by titration methods, CO_3^{-2}, HCO_3^-, Ca^{+2}, Mg^{+2}, and Cl^-, where determined by titration methods (Digital titrator), while Iron, and Copper ions were determined spectrophotometrically by using 1,10 phenanthroline, Bicinchoninate indicators respectively.

Fluoride ion was determined by using SPADNS reagent by spectrophotometric method. Nitrate and sulphate ions as well were determined spectrophotometricly by using Nitraver 5, Sulfave 4 indicators, respectively.

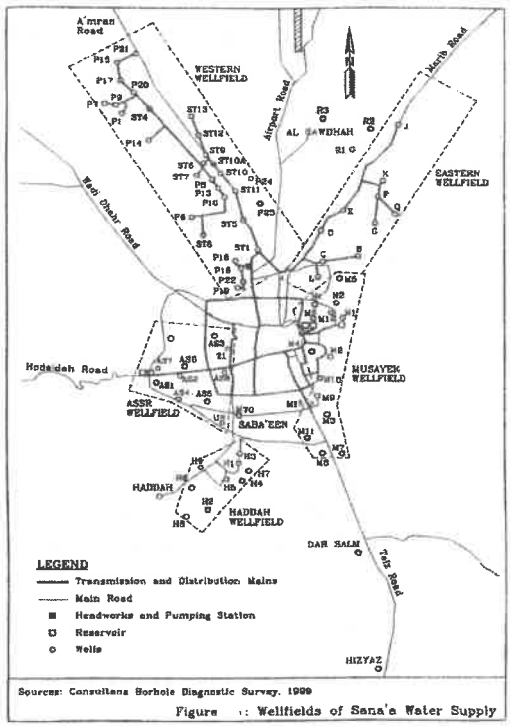
All samples were collected carefully after the pump has run long enough to deliver water representative of the groundwater feeding the well. Polyethylene containers were used for storage purposes. The determinations were done within 24 hours and kept at 4^0 C. Redistilled water were used for all our preparations and determinations. Temperature at the time of the determinations was 20 – 25^0 C.

CASE STUDY PRINCIPLES

There are hundreds of sources of Sana'a drinking water (Fig.1). These sources are classified to many classes. In the selection of the samples that are intended to be analysed in our study work, we try to cover all those classes, 31 chosen samples are classified as follows:

1. Bottled water

This class of drinking water includes treated water that is bottled, and marketed. The ten samples of this source are sub-divided into two types according to the techniques of their treatment:



Sources: Consultans Borhole Diagnostic Survey. 1999

Figure : Wellfields of Sana'a Water Supply

a. Completely treated mineral bottled water

Water from this source is supposed to be treated by high-developed techniques in special factories to insure a high degree of suitability to human consumption according to the international standards . Samples from the five types consumed in Sana'a are collected and categorized into:
1. Samples whose sources are located in Sana'a city:
Sample no.1 Hadda mineral water, Sample no.2 Shamlan mineral water.
2. Samples whose sources are outside Sana'a basin:
Sample no. 3 Nakhlan mineral water, from Ibb governorate
Sample no. 4 Ma'arib mineral water, from Ma'arib governorate and
Sample no. 5 Alhayah mineral water, from Dhamar governorate.

b. Partially treated bottled water:
The water from these sources is bottled and marketed in indisposable containers. They are commonly used in most Yemeni cities. Five samples are collected from this type, numbered from 6-10. These samples are:
Sample no. 6 Alkods treated water: The station of treatment is located in Ma'arib street, the source of water is shandak's well which is located in Sa'awan with depth of 350 m.
Sample no. 7 Alferdows treated water, Sample no. 8 Alkowther treated water, Sample no. 9 Dhahban treated water, and Sample no. 10 Almoayad treated water.

2. Private wells:
Samples collected from this source are five, given the numbers from 11 to15. Many regions in Sana'a are dependent on private wells as a main source for drinking water (45% of the population), because the governmental network distribution hasn't reached these regions yet or due to the frequent cut.
The following table (I) gives some information about the five private wells included in the analytical work:

Table (I) Shows the areas of the analyzed private wells

Sample no.	11	12	13	14	15
Well's name	Senan	Alfusail	Alfelahi	Shumailah	Mathbah
Location	60 street	Aljeraf	Old city	Taiz street	Mathbah

3. Governmental drinking water supply:

This is the most common source of drinking water in Sana'a city (55% of the population). It is distributed under the supervision and control of the National Water and Sanitation Authority (NWSA)-Sana'a branch. Sixteen samples are collected from this source, with the numbers from 16-31. We chose the samples randomly to incorporate the whole capital. Those samples are of two types:

a. Samples collected directly from the wells:

These are six samples, which are given the numbers 16 to 21. Some information about these wells is illustrated in the following table (II):

Table (II) shows the areas of the analyzed governmental wells

Sample no:	16	17	18	19	20	21
Well name	Alkadisiah	Almontaza	22 May Garden	Alssabeen Garden	Alttaiseer	Old Sana'a University
Location	Taiz street	Nokom	North 60 street	45 street	Riadh street	Old Sana'a University

b. Samples collected from the houses taps:

These samples have the numbers 22 to 31 and collected from different regions of the city that involve all directions of Sana'a city.

*Results of individual samples analysis are presented in Appendix A.

RESULTS AND DISCUSSION

1. Mineral water samples:

Table III: Determination of various parameters for completely treated bottled water.

Parameters	WHO	Yemen standard	Results
PH	6.5 - 8.5	6.5 - 8	7.53 - 8.07
EC μS/cm	--	400 - 800	182 - 432
TDS mg/l	1000	Max. 650	118 - 281
$HCO3^-$ mg/l	250	Max. 240	53.7 - 214.7
TH(Ca Co_3) mg/l	500	Max. 200	12 - 162
Ca^{+2} mg/l	2.4 - 46.6	Max. 65	3.2 - 49.7
Mg^{+2} mg/l	--	Max. 20	0.97 - 19.43
Cl^- mg/l	250	Max. 200	16.7 - 31.5
Na^+ mg/l	200	42 - 90	25.7 - 52.4
K^+ mg/l	--	1.7 - 4.5	0.30 - 2.33
Fe^{+2} mg/l	0.3	Max. 0.3	0.00 - 0.05
So_4^{-2} mg/l	250	Max. 200	4 - 35
No_3^- mg/l	23	Max. 7.8	3.25 - 16.72
Cu^{+2} mg/l	1	Max. 0.5	0.00 - 0.32
F^- mg/l	0.5 - 1.5	0.6 - 1	0.11 - 1.30

Fluoride ion: The results of analysis of Fluoride contents showed that its concentration is lower than the minimum level of the Yemen standard concentration range in the: Nakhlan (0.11 mg/l), Ma'areb (0.15 mg/l), and Alhayah (o.46 mg/l). This may enhance fluoride deficiency, especially in children or old persons, and may lead to some dental health problems (7-9).

In Hadda treated water, fluoride concentration exceeds the maximum level, which may cause fluorosis. Fluoride concentration in Shamlan is just

near the minimum level, which may causes caries. These results are not suitable to what is considered to be as mineral water in Yemen. According to WHO guideline values, fluoride concentration of Nakhlan, Ma'arib, Alhayah, is lower than the required level, these sources require fluoridation.

Nitrate ion: Nitrate ion concentration is an indication of bacterial growth in water, where it increases due to nitrogen fertilizing. The typical nitrate ions concentration is < 50 mg/l in drinking water, especially in chlorinated supplies and mineral water (5,10).

What makes us feel concerned is when we find that the nitrate ion concentration has exceeded the maximum level of mineral water standard, which is supposed to be treated by modern or recent methods for the sake of getting complete or high purity (see table 1 in appendix A).

Nakhlan (13.64 mg/l), Ma'areb (16.72 mg/l), Alhayah (6.2 mg/l) and Shamlan (4.84 mg/l). Hadda (3.52 mg/l) is the best of five samples in nitrate ion concentration.

Total Hardness (TH): Total hardness results are in the range (12 - 162 mg/l) as shown in table 1, by comparing these results with WHO guideline value (500 mg/l), all samples are within the limits of WHO. Sample no. 5 showed the highest total hardness "medium hard water" (162 mg/l), while sample No. 3 show the lowest total hardness "soft water" (12 mg/l). Sample no. 5 is hard because it has the largest value of Ca^{+2} (49 mg/l) and large amount of Mg^{+2} (13.09 mg/l). Other results are conforming with both WHO & Yemen standards (4,11).

2. Partially treated water samples:

Table IV: Determination of various parameters for partially treated water samples.

Parameters	WHO	Yemen standard	Results
PH	6.5 – 8.5	6.5 – 8.5	7.82 – 8.55
EC μS/cm	--	Max. 1000	367 - 658
TDS mg/l	1000	Max. 1000	239 - 428
$HCO3^-$ mg/l	250	Max. 350	73.2 – 243.8
TH(as$CaCO_3$)mg/l	500	Max. 300	32 - 190
Ca^{+2} mg/l	2.4 - 46.6	Max. 85	9.6 – 44.9
Mg^{+2} mg/l	--	Max. 30	1.93 – 18.94
Cl^- mg/l	250	Max. 300	20 – 130
Na^+ mg/l	200	Max. 200	31.6 – 135.6
K^+ mg/l	--	Max. 12	1.08 – 3.57
Fe^{+2} mg/l	0.3	Max. 0.7	0.00 – 0.04
So_4^{-2} mg/l	250	Max. 300	31 - 45
No_3^- mg/l	23	Max. 45	3.74 – 31.24
Cu^{+2} mg/l	1	Max. 0.7	0.005 – 0.065
F^- mg/l	0.5 – 1.5	Max. 1	0.52 – 0.88

pH: The pH range is between (7.82 - 8.55) as seen in table IV. Sample no. 8 has the highest value (8.55). Sample no. 10 showed the lowest value 7.82, (see table 2 in appendix A). When we compare this range (7.82 – 8.55) with WHO range, which is (6.5 - 8.5) we found that most samples are within the limits of WHO, only sample no. 8 which has pH 8.55, is significantly higher value than WHO and this result is due to CO_3^{-2} ion concentration.

Nitrate: The highest value of NO_3^- concentration is found in sample no. 7 where the concentration is 31.24 mg/l, and the lowest value is found in sample no. 9 where the concentration is 3.79 mg/l. The concentration of

NO_3^- in other samples (6, 8, 9, &10) are within the range of WHO values (5,10).

Fluoride: The higher F^- concentration is found in sample no. 6 where the concentration is 0.88 mg/l, and the lower F concentration is found in sample no. 7 where the concentration is 0.52 mg/l i.e. all samples are located within the WHO range.

Total Hardness (TH): Results of total hardness are in the range (32 - 190 mg/l), by comparing with WHO value (500 mg/l); all samples are within the limits of WHO. Sample no. 9 showed the highest total hardness "medium hard water" 190 mg/l, while sample no. 8 showed the lowest total hardness "partial soft water" 32 mg/l. Sample no. 9 is hard because it has the largest value of Ca^{+2} (44.9 mg/l) and Mg^{+2} (18.94 mg/l). This value is within the WHO limit. Other results are conforming with both WHO & Yemen standards.

3 Private well samples :

Table V: Determination of various parameters for private well samples.

Parameters	WHO	Yemen standard	Results
PH	6.5 - 8.5	6.5 - 9	7.35 - 8.31
EC μS/cm	--	450 - 2500	434 - 1234
TDS mg/l	1000	650 - 1500	242 - 802
$HCO3^-$ mg/l	250	150 - 500	139.1 – 268.4
TH ($CaCO_3$) mg/l	500	100 - 500	104 - 280
Ca^{+2} mg/l	200	75 - 200	32.1 – 89.8
Mg^{+2} mg/l	--	30 - 150	6.55 – 20.38
Cl^- mg/l	250	200 - 600	48.6 – 186.8
Na^+ mg/l	200	Max. 400	52.8 – 159.8
K^+ mg/l	--	8 - 12	1.56 – 5.36
Fe^{+2} mg/l	0.3	0.3 - 1	0.050 – 0.360
So_4^{-2} mg/l	250	200 - 400	49 - 223
No_3^- mg/l	50	10 – 50	3.02 – 45.54
Cu^{+2} mg/l	1	0.5 - 1	0.02 – 0.54
F^- mg/l	0.5 – 1.5	0.5 – 1.5	0.28 – 1.31

Iron ion: The obtained results of analysis of Iron ion concentration as shown in table V ranged between (0.05 - 0.36 mg/l); most of them fall within the permissible level, except in sample 13 which showed higher concentration than the permissible level set by WHO (12).

Nitrate ion: The obtained results of analysis for Nitrate concentration gave a range between (3.02 - 45.54 mg/l) i.e. no risk for health. However, sample no. 13 for prolonged consumption of NO_3^- concentration above 50 mg/l may lead to health hazardous effects, so this must be kept in mind to prevent such amount in NO_3^- concentration.

Fluoride ion: The results of analysis of fluoride showed low fluoride concentration ranging between (0.28–1.31mg/l). Fluoride concentration in samples no. 11&15 is within the range, but Fluoride concentration in samples no. 12 (0.34mg/l), 13 (0.47 mg/l), & 14 (0.28 mg/l) have values lower than the required level, so this may cause probable risk specially in children and olds.

Total hardness (TH): The obtained results are in the range (104 – 280 mg/l), as shown in table III, by comparing with WHO guideline value 500 mg/l, all samples fall within the limits of WHO. Sample no. 12 showed the highest total hardness (280 mg/l) "hard water", while sample 14 showed the lowest total hardness (104-mg/l) "low hardness water". Sample no. 12 is hard because it has a large value of both Ca^{+2} (78.5 mg/l), and Mg^{+2} 20.38 mg/l.

4. Governmental well samples:

Table VI: Determination of various parameters for Governmental well samples

Parameters	WHO	Yemen standard	Results
PH	6.5 – 8.5	6.5 – 9	7.56 – 8.81
EC μS/cm	--	450 - 2500	395 - 1160
TDS mg/l	1000	650 - 1500	275 - 754
$HCO3^-$ mg/l	250	150 - 500	150.8 – 297.8
TH ($CaCO_3$)mg/l	500	100 - 500	84 - 233
Ca^{+2} mg/l	200	75 - 200	28.9 – 73.8
Mg^{+2} mg/l	--	30 - 150	0.73 – 11.83
Cl^- mg/l	250	200 - 600	26.8 – 180.1
Na^+ mg/l	200	Max. 400	32.8 – 232
K^+ mg/l	--	8 - 12	1.30 – 2.73
Fe^{+2} mg/l	0.3	0.3 - 1	0.01 – 1. 05
So_4^{-2} mg/l	250	200 - 400	41 - 665
No_3^- mg/l	50	10 – 50	1.76 – 49.3
Cu^{+2} mg/l	1	0.5 - 1	0.02 – 0.28
F^- mg/l	0.5 – 1.5	0.5 – 1.5	0.25 – 1.21

pH: The highest value is 8.81 for sample no. 18 and the lowest value is 7.56 for sample no. 17,(see table 4 in appendix A), which showed that only sample no. 18 is out of the WHO range.

Bicarbonate ion: The highest value is 297.8 mg/l for sample no. 20 and the lowest value is 150.8 mg/l for sample no. 18, so only sample no. 20 is out of the WHO range.

Sodium ion: The highest concentration of Na^+ was obtained in sample no. 20, where the concentration is 232.0 mg/l, and the lowest concentration in sample no. 19 where concentration is 32.8 mg/l. From the comparison of these results with WHO values, we found that only sample no. 20 showed higher level than WHO concentration. This may cause healthy hazardous especially to those suffer from cardiovascular problems.

Nitrate ion: The highest value of NO_3^- concentration was found in sample no. 21 where the concentration is 49.30 mg/l, and the lowest is present in sample no. 20, where the concentration is 1.76 mg/l, by comparison of this value with WHO value we found that, sample no. 21 is just 0.7 mg/l, below the permissible WHO level, this sample may be of high risk to those when they consume this type of drinking water for prolong period of time, chronic drinking water containing as much as 49.30 mg/l may increases the carcinogenic effects, which leads to Cardiovascular problems among the consumers.

Fluoride ion: The highest value of (F^-) concentration was found in sample no. 17 (1.21 mg/l), while the lowest concentration is found in sample no. 19 (0.25 mg/l). By comparison of those values with WHO values we found that samples 16, 18, & 20 are within the range, but samples 19 & 21 are below the range of WHO value (0.5 – 1.5 mg/l), which may causes caries on prolonging consumption.

Total Hardness (TH): Results of total hardness are in the range (84 - 233 mg/l), as shown in table IV, by comparing with WHO guideline value 500 mg/l, all samples are within the limits of WHO. Sample number 17 showed the highest total hardness concentration (233 mg/l) "hard water", while sample no. 20 the lowest total hardness of 84 mg/l "partial soft water". Sample 17 was hard because it has the largest value of both Ca^{+2} (73.8 mg/l), and Mg^{+2} (11.83 mg/l).

Sulphate ion: The highest concentration was obtained in sample no. 21 (665 mg/l), and the lowest concentration is in sample no. 16 (41 mg/l), sample no. 21 falls far above upper permissible WHO value 250 mg/l (13,14).

5. Houses tap water samples:

Table VII: Determination of various parameters for houses tap water samples.

Parameters	WHO	Yemen standard	Results
PH	6.5 – 8.5	6.5 – 9	7.60 – 8.21
EC μS/cm	--	450 - 2500	423 - 748
TDS mg/l	1000	650 - 1500	275 - 486
$HCO3^-$ mg/l	250	150 - 500	127 – 278
TH (Ca Co_3) mg/l	500	100 - 500	128 - 284
Ca^{+2} mg/l	200	75 - 200	33 – 502
Mg^{+2} mg/l	--	30 - 150	10.6 – 21.35
Cl^- mg/l	250	200 - 600	28.5 – 77.1
Na^+ mg/l	200	Max. 400	43.3 – 67.6
K^+ mg/l	--	8 - 12	2.37 – 7.70
Fe^{+2} mg/l	0.3	0.3 - 1	0.01 - 1. 4
So_4^{-2} mg/l	250	200 - 400	34 - 175
No_3^- mg/l	50	10 – 50	1.51 – 19.3
Cu^{+2} mg/l	1	0.5 - 1	0.015 – 0.421
F^- mg/l	0.5 – 1.5	0.5 – 1.5	0.10 – 1.32

Bicarbonate ion: The results of bicarbonates concentrations ranged between (127 - 278 mg/l) as shown in table VII, most of the samples are within the range. However, sample no. 26 exhibits higher concentration than the WHO permissible level.

Iron ion: The results of Iron levels ranged from 0.01 - 1.4 mg/l. So that most of samples are within the range. However, the samples number 29, 24, 23, and 26 showed higher concentration than the permissible. This may be attributed to the corrosion of the pipe line network.

Fluoride ion: The results of Fluoride levels ranged between (0.01 - 1.32 mg/l) as seen in table V, most of samples are within the range. However, the following samples 24 (0.42 mg/l), 30 (0.15 mg/l), and 31 (0.10 mg/l) showed lower concentration than the permissible WHO level.

Total Hardness (TH): Total hardness results of houses tap water were in the range between (150 – 284 mg/l), by comparing with WHO guideline value 500 mg/l, all samples are within the limit of WHO. The samples 23 & 24 showed the highest total hardness "Hard water" (284 mg/l), while sample number 25 showed the lowest total hardness "Partial soft water" (150 mg/l). The total hardness values of samples 23 and 24 are due to the large values of Ca^{+2} (80.2 mg/l), and Mg^{+2} (20.34 mg/l). Other results are conforming with both WHO & Yemen standards.

CONCLUSIONS

After the analysis of the 31 samples and the discussion of the obtained results, we concluded the following points:

pH: The pH results of the 31 samples are between (7.35 - 8.81) with average pH = 7.95. Most of the results are within the permissible WHO range (6.5 – 8.5). From the 31 samples, only two samples showed higher pH value due to the presence of high concentration of carbonates. These two samples are: Sample 8 "Al-kawther treated water" pH=8.55, and sample 18 "Houses tap water" pH=8.81.

Total Hardness (TH): The results of the 31 samples showed values between (12 - 284 mg/l); with average TH of "158.2 mg/l", i.e. all the results are within the permissible WHO range.

The TH results of mineral water were in the range of 12 - 162 mg/l, with average TH=79.2 mg/l i.e. the results showed that the water is between "soft water and hard water". Alhayah (TH= 162 mg/l), and Shamlan (TH=140 mg/l), are hard, while other water samples are soft waters. Nakhlan is the softest water (TH=12 mg/l).

For the partially treated water, the results showed TH between (32 – 190 mg/l), with average TH value of 122.4 mg/l. Dhahban water is "very hard", Almoaed is "hard", Alkods and Alferdaws waters are of intermediate hardness, while Alkowther is soft water.
For private wells, the results ranged between (104 - 208 mg/l). With average TH= 184.6 mg/l.

For the governmental wells, the results are ranged between (84 - 233 mg/l), with average of 143.8 mg/l.

For the houses tap water the results are between (128 – 284 mg/l), with average TH=216.1 mg/l.

So, by comparison according to total hardness, mineral water samples showed the lowest total hardness values followed by partially treated water, governmental wells, private wells and finally houses tap waters which are the hardest samples.

Iron: The obtained results showed that iron is found in Sana'a groundwater in trace amount, that is much lower than the permissible WHO range.

1. Houses tap water, because of the distribution network of most regions of Sana'a is very old. Pipe corrosion takes place which increases the concentration of iron in drinking water. High concentration of iron above 0.3 mg/l appears in 40% of the houses tap water samples.

2. In Alfelaihe private well iron concentration is slightly higher than the allowed WHO range, it is 0.36 mg/l, indicating that iron is found naturally in groundwater of the region around Alfelaihi well in the old city.

Nitrate: The results showed variable concentration of nitrate in the samples, ranged between (1.15 – 49.30 mg/l), with average NO_3^- concentration of 12.14 mg/l. We found that the lowest NO_3^- concentration was reported in the mineral water samples ranging between (3.52 – 16.72 mg/l).

Houses tap water samples, with exception of samples no. 30 (16.28 mg/l) & no. 31 (19.30 mg/l) that are collected from some houses in the new university region of Sana'a, the obtained results showed the lowest concentration in Sana'a basin, range between (1.51 – 12.32 mg/l). The mineral water samples were ranged between (3.52 – 16.72 mg/l) with average of 8.912 mg/l. Partially treated water ranged between (3.74 – 31.24 mg/l) with average of 10.728 mg/l, and Private wells from (3.02 – 45.54 mg/l), with average of 12.968 mg/l. And finally the highest NO_3^- is reported in the governmental wells (1.76 – 49.30 mg/l) with average of 18.745 mg/l.
Samples no. 13 "Alfelaihi", and no. 21 "governmental well", showed high NO_3^- concentration, 45.54 and 49.30 mg/l respectively which are very

closely to the upper limit of WHO 50 mg/l, and may causes very serious effects on human health. These samples and other sources of water of high NO_3^- concentration require specific treatment to decrease or even prevent the increase of nitrate concentration. Nitrate concentration in Nakhlan and Ma'areb mineral waters should be reduced to be suitable for completely treated water according to Yemen standards (7.8 mg/l).

Fluoride: Fluoride levels in our samples were mostly lower than the required WHO level (0.5 mg/l). We summarised our results and discussion as follows:

The obtained results are ranged from (0.1 – 1.32 mg/l), with average of 0.617 mg/l; 11 samples that are reported to have a deficiency in fluoride concentration below 0.5 mg/l; 26 samples that are reported to have lower fluoride concentration than the optimal concentration which is around 1 mg/l.

The arrangement of the several types of samples were unexpected; the best results are reported for the partially treated water (F^-) ranges between (0.52 – 0.88 mg/l) with average of 0.646 mg/l. There is no deviation from WHO range.

Houses tap water results showed (F^-) concentration between (0.1 – 1.32 mg/l) with average of 0.6 mg/l. The number of samples deviated from the WHO range are 3 samples.

Governmental wells showed F^- concentration ranging between (0.25 – 1.21 mg/l) with average of 0.698 mg/l. There are two samples deviated from the WHO range.

Private wells have occupied the third rank of safety, the obtained results were ranged from (0.28 – 1.3 mg/l), with average of 0.624 mg/l. There are three samples deviated from the WHO range.
Mineral waters were found to be the lowest in fluoride concentration ranging from (0.15 – 1.31 mg/l), with average of 0.52 mg/l. Only two

samples are located in the permissible WHO range that are shamlan F^- = 0.58 mg/l, and Hadda F^- = 1.31 mg/l. However, these two samples are out of the permissible Yemen standard, that were from 0.6 – 1 mg/l for completely treated water. I.e. only Shamlan and Hadda were in the permissible WHO range for fluoride level, while Nakhlan, Ma'areb and Alhayah are out of the range.

Finally we tried to boiled one of the houses tap water samples, followed by cooling and filtration in commercial house hold water filter (sample 31), see table 5, appen. A.

The quality of drinking water decreases from right to left as follows:
Hadda > Shamlan > Alhayah > Nakhlan > Ma'areb.

The comparison between the five partially treated bottled water samples indicated the following points:

Alkods was proved to be the best quality according to WHO standard.
Alferdaws has the highest Nitrate concentration and the lowest in Fluoride concentration, so it is not acceptable.

Almoaed has the lowest level of SO_4^{-2} and Cl^- concentrations.

Thahban has the lowest iron ion concentration, and the highest level of total hardness. And Alkowther has the highest pH & E.C. values.

At the end of our conclusion we can recommend the following points to support the improvement of the water supply in Sana'a city:-

* Establishing specialized laboratories for quality control of drinking water either for private wells or treated water and conformity of them to health standards.

* Government must support scientific research, which illustrates relationship between some of the health problems, and the water used in the same region.

* Manufacturers of the treated water bottles must be responsible for the agreement between actual concentration of ions content, to comply with the regulations.

* Improvement of the environmental hygiene and health education programs.

REFERENCES

1. WHO, 1985, Standards Methods for Examination of Water and Waste Water, 16th edition.
2. WHO, 1998, Guidelines for Drinking Water Quality 2nd edition, Vol. 1&2, Authorized report Geneva.
3. Fara Mohamed, 1999, Groundwater Exploitation and its Relation to the Environmental Deterioration Conditions of Aquifers in Yemen, XXIX Congress of IAH, Bratislava, Slovakia.
4. WHO, 1973, (Technical Report Series, No. 532). Trace elements in human nutrition: Report of a WHO Expert Committee, Geneva, World Health Organization.
5. WHO, 1985, Regional office for Europe, Health hazards from nitrate in drinking water, Report on a WHO meeting, Copenhagen 5-9 march, 1984. (Environmental Health Series, No.1).
6. Environmental Protection Agency, July 1976, Quality Criteria for Water, USA.
7. Office of drinking water, 1985, Drinking water criteria, Document on fluoride, Washington DC, US, Environmental protection Agency,(TR-823-5).
8. Murray, ed. 1986, Appropriate use of fluorides for human health, Geneva, World Health Organization.
9. National Academy of sciences, 1977, Drinking water and health, Washington, DC, National Academy, press (400 – 411).
10. Office of Drinking Water, 1987, estimated national occurrence and exposure to nitrate and nitrate in public drinking water supplies. Washington, DC, US, Environmental Protection Agency.
11. Nerilc et. al, 1985, Magnesium and certain other elements and cardiovascular disease, science of the total environment, 4249 – 75.

12. International organization for standardization water quality, 1988, Determination of Iron, Geneva, (ISO 6332 - 1988).
13. International organization for standardization water quality, 1990, Determination of Sulphate, Geneva, (ISO 9280 - 1990).
14. UNEP/ WHO/UNESCO/WMO/GEMS, 1990, Water data summary (1985 - 1987), Barlington, Canada, Center for inland waters.

RESULTS OF SAMPLES ANALYSIS (Appendix A)

Table (1) The analytical results of the completely treated samples

	WHO	Yemen Std.	Hadda	Shamlan	Nakhlan	Maareb	Alhayah
Sample No.			1	2	3	4	5
Temp. C^0	---	8--25	20	24	23	22	22
pH	6.5—8.5	6.5—8.5	8.07	7.76	7.53	7.56	7.87
E.C. (μS/cm)	---	400--800	182	287	211	204	432
T.D.S. (mg/l)	1000	650	118	187	137	133	281
Ph.A (mg/l)	----	---	0	0	0	0	0
CO_3^{-2} (mg/l)	----	---	0	0	0	0	0
T.A. (mg/l)	200--250	---	48	112	72	44	176
HCO_3^{-2} (mg/l)	250	240	58.6	136.6	87.8	53.7	214.7
Ca^{+2} (mg/l)	24—46.6	65	3.2	24.1	3.2	12.8	49.7
T.H. (mg/l)	500	200	36	140	12	46	162
Mg^{+2} (mg/l)	---	20	6.80	19.43	0.97	3.40	13.09
Cl^- (mg/l)	250	200	37.2	30.2	31.5	27.8	16.7
Na^+ (mg/l)	200	42--90	36.8	25.7	52.4	29.6	26.4
K^+ (mg/l)	---	1.7—4.5	0.31	2.33	0.30	2.10	2.01
(Fe^{+2}-Fe^{+3})	0.3	0.3	0.000	0.010	0.000	0.050	0.010
SO_4^{-2} (mg/l)	250	200	16	35	4	21	25
NO_3 (mg/l)	23	7.8	3.25	4.48	13.64	16.72	6.20
Cu^{+2} (mg/l)	1	0.5--5	0.040	0.030	0.000	0.020	0.320
F^- (mg/l)	0.5—1.5	1	1.30	0.58	0.11	0.15	0.46

Table (2): The analytical results of the partially treated samples

	WHO	Yem. Std.	Alkods	Alferdaws	Alkwther	Dhahban	Almoaed
Sample No.			6	7	8	9	10
Temp. C^0	---	8--25	22	22	23	23	22
pH	6.5—8.5	6.5—8.5	7.89	8.05	8.55	7.94	7.82
E.C. (μS/cm)	---	300--1000	367	656	658	467	425
T.D.S. (mg/l)	1000	100	239	426	428	304	276
Ph.A (mg/l)	----	---	0	0	22	0	0
CO_3^{-2} (mg/l)	----	---	0	0	26.4	0	0
T.A. (mg/l)	200--250	---	98.8	133	104	200	383
HCO_3^{-2} (mg/l)	250	350	120.5	162.3	73.2	243.8	229.4
Ca^{+2} (mg/l)	24—46.6	8.5	36.1	16.0	9.6	44.9	38.8
T.H. (mg/l)	500	300	116	60	32	190	164
Mg^{+2} (mg/l)	---	30	6.29	4.83	1.93	18.94	16.18
Cl^- (mg/l)	250	300	36.0	82.9	130.0	22.6	20.0
Na^+ (mg/l)	200	200	31.6	123.2	135.6	33.0	36.3
K^+ (mg/l)	---	12	1.41	1.08	1.28	3.50	3.75
(Fe^{+2}-Fe^{+3})	0.3	0.7	0.040	0.010	0.025	0.000	0.015
SO_4^{-2} (mg/l)	250	300	36	45	41	40	31
NO_3^- (mg/l)	23	45	6.56	31.24	7.48	3.74	4.62
Cu^{+2} (mg/l)	1	0.7	0.045	0.005	0.015	0.065	0.025
F^- (mg/l)	**0.5—1.5**	**1**	**0.88**	**0.52**	**0.59**	**0.59**	**0.65**

Table (3): The analytical results of the private wells samples

	WHO	Yem. Std.	Senan	Alfusail	Alfeliahi	Shumila	Mathbah
Sample No.			11	12	13	14	15
Temp. C^0	---	25	24	23	23	22	23
pH	6.5—8.5	6.5--9	8.31	7.35	7.84	8.17	8.27
E.C. (μS/cm)	--	450--2500	509	748	1234	434	541
T.D.S. (mg/l)	1000	650--1500	331	486	802	242	352
Ph.A (mg/l)	----	---	0	0	0	0	0
CO_3^{-2} (mg/l)	----	---	0	0	0	0	0
T.A. (mg/l)	200--250	---	148	220	122	114	146
HCO_3^{-2} (mg/l)	250	150--500	180.6	268.4	148.8	139.1	178.1
Ca^{+2} (mg/l)	200	75--200	33.7	78.5	89.8	32.1	45.5
T.H. (mg/l)	500	100--500	126	280	272	104	141
Mg^{+2} (mg/l)	---	30--150	10.9	20.38	11.58	8.73	6.55
Cl^- (mg/l)	250	200--600	67.0	67.0	186.8	46.9	48.6
Na^+ (mg/l)	200	400--400	84.6	52.8	159.8	63	61.7
K^+ (mg/l)	---	8--12	2.88	2.80	2.83	1.56	5.36
(Fe^{+2}-Fe^{+3})	0.3	0.3--1	0.050	0.080	0.360	0.060	0.160
SO_4^{-2} (mg/l)	250	200--400	49	90	223	66	70
NO_3^- (mg/l)	50	10--50	7.92	4.40	45.54	3.96	3.02
Cu^{+2} (mg/l)	1	0.5--1	0.050	0.540	0.370	0.020	0.110
F (mg/l)	0.5—1.5	0.5—1.5	0.72	0.34	0.47	0.28	1.31

استنزاف المياه الجوفية وعلاقته بظروف تدهور نوعية إمدادات مياه الشرب في صنعاء

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خلاصـــة :

كان الدافع الرئيس لأجراء هـذا البحـث هـو إعطـاء الاهتمـام الـلازم لنضـوب الميـاه الجوفيـة والتلوث في حوض صنعاء. الأمر الذي جعل هذا الموضوع على رأس المشاكل التي تستلزم إجراء دراسـات وبحـوث ميدانية شاملة واهتمام لاستيعابها والخروج بحلول مناسبة لها. إن بحثنا هذا موجه لدراسة الصفات النوعيـة الكيميائيـة لمياه الشرب في صنعاء.

إن نتائج تحليل إحدى وثلاثين عينة جمعت من مصادر مختلفة لمياه الشرب في مدينة صنعاء، قـد أظـهرت العديد من المستويات غير المقبولة بالنسبة للأيونات الخاصة، بـ (SO_4^{-2} ، F^- ، NO^-_3 ، Fe^{+2} ، Fe^{+3}) والتي تسبب مشاكل خطيرة عند زيادة تركيزها عن الحد الأعلى المسموح به من قبل منظمة الصحة العالميـة، ودليـل المواصفات الوطنية لمياه الشرب في اليمن. وفي نفس الوقت هنالك العديد من عينات المياه من مواقع مختلفـة أظـهرت مستويات مقبولة للعناصر الشائعة كما تظهر ذلك الجداول التي تحـدد نوعيـة ميـاه الشـرب في مدينـة صنعـاء. إن الاختلافات في التراكيز الواردة في الأيونات الأربعة إنما تعزى إلى الطبيعة الجيولوجية والكيميائية لخصائص الصخـور والتربة لكل منطقة، وعمق الآبار وكمية المياه المخزونة فيها، وكذلك للتلوث الناتج جراء مياه المجاري السائبة.

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