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RESEARCH ARTICLE

ESTIMATION OF PHYSICAL AND CHEMICAL PROPERTIES OF GROUNDWATER OF SELECTED AREA FROM AL-DHALIA DIRECTORATE, AL-DHALIA GOV., YEMEN

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Abstract

In this study, the concentrations of the physical properties such as the acidity number (pH), temperature (T), electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH) and, the chemical properties such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), nitrates (NO_3^{-}), sulfates (SO_4^{2-}), bicarbonate (HCO_3^{-}), phosphates (PO_4^{3-}), fluoride (F^{-}), and chloride (Cl^{-}) in the groundwater in selected areas in Al-Dhalia district, Al-Dhalia, governorate were determined by collecting water samples from 16 wells and thereafter the samples were analyzed, in the laboratory of the water resources authority in Aden, according to the recommended methods mentioned in the literature. The analysis results showed that most of the well water is not suitable for drinking due to their contents of some chemical and physical properties were exceeded the maximum permissible limit for WHO (1997) and Yemen ministry of water and environment (YMWE,1999).

Keywords: Physical and chemical properties, Groundwater, Al-Dhalia district Al-Dhalia Governorate.

1. Introduction

Water is a chief natural resource essential for the existence of life and is a basic human entity [1]. As many health problems are derived from poor water and sanitation, water quality is as important as its quantity for satisfying basic human needs [2]. Uncontrolled hazardous waste sites are major environmental and public health concerns in many countries. Groundwater pollution is one of the most common environmental problems nowadays [3]. Nitrate concentrations in global water supplies are likely to increase in the future due to population growth, increases in nitrogen fertilizer use, and increasing intensity and concentration of animal agriculture [4].

Groundwater pollution unlike others is very critical, as once an aquifer becomes polluted, it is a very difficult, expensive and time-consuming affair to clean it up and may remain unusable for decades [5]. In Yemen, groundwater is considered as the main water source for drinking, domestic uses and irrigation purposes [6]. The mountainous headwater systems and the impacts of anthropogenic activities on headwater-scale has been largely impeded by their small size, large numbers, remote locations, rugged terrain, harsh climate conditions, and lack of road access, logistics, and available data [7]. In the study area of the Al-Dhalia District, Al-Dhalia governorate, surface and groundwater suffer from accelerated chemical contamination from domestic wastewater, nitrogenous fertilizers and pesticides. Such these wastes contain many organic and inorganic materials that are considered the main cause of groundwater pollution. As a result, the number of wells that are unfit for human use has increased. Groundwater is an important source of drinking water for humankind. It contains over 90 % of the freshwater resources and is an important reserve of good quality [8]. The main challenge is the cost recovery of the unit price of water which will be the main obstacle to start providing desalinized water for the public especially in the mountainous areas [9] The importance of this study comes as a result of the lack of periodic chemical analysis. Therefore, through this study, we are trying to contribute to knowing the extent of pollution by some physical and chemical properties in the water of some wells, finding conclusions and suggesting appropriate solutions for that.

1.1 Spatial and temporal limits of the study area

From the administrative point of view, the study area is located in Al-Dhalia district, Al-Dhalia governorate which determines the spatial location of Al-Dhalia governorate in the southern part of the central region of the Republic of Yemen. Where (astronomically) geography is confined between the latitudes 13 °, 30 ° - 14 °, 15 °, north of the equator, and longitudes 44 °, 10 ° - 44 °, 48 ° east of Greenwich (Fig. 1). The spatial limits of the study area from which well water was sampled in the range of the southern area of Al-Dhalia district. The pelvic area of the study area is estimated according to the sources of runoff of surface and groundwater at about 86 square kilometres, which represents 24.9% of the total area of Al-Dhalia governorate, which amounts to about 345 square kilometres. Al-Dhalia governorate is bordered to the north by Al-Bayda governorate, to the east by parts of Al-Bayda and Lahj governorates, to the south by parts of Lahj and Taiz governorate, to the west by Ibb governorate, and the capital of Al- Dhalia governorate is Al- Dhalia city [10, 11].

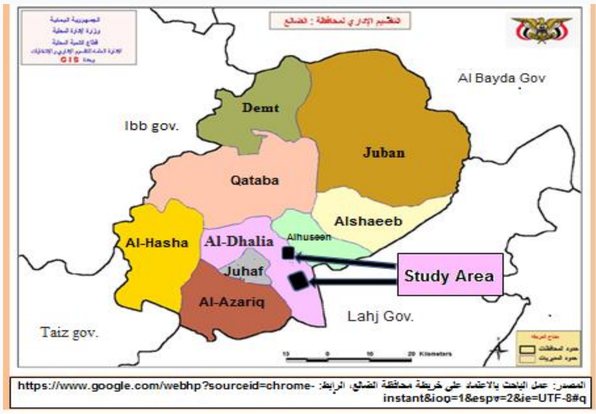

Figure 1: showing the location of the groundwater wells from which the study samples were taken in Al-Dhalia dist., Al-Dhalia governorate.

2. Experimental

2.1 Positioning

Initially, the purpose of going to the study area (Al-Dhalia Directorate) was in September (2014), for determining the location of the wells to be studied, and how close is it to the sewage? It was only a cluster of rural villages or the city of Al-Dhalia. Sixteen sites were identified for the wells to be studied. 5 located in the city of Al-Dhalia "characterized by its proximity to sewage water", while the other wells (eleven wells) are located in rural villages and far from the city of Al-Dhalia and there is no gathering of any wastewater, but it is located on the course of torrents Coming from the city. At each location, the coordinates were taken using a GPS (Tables 1 and 2).

2.2 Sampling and analysis

Sixteen representative wells water samples were collected from Al-Dhalia district, Al-Dhalia Governorate, so that full geographic representation has been made for the distribution of physical and chemical properties in the groundwater of the study area. To ensure the collection of representative water samples from the borehole and dug-wells, a large quantity of water from were pumped out or bailout for at least thirty minutes to remove water from bore storage in the case of the borehole and the dug wells before sampling. Temperature, pH, and conductivity were measured at the sampling sites within 20 minutes of the sample taking the time. Groundwater samples were analyzed for water quality parameters according to the American Public Health Association (APHA) methods [12] in the laboratory of the water resources authority in Aden Governorate.

2.3 Statistical processing of data

Statistical analysis was done for all samples by SPSS Program.

3. Results and Discussion

In the present study, the physical properties such as acidity number (pH), temperature (T), electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH) and, chemical properties such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), nitrate (NO_3^{-}), nitrite (NO_2^{-}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), phosphate (PO_4^{3-}), fluoride (F^{-}) and chloride (Cl^{-}) were taken into the consideration. The physical and chemical properties concentrations of groundwater samples, the guideline values for drinking water as specified by the WHO (1997) [13] and Yemen's Ministry of Water and Environment (YMWE, 1999) [14] are summarized in (Table 3 and 4).

3.1 Electrical Conductivity (EC)

The EC values ranged from 1242.00µs/cm to 4615.33µs/cm. EC values of 6 samples No. 1, 2, 3, 4, 5, and 10 were exceeded the permissible limits of WHO and YMWE (2500 µs /cm), while the remain 10 samples were not exceeded the permissible limits of WHO and YMWE (2500 µs /cm). The EC provides a quick indication of the ionic content of the water sample. Naturally, high EC values in groundwater is due to high concentration of mineral ions (Ca^{2+} , Mg^{2+} , Na^{+}, K^{+}, HCO^{3-}, SO_4^{2-}, Cl^{-}, NO_3^{-}, ...) [17]. The EC is directly correlated with the total dissolved salts. The high EC values in samples No. 1, 2, 3, 4, 5 and 10 may be due to the decrease in water table above the bottom of wells, excessive pumping of well water causes movement of the base soil component [18]. In addition, the anthropogenic sources of TDS pollution, as sewage,may be contributed to the high EC values.

3.2 Total Dissolved Solid (TDS)

TDS in wells samples ranged from 825 mg/L to 2766.33 mg/L. TDS contents of six samples No. 1, 2, 3, 4, 5 and 10 were exceeded the admissible limits, whereas the remain 10 samples were not exceeded the admissible limits for WHO and YMWE (1500mg /L). The TDS amounts in natural water is usually less than 500 mg/L, and water with more than 500 mg/L is undesirable for drinking and many industrial uses. High TDS in samples No. 1, 2, 3, 4, 5 and 10 is likely due to the wastewater and domestic sewage since these samples locate at Al-Dhalia city. High TDS is due to the presence of HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^- and Ca^{2+}, which may originate from natural sources, sewage, urban runoff and industrial wastewater and, TDS can also be derived from chemicals used in the water treatment process and from pipes or other hardware used in the plumbing [19].

Table 1: Location of sampling sites with their latitude and longitude

Sample No.	Name of wells	Latitude	Longitude	Location
1	A. Algadi's well*	13 42 14.54	44 44 3.31	Al-Dhalia city
2	M. Hamood's well*	13 42 21.97	44 44 1.12	"
3	Ghassan's well*	13 42 17.08	44 43 57.40	"
4	A. Ther's well*	13 42 16.93	44 44 1.04	"
5	M. Ahmed's well*	13 42 30.18	44 44 0.68	"
6	Urban project*	13 37 53.33	44 49 0.31	al-Sailah (rural villages)
7	S. Saleh's well**	13 37 20.52	44 48 55.68	"
8	A. Mohamed's well**	13 37 15.95	44 48 57.33	"
9	F. Mahmod's well**	13 37 21.13	44 48 48.26	"
10	A. AlhaJ's well**	13 36 29.97	44 49 8.40	"
11	A. Al-Somali's well**	13 36 23.85	44 49 8.02	"
12	H. Abdullah's well**	13 36 22.66	44 49 15.22	"
13	S. Aobl's well*	13 35 55.90	44 49 11.14	"
14	Alhamora project**	13 37 10.04	44 49 34.64	"
15	Almagbah project**	13 37 3.62	44 48 3.62	"
16	Al-Tafwah project**	13 37 17.99	44 48 50.22	"

*refer to hand dug-wells;
**refer to artesian wells

Table 2: Detailed data on the locations of the studied wells sample.

S. No.	Name of wells	Depth (meter)	Distance to the sewage site (meter)	Types of wastewater adjacent	Water Uses
1	A. Algadi's well*	31	20	Sewerage network collected from the Al-Dhalia city	Household & Irrigation
2	M. Hamood's well*	18	24	"	"
3	Ghassan's well*	21	36	"	"
4	A. Ther's well*	24	13	"	"
5	M. Ahmed's well*	18	40	"	"
6	Urban project*	25	--	Absorptive holes of houses	Drinking and irrigation
7	S. Saleh's well**	500	--	None	Household & irrigation
8	A. Mohamed's well**	280	--	None	Household & irrigation
9	F. Mahmod's well**	54	--	None	Household & irrigation
10	A. AlhaJ's well**	8	150	Agricultural and rural wastes	Drinking and irrigation
11	A. Al-Somali's well**	90	--	Agricultural and rural wastes	Household & irrigation
12	H. Abdullah's well**	50	--	Agricultural and rural wastes	Household & irrigation
13	S. Aobl's well*	20	--	None	Drinking and irrigation
14	Alhamora project**	40	--	None	Household
15	Almagbah project**	80	164	Rural waste	Household
16	Al-Tafwah project**	20	--	Rural waste	Household

*refer to hand dug-wells;
**refer to artesian wells

Table 3: Results of physical and chemical properties analysis (mean) in the studied Well water

Sample No.	pH	T (ºC)	EC (µs/cm)	TDS (mg/L)	T.H (mg/L)	Ca^{++} (mg/L)	Mg^{++} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	NO_3^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	PO_4^{3-} (mg/L)	F^- (mg/L)	sCl^- (mg/L)
1	7.4	28	**4181.3**	**2506.0**	**832.0**	135.7	**119.8**	**534.7**	**28.43**	**119.30**	**445.66**	**750.00**	**0.703**	0.313	**700.57**
2	7.4	29	**3600.7**	**2161.3**	**1035.0**	**216.7**	**120.2**	334.6	**15.04**	**69.97**	284.73	**570.20**	**0.503**	BDL	**585.47**
3	**8.9**	25	**4369.0**	**2615.3**	**1315.0**	**213.8**	**190.0**	386.7	**25.30**	9.07	**420.03**	338.30	0.399	BDL	**725.30**
4	8.3	27	**4615.3**	**2766.3**	**1328.3**	**210.6**	**195.1**	**432.0**	**25.33**	20.93	**520.63**	285.06	**0.606**	BDL	**750.00**
5	8.0	25	**4071.3**	**2447.3**	**1442.2**	**273.2**	**184.5**	254.0	**30.53**	**132.47**	**560.80**	**600.10**	**0.903**	BDL	**390.37**
6	8.2	25	1439.7	879.0	**521.2**	85.4	**74.8**	96.0	8.01	1.71	217.93	117.10	**0.8270**	0.058	**147.20**
7	8.4	50	1517.7	908.0	290.5	50.1	40.2	195.7	9.01	3.43	209.77	145.06	0.402	**1.583**	**200.18**
8	7.8	36	2304.7	1384.3	**741.2**	115.3	**109.9**	186.7	**15.03**	23.07	360.30	439.90	**1.027**	0.297	**288.07**
9	8.3	54	1538.0	907.3	455.3	70.1	**67.9**	135.0	12.03	8.03	215.97	94.06	**0.683**	1.373	**208.17**
10	7.8	34	**2546.7**	**1528.0**	**875.1**	107.3	**148.1**	170.0	**17.04**	**94.27**	368.23	430.17	**1.017**	1.357	**350.33**
11	8.5	50	1545.0	916.7	392.6	83.4	44.8	159.7	10.02	2.02	209.83	108.07	0.402	1.487	**245.10**
12	8.2	49	1546.7	923.7	375.8	76.1	45.1	175.0	10.02	4.03	217.83	106.06	**0.604**	**1.520**	**270.12**
13	8.0	37	1751.7	1061.7	**574.4**	62.3	**102.0**	128.7	12.04	20.90	297.73	320.27	**0.605**	1.343	**199.22**
14	8.00	44	1242.0	825.3	70.1	24.1	2.4	317.3	**25.27**	6.76	299.87	195.13	0.320	**9.450**	**244.07**
15	7.8	44	1460.0	975.0	70.0	24.2	2.4	301.6	**19.72**	13.13	290.33	195.17	**0.462**	**9.263**	**210.13**
16	7.9	49	1464.3	971.7	80.0	25.2	4.1	311.3	**21.72**	15.60	210.10	185.27	**0.743**	**9.460**	**270.17**
Min	7.4	25	1242	825	70.0	24.1	2.4	96.0	8.01	1.71	209.83	94.06	0.320	BDL	**147.20**
Max	8.9	54	4615	2766	1442.2	273.2	195.1	534.7	30.53	132.47	560.80	750.00	1.027	9.460	**750.00**
WHO	8.5	25	- - -	1500	- - -	200	150	400	12	50	400	- - -	0.45	1.5	**600**
YMWE	9	25	2500	1500	500	200	50	400	12	45	400	500	0.5	1.5	**600**

Table 4: Percentage of samples of level more than WHO [13] and YMWE [14], maximum admissible limit (MAL) of different drinking water parameters.

Property	Percent of samples more than WHO		Percent of samples more than (YMWE)	
	No. of samples	%	No. of samples	%
pH	1	6.25	Nil	**Nil**
T (ºC)	13	81.25	13	**81.25**
EC	- - -	- - -	6	**37.5**
TDS	6	37.5	6	**37.5**
T.H	- - -	- - -	9	**56.25**
Ca^{++}	4	25	4	**25**
Mg^{++}	3	62.5	10	**62.5**
Na^{+}	2	12.5	2	**12.5**
K^{+}	10	62.5	10	**62.5**
NO_3^-	4	25	4	**25**
SO_4^{-2}	4	25	4	**25**
HCO_3^-	- - -	- - -	3	**18.75**
PO_4^{3-}	11	68.75	10	**62.5**
F^-	5	31.25	5	**31.25**
Cl^-	3	18.75	3	**18.75**

3.3 Total Hardness (TH) as CaCO3 (mg /L)

The range of TH in the studied samples was 70.00 mg/L - 1442.2 mg/L. TH contents in seven samples No. 7, 9, 11, 12, 14, 15 and 16 were not exceeded the permissible limits for WHO and YMWE (500 mg/L), while the remain nine samples were exceeded the permissible limits for WHO and YMWE (500 mg/L).

TH in natural water varies according to the nature of the geological formations through which the water passes, and Ca^{2+} and Mg^{2+} are among the most common ions causing hardness in natural waters [20]. The increase in TH, in most of the samples, is likely due to the effect of the city's sewage pools close to the wells. The reason for the high hardness is also the high concentrations of Ca^{2+}, Mg^{2+} and HCO_3^- that reflect mineral dissolution and rock weathering processes [21].

3.4 Calcium (Ca^{2+})

Ca^{2+} level in the studied samples ranged from 24.1 mg/L to 273.2 mg /L. Ca^{+2} levels in four well water samples No. 2, 3, 4 and 5 were exceeded the permissible limits of WHO and YMWE (200mg /L), while the remain twelve samples were not exceeded the permissible limits of WHO and YMWE (200mg /L). Ca^{2+} amounts differ from site to site and this is due to the different types of water-bearing rock layers, and the water quality feeding these wells plays a big role in their quality [21]. And also, Ca^{+2} levels in groundwater differs according to the land wetness, lowest concentrations are observed in ridge water. Higher calcium concentrations are found in groundwater recharged in wetlands, especially in infiltrated surface water [22]. Calcium is an essential ingredient for living organisms that play a role in bone and teeth formation, along with permeability of cell walls [23]. The continuous high intake of calcium may cause stone problem [24].

3.5 Magnesium (Mg^{+2})

Mg^{2+} contents in the studied samples ranged from 2.4 mg/L to 195.1mg/L. Mg^{2+} levels in three samples No. 3, 4 and 5 were exceeded the permissible limits for WHO (50 mg/L) and YMWE (150 mg/L) and, in seven samples No. 1, 2, 6, 8, 9, 10 and 13 were exceeded the permissible limits of WHO (50 mg/L) and, in the remain six of the samples were not exceeded the permissible limits for WHO (50) and YMWE (150 mg/L). The higher Mg^{2+} levels in samples No. 3, 4 and 5 may be due to the pollution from municipal wastewater and domestic sewage of Al-Dhalia city. The variation in Mg^{2+} levels, in water samples, attributes to the variation in rocks composition. Water-rock interaction is the primary source of Ca^{2+}, Mg^{2+}, HCO_3^- in groundwater [25]. The proportion of major ions can be derived from the crystalline dolomitic limestone and Calcium–magnesium silicates weathering, chiefly from calcite, gypsum, and plagioclase feldspar [26]. The calcium and magnesium ions present in the groundwater are possibly derived from leaching of calcium and magnesium-bearing rock-forming silicates [27]. Magnesium gives undesirable taste to drinking water; magnesium in drinking water may have a laxative effect [28].

3.6 Sodium (Na^+)

Na^+ ranged from 96.0 mg /L to 534.7 mg /L. Na^+ levels in sample No. 1 and 4 were exceeded the permissible limits for WHO and YMWE (400mg /L), while the remain fourteen samples were not exceeded the permissible limits for WHO and YMWE (400mg /L). Na^+ in the studied sample was the predominant cation and, this is in agreement with the result Al-Amy et al [29] gotten in their study of groundwater in Al-Dhalia Basin. The high Na^+ in the groundwater may be related to the cation exchange operative in the aquifers [29]. In addition, high Na^+ content refer to the rock weathering and soil dissolution, the high concentration of Na^+ among the cationic concentrations reflects rock weathering and/or dissolution of soil salts stored by the influence of evaporation [26]. Pollution from domestic wastewater may be contributed to high Na^+ in wells water, especially that wells locate in / or adjacent to Al-Dhalia city, Laundry wastewater can increase Na^+ in groundwater, soap contains builders like $Na_5P_3O_{10}$ and Na_2SO_4 this explanation according to [15]. And with respect to the wells located in Al-Silah, where volcanic features, the reason for high Na^+ may be water-rock interaction, enrichment in Na^+ is related to water-rock interaction processes (volcanic rocks being rich in sodium) this explanation according to [26].

3.7 Potassium (K^+)

K^+ ranged from 8.01mg /L to 30.53mg /L. K^+ levels in samples No. 6, 7, 9, 11, 12 and 13 were not exceeded the permissible limits for WHO and YMWE (12mg /L), while in the remain ten samples were exceeded the permissible limits for WHO and YMWE (12mg /L), K^+ concentration of groundwater up to 10 mg/L are attributed to orthoclase or clay weathering, K-feldspar and biotite may not be weathered significantly [26]. The reason for the high K^+ in the studied well's water is likely the anthropogenic sources of pollution such excessive use of agricultural fertilizers, cesspits and sewage that present in the studied area, K^+ can be added to groundwater through fertilizers use and breakdown of animal or waste products [30].

3.8 Nitrate (NO_3^-)

NO_3^- ranged from 1.71mg/L to 132.47mg/L. NO_3^- levels in four samples No 1, 2, 5 and 10 were exceeded the permissible limits for WHO (50 mg/L) and YMWE (45mg/L), whereas in the remain twelve samples were not exceeded the permissible limits for WHO (50 mg/L) and YMWE (45mg/L). The source of high NO_3^- in samples No. 1, 2, 5, and 10 may be wastewater. Also, the fertilizers, agricultural, septic systems and sewer may be contributed to increasing the water content of NO_3^- , while only a small proportion of the NO_3^- leached in a given year is derived directly from inorganic fertilizers, the overall rate of nitrogen mineralization and leaching normally relates in a general way to fertilizer application rates [31]. NO_3^- in natural waters has been increasing during the last few decades, coinciding with the increased use of mineral fertilizers and a higher yield of cultivated plants in agriculture [32]. Dense populations and discharges from point sources like septic systems or broken sewer systems contribute significantly to water pollution by nitrate in urban and suburban areas. Nitrate contaminated water causes a disease known as methamoglobinia or blue baby syndrome, nitrogen is considered more toxic when it is in nitrite form than in nitrate, Nitrosamine is carcinogenic and it affects esophagus and pharynx [33].

3.9 Sulfate (SO_4^{2-})

SO_4^{2-} concentration ranged from 209.77mg/L to 560.80mg/L. SO_4^{2-} levels in four samples No. 1, 3, 4 and 5 were exceeded the permissible limits for WHO and YMWE (400mg/L) while in the rest twelve samples were not exceeded the permissible limits for WHO and YMWE (400mg/L). The variation in SO_4^{2-} levels of the studied samples is returned to the variety of SO_4^{2-} pollution sources, for example, samples No. 1, 3, 4 and 5, that locate near Al-Dhalia city's sewage, have higher level of SO_4^{2-}. SO_4^{2-} is present in the groundwater as a result of their melting from the sulfate groups found in igneous and sedimentary rocks. Sulfates in groundwater may also be derived from soluble minerals such as gypsum ($CaSO_4 \cdot 2H_2O$ or anhydrite $CaSO_4$) [34]. Sewage leakage into groundwater in addition to the use of chemical and natural fertilizers in the study area. Nitrate and sulphate enter groundwater from effluents from septic systems and livestock waste in residential areas, and as a result of fertilizers used in agriculture and sewage effluents [35]. There are adverse health effects on human health due to drinking water sulfate, diarrhea, catharsis, dehydration. Gastrointestinal irritation may be associated with the ingestion of water containing SO_4^{2-} [36].

3.10 Bicarbonate (HCO_3^-)

HCO_3^- ranged from 94.06 mg/L to 750.00 mg/L. HCO_3^- levels in thee samples No. 1, 2 and 5 were exceeded the permissible limits for YMWE (500mg/L) whereas in the rest thirteen samples were not exceeded the permissible limits for YMWE. The source of HCO_3^- in samples No. 14, 15 and 16 that locate in Al-Silah, may be the silicate, since the HCO_3^- levels were higher than TH (as $CaCO_3$), The high bicarbonate when compared to carbonate in the water is the result of the reactions of soil CO_2 with dissolution of silicate minerals [27]. The possible sources of bicarbonate include the presence of organic matter in the aquifer that is oxidized to produce carbon dioxide, which promotes dissolution of minerals. HCO_3^{2-} may be resulted from the weathering of silicate minerals [30]. The HCO_3^- has no known adverse health effects on human health, if it exceeds 300 mg/L in the drinking water, in general. However, it should not exceed 300 mg/L in the potable water, as it may lead to kidney stones in the presence of higher concentration of Ca^{2+}, especially in dry climatic regions [33].

3.11 Phosphate (PO_4^{3-})

PO_4^{3-} in the studied samples ranged from 0.320mg/L to 1.027mg/L. PO_4^{3-} levels in four samples No. 3, 7, 11 and 14 were not exceeded the permissible limits for WHO (0.45 mg/L) and YMWE, (0.5mg/L) while the rest twelve samples were exceeded the permissible limits for WHO and YMWE. Most of the studied wells water have high PO_4^{3-}, and the reason is likely the different sources of PO_4^{3-} the studied samples were vulnerable to dissolution of minerals that contain phosphate in aquifer sediments, agricultural fertilizer, animal waste, and leaking septic systems or infiltration of wastewater [37]. Phosphates enter the groundwater through point and non-point sources; the point sources are sewage effluents and industrial discharges [33]. Naturally occurring levels of PO_4^{3-} in surface and groundwater bodies are not harmful to human health, animals or the environment. Conversely, extremely high levels of PO_4^{3-} can cause digestive problems [38].

3.12 Fluoride (F^-)

F^- in the studied samples ranged BDL mg/L to 9.460 mg/L. F^- levels in four samples No. 7, 14, 15 and 16 were exceeded the permissible limits for WHO and YMWE (1.5 mg/L), while the remain twelve samples were not exceeded the permissible limits for WHO and YMWE (1.5 mg/L). Nine samples of the studied well water were of high fluoride levels (more than 1.343 mg/L). The reason for the rise of F^- is that the waters of the study area pass through sedimentary rocks containing fluorspar, which is one of the terrestrial minerals that is a source of fluorine, and this is consistent with what has been mentioned in literature [18], i.e, the fluorspar mineral present in the rocks Sedimentology is the most important source of fluorine in groundwater. F^- in groundwater can be increased as a result of precipitation of $CaCO_3$ at high pH, which removes Ca^{2+} from solution allowing more fluoride to dissolve [29]. The alkaline groundwater generally tends to solubilise fluoride minerals like fluorite, appatite and cryolite [39]. Low level of F- has positive effects, whereas high level has negative effects on human health. The lesser concentration of fluoride has beneficial effect in preventing dental caries and higher concentration has increased risk of dental fluorosis and even higher concentration that of 1.5 mg/l could lead to skeletal fluorosis [39].

3.13 Chloride (Cl^-)

Cl^- in the studied samples ranged from 147.20mg/L to 750.00 mg/L. Cl^- levels in three samples No 1, 3 and 4 were exceeded the permissible limits for WHO and YMWE (600mg/L), while the remain thirteen samples were not exceeded the permissible limits for WHO and YMWE (600mg/L). The high levels of Cl^- in most of the samples is due to that the compound of Cl^- are soluble in water and the different sources of well water pollution by the Cl^- compounds. Cl^- is found in all natural waters and, its multiple sources include many sedimentary rocks, fertilizers, septic tanks, industrial effluent and domestic fertilizers [25]. Regarding chloride, the high concentrations may be associated with the improper management and treatment of domestic wastewater and fertilizers (chloride-contaminated water from sewage) [40]. Adverse effects related to high Cl^- are increased number of polymorhonuclear leukocyte and disturbed blood cell counts in full blood count analysis; chlorides in drinking water usually create taste and odor problems at levels exceeding 250 mg/L [41].

4. Conclusions

- K+ and PO_4^{3-} levels in more than 60% of the studied well water were above the maximum admissible limit (MAL) for WHO (1997) and YMWE (1999) for drinking water .
- Mg^{2+} in more than 60% of the studied well water was above the MAL for WHO.
- TH in more than 50% of the studied well water was above the MA for YMWE.
- F^- in more than 50% of the studied wells was above the MAL for WHO and YMWE.
- TDS in more than 37% of the studied well water was above the MAL for WHO and YMWE.
- EC values in more than 37% of the studied well water was above the MAL for YMWE .
- Ca^{2+}, NO_3^- and SO_4^{2-} in 25% of the studied well water were above the MAL for WHO and YMWE.
- Cl^- in more than 18% of the studied wells was above the MAL for WHO (1997) and YMWE (1999).
- HCO_3^- in more than 18% of the studied well water was above the MAL for YMWE (1999).

- Na^+ in more than 12% of the studied well water was above the MAL for WHO (1997) and YMWE (1999).

5. Recommendation

- Groundwater in the study area is the main drinking water source, so it should not be overused.
- To help maintaining water quality and quantity, the random drilling of wells must be prevented or restricted, and scientific laws must be followed for the drilling process and drilling sites.
- The study recommends the water office put guidance and warning boards on the main and side roads, containing real data on the dangers of overpumping, specifying the depth of the well and the amount of pumping according to the nature of the rock formation .
- Accelerating the study of the sewage drainage project for the city of Al-Dhalia city, which is expected to join the neighboring cities during the coming years.
- The necessity of removing domestic disposal, wastewater collections and cultivation wastes from well areas. Carrying out chemical, physical and microbiological analyzes periodically.
- The necessity of mixing the water of high values (TDS, TH, NO3-) with water from other sources with low values for these elements, before they are pumped to the citizens .
- Carrying out a detailed study to find a suitable method for treating water with high values of hardness (TH), especially as the water of the study area is hard very to hard water, and knowing the relationship between hardness of water and cases of increased kidney failure .
- In order to judge in a scientific and integrated manner the suitability of water for human consumption, it is necessary to conduct radiation and organic pollutants that affect public health.
- The municipality shall set up modern technical specifications for cesspits, preventing household wastewater from leaking into aquifers, and requiring cesspits to siphers the water of those pits into basins that are prepared to receive them at the new plant site.
- The study recommends that the concerned authorities (official and private) and everyone related to the uses of fertilizers and pesticides for agricultural purposes in Al-Dhalia Governorate, and the study area, should do in order to restrict or control use of fertilizers and pesticides.

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مقالة بحثية

تقدير الخواص الفيزيائية والكيميائية في المياه الجوفية لمناطق مختارة من مديرية الضالع، محافظة الضالع، الجمهورية اليمنية

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المُلخّص

في هذا البحث تم دراسة تراكيز بعض الخواص الفيزيائية مثال درجة الحموضة (pH) ودرجة الحرارة (T) والموصلية الكهربائية (EC) والمواد الذائبة الكلية (TDS) والقساوة الكلية (TH) والخواص الكيميائية مثال الكالسيوم (Ca^{2+}) والمغنيسيوم (Mg^{2+}) والصوديوم (Na^{+}) والبوتاسيوم (K^{+}) والنيترات (NO_3^{-}) والكبريتات (SO_4^{2-}) والبيكربونات (HCO_3^{-}) والفوسفات (PO_4^{3-}) والفلوريد (F^{-}) والكلورايد (Cl^{-}) في المياه الجوفية من مناطق مختارة في مديرية الضالع، محافظة الضالع. وذلك بجمع العينات من 16 بئرا شملت 9 من الآبار الارتوازية و 7 من الآبار المحفورة يدويا، ومن ثم التحليل وفقا للطرق القياسية الموصى بها. بينت نتائج التحاليل ارتفاع تراكيز بعض الخواص الفيزيائية مثال الموصلية الكهربائية (EC)، المواد الذائبة الكلية (TDS)، القساوة الكلية (TH)، والخواص الكيميائية مثال المغنيسيوم (Mg^{2+})، البوتاسيوم (K^{+})، الفوسفات (PO_4^{3-})، والفلوريد (F^{-}) في معظم مياه الآبار المدروسة حيث تجاوزت الحد الأعلى المسموح به (MAL) وفقاً لمواصفات منظمة الصحة العالمية (WHO) ومواصفات وزارة المياه والبيئة اليمنية (YMWE) لمياه الشرب.

الكلمات الرئيسية: الخواص الفيزيائية والكيميائية، المياه الجوفية، مديرية الضالع، محافظة الضالع، اليمن.

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