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WATER QUALITY ASSESSMENT USING THE NSFWQI MODEL FOR DRINKING AND DOMESTIC PURPOSES: A CASE STUDY OF GROUNDWATER ON THE LEFT SIDE OF MOSUL CITY, IRAQ

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Abstract

The current research targets to evaluate the groundwater quality of some quarters in the left side of Mosul city, the water samples were collected randomly from twelve wells (twelve replicates from each well), to determine the physical, chemical and bacterial properties using National Sanitation Foundation Water Quality Index (NSFWQI).

The results showed that the studied groundwater qualities were Medium for drinking and domestic uses. This deterioration in the quality is due to the high levels of total dissolved solids, biochemical oxygen demand, nitrate, turbidity and faecal coliform bacteria, which reached (1559, 7.00 and 10.7) ppm, 28.9 NTU and 2420 cell. 100ml^{-1} consecutively.

Key words : Groundwater quality of Mosul city, NSFWQI, Bacterial tests**.**

Introduction

The water problem is one of the most important pillars of the national security of any country, especially the arid and semi-arid regions that are surface water sources from contiguous countries as is the case in Iraq, which complicates the problem in addition to the climate problems and the scarcity of rainfall, as the countries from which the sources of the river's water try to control on water and its economic and political exploitation to achieve strategic goals, and these may increase the potential for conflicts that worsen over time as a result of social and economic developments. The future expectations of the water problem in Iraq will be dangerous and catastrophic due to external threats represented by the construction of dams and water projects in the source countries as well as pollution and waste of available water resources (Al-Saffawi, 2018a).

Providing adequate water for human use has become a difficult problem facing people in many parts of the earth, especially in developing countries, as large numbers of human pathogens are transmitted by water and cause various types of diseases and even dangerous ones, which may cause death such as cholera, typhoid, and Shigellosis... etc. (Al-Saffawi and Al-Asaaf, 2018), and studies indicate that more than 3 million deaths occurred Annually due to the use of unsafe drinking water, especially diarrheal diseases in children (Al-Saffawi, 2018b). Studies show that more than 30% of the people in developing countries need clean and safe water and that 875 million cases of diarrhea occur every year due to insecurity of drinking water in these countries and the horrific truth of the expectations of that two-thirds of the world's population, they will have water shortages by 2025, as 25 countries will suffer from water shortages in Africa alone (UNEP, 2008; Al-Shanona *et al.,* 2020), therefore, the necessary measures should be taken to reduce the exacerbation of water shortages through efficient water management, combating pollution problems of water resources and rationalizing water consumption, with the use of modern technology in the study and evaluation of water, such as the use of mathematical models, which spread after a mathematical

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model was proposed by Horton in 1965 and subsequently developed by Brown in 1970. Over time, a large number of models were proposed and developed because of the ability to demonstrate a single value that reflects the interactions between the large numbers of data and characteristics of water that are understood by all (Krishan *et al.*,2016; Ramadhan *et al.*,2018).

Among the studies conducted in Nineveh governorate in this field is a study of Al-Saffawi *et al.*, (2018) to evaluate the water quality of some water sources for the village of Abu Maria, Tal-Afar district using the (WQI), which indicated that its quality was from the very poor category for drinking and domestic use. Al-Saffawi (2018b) also conducted a study on the application of the Canadian model (CCME WQI) to assess the quality of groundwater for the Al-Mahallabiyah area west of Mosul city, Iraq for drinking purpose, which indicated that 17% of water samples were from Poor quality for drinking and the rest was from the Marginal water category. As for Talaat *et al.*, (2019), they conducted an assessment of groundwater quality for the left side of Mosul city, Iraq, using a weighted mathematical model (WQI) The results indicated that the studied groundwater was ranged from poor to unsuitable qualities for drinking and domestic purposes. They attributed the deterioration in the quality of water to high levels of most of the studied characteristics. Therefore, the current study came to identify the status of the groundwater of Al-Mothana, Al-Zohoor Al-Sideq and Al-Hadba quarters on the left side of Mosul city for drinking and domestic uses.

Materials and Methods

Location of the study area

This study was conducted in some quarters on the left side of Mosul city in northern Iraq and includes four quarters (Al-Mothana, Al-Zohoor, Al-Sideq and Al-Hadba), and due to the difficult conditions as a result of the destruction of infrastructure, including the transmission and distribution networks of electricity and the water distribution network piped, the population tended to dig wells to use the water whose depths ranged between (6.0 - 67) m, that is, the studied wells are between shallow and deep wells. The locations coordinates of the wells studied using the GPS of Google Earth have been fixed, as shown in table 1 and Fig. (1), which clarifies its specifications and uses.

Table 1: Coordinates and specifications of water wells in some quarters on the left side of Mosul.

Well sites		E	N	Depth m	H_2S	Using
Al-Mothana Qaurter	1	43°167	36.376	12	Nil	For different uses
	2	43.165	36.379	10	Nil	
	3	43.163	36.378	10	Nil	
	4	43.166	36.376	10	Nil	
Al-Zohoor Qaurter	5	43.188	36.381	7.0	Nil	
	6	43.185	36.382	50	Nil	
	7	43.188	36.383	6.0	Nil	
Al-Sideq Qaurter	8	43.155	36.394	35	Nil	
	9	43.161	36.391	9.0	Nil	
	10	43.157	36.391	28	Nil	
Al-Hadba Q.	11	43.154	36.395	67	Nil	
	12	43.148	36.395	48	Nil	

Materials and Methods

In the current study, One hundred and forty four water samples were collected from twelve wells scattered in the area (during the autumn and winter season of 2019-2020) using polyethene bottles that were cleaned with distilled water, also washed with sample water before filling it. As for oxygen, the samples were collected from the water using special bottles and field-stabilized by adding a solution of manganese sulfate (Winkler a) and alkali iodide azide (Winkler B) solution, as for bacteriological examination samples, sterile vials were used and the samples were kept away from light and in the container until reaching the laboratory (APHA, 1998).

As it measured water temperature and electrical conductivity values using the field apparatus (German-origin) and in the laboratory, each of parameter like pH, total dissolved solids (TDS) turbidity, dissolved oxygen (DO), Biochemical oxygen demand (BOD), nitrate, phosphate and faecal coliform (F. C.) were measured based on international standard methods (APHA, 1998).

Geology of study area

Nineveh Governorate is distinguished by the widespread formation of Plaspi (middle-upper Eiocene) that consisting limestone, marl, and Al-Fatha (middle Miocene) formation contains limestone, evaporated salts, gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$) and marl, and this formation is spread in the Governorate and the formation of the Anjana (Upper Miocene) that It consists of succession of sandy, clay rocks and marl, these formations impact in the quality of water passing through it (Al-Saffawi and Al-Sardar,2018; Al-Hamadany and Al-Saffawi,2018)

Estimation of NSFWQI model

Water quality was determined by using the National Sanitation Foundation water quality index (NSFWQI). This index is beneficial tools for expression easier, water quality to public

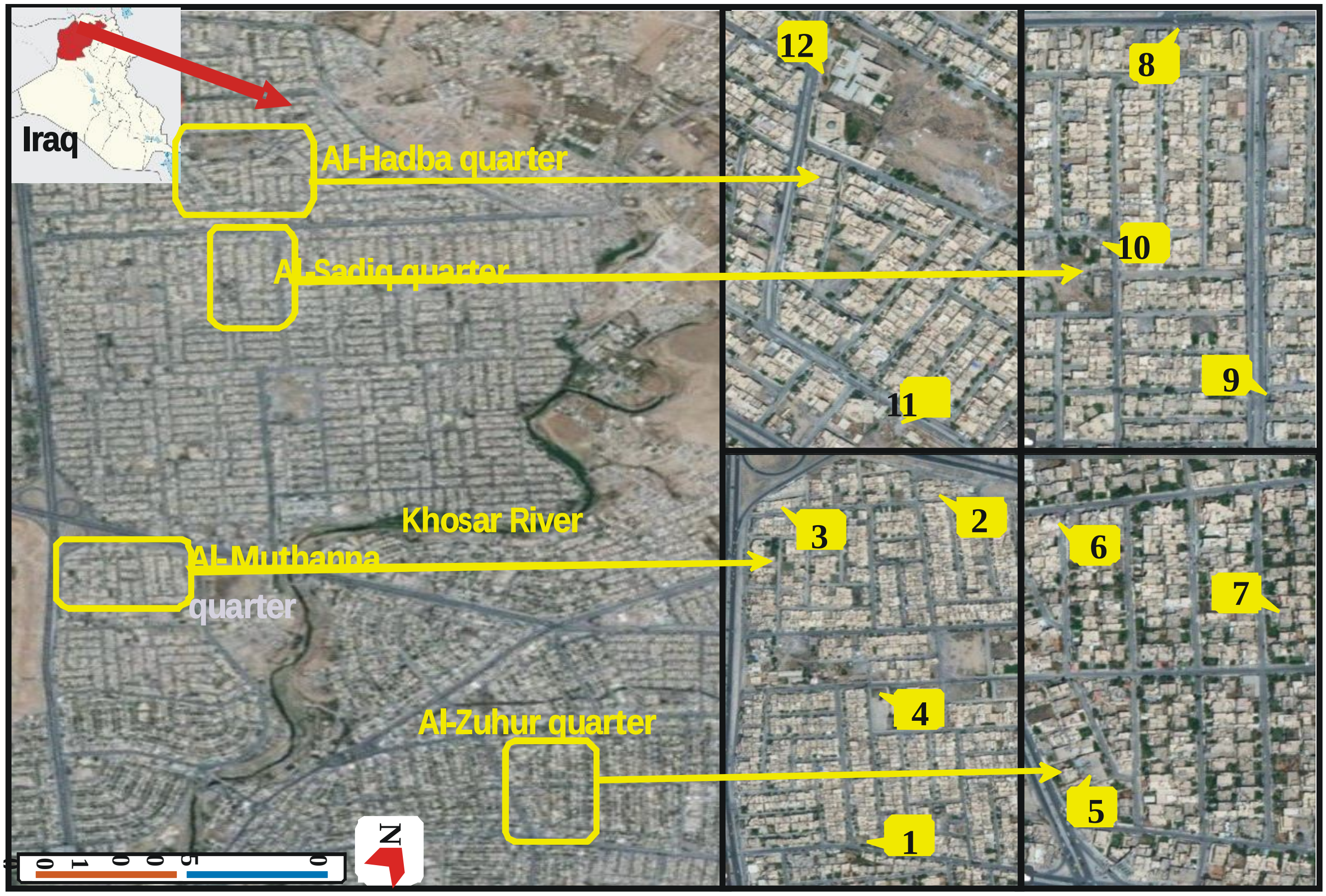

Fig. 1: Well sites and quarters on the left side of the city of Mosul.

consciousness and managerial purposes and epitomizes a large number of data on water quality and in a word is suitable or unsuitable water quality. The properties used in this index include Temperature, pH, total dissolved solids (TDS), turbidity, dissolved oxygen (DO), Biochemical oxygen demand (BOD), nitrate, phosphate and faecal coliform, For calculating this index, the following equa-tion is applied (Javid *et al.*, 2014; Sayadi and Ghaleno, 2016):

$$NSFWQI = \sum_{i=1}^{n} QiWi$$

Table 2: Assigned weight for parameters NSF-WQI.

Param.	T°C	pH	TDS	Turb.	DO	BOD	PO_4	NO_3	F.C
Unite	°C	——	ppm	NTU	ppm	ppm	ppm	ppm	Cell*
Weight	0.10	0.12	0.08	0.08	0.17	0.10	0.10	0.1	0.15

*cell. 100ml^{-1} .

Groundwater quality classification is done according to NSFWQI by (Table 3).

Table 3: NSFWQI for water quality classification (Fathi *et al*, 2018).

Values	0.0-25	26 -50	51-70	71-90	91 -100
Water Status	Very Bad	Bad	Medium	Good	Very good

From the above equation, Qi is the quality of the ith parameter obtained from conversion curves (a number between 0 and 100) and Wi is the importance weight of the ith parameter (Hamdan *et al.*, 2018). To calculate the final index in this method, each sub-index obtained from the related curves is multiplied by the importance of weight (Table 2) (Mustapha and Aris, 2011).

Results and Discussion

The adjectives tests for the collected groundwater quality properties are shown in table 4. So as to reach a better opinion of groundwater quality retrogradation causes, the results are discussed as follows:

Physical properties

It was observed from the field survey that the studied water was transparent and odourless, due to the lack of a gas hydrogen sulfide[11]. As for the water temperature, it plays an important role in the reactions that occur in water and the dissolution of salts from the rocks that pass through them, as well as the activity of microorganisms in the processes of oxidation and reduction (Falowo *et al.*, 2017).

The results are shown in table 3 indicate that the fluctuation in the studied water temperature is very limited, which ranged between (20-25) °C and this is what many previous studies have indicated as a result of the water presence away from the earth surface and the climatic impacts (Al-Saffawi and Al-Shanoona, 2012). As for the total dissolved salts, their concentrations fluctuated between (534 to 1514) ppm and this great difference in concentration is due to the nature of the geological formations through which the water passes. The groundwater passing through the wealthy layers of evaporated salts is characterized by high salt values in them and poor quality water (Al-Hamdany and Al-Saffawi, 2018). As for turbidity, it is a characterization of the optical properties of the water which is specified by the amount of light released and absorbed by particles in the water. Turbidity is derived from suspended matter like mud, sand, organic and inorganic substances and microorganisms Ichwana *et al.,* 2016). The results of the study indicate that the mean values ranged between 0.33 to 15.2 NTU and that 42% of the tested water samples passed the international permissible limits for drinking. This rise may be due to the influence of human activities on wells water pollution like septic tanks.

Chemical properties

pH is a property that determines the water appropriateness for different purposes and the pollution degree in the studied water. The pH values varied from 7.14 to 7.99 which it is within the permissible limits of natural water and the permissible level of drinking water, which indicates that the water samples are of a slightly alkaline nature (WHO, 2004). It is noted from the results table 4, the decrease in the fluctuation of pH values that belong to the acid neutralization capacity(ANC) for Iraqi water and soil which rich in bicarbonate salts occurring from the reactions of water containing CO_2 gas during its movement in the geological layers and the transmutation of unsolvable calcium carbonate to dissolved bicarbonate as In the following equations (Al-Saffawi, 2018b):

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$CaCO_3 + 2H_2CO_3 \longrightarrow Ca^{+2} + 2H_2CO_3$$

As for the concentration of dissolved oxygen in water, it is considered one of the important criteria for determining the quality of water and the degree of its pollution as well as its role in preventing the formation of harmful compounds and bad odours Al-Saffawi, 2019). The results of the study shown in table 3 indicate that the concentration of dissolved oxygen was between (2.08-7.70) ppm, also 53% of the studied samples exceeding the permissible limits and the reason for the decrease is due to the lack of friction with the atmospheric air, as well as, the relative rise in the water temperature will lead to an increase in the microbial degradation activity of organic matter, etc. which leads to a decrease in dissolved oxygen in the groundwater, and this is confirmed by the relative rise in the BOD_5 values that ranged from (1.0 to 17.0) ppm (Al-Saffawi and Talaat, 2018).

High nitrate concentration in drinking water has serious effects on consumer health, such as blue baby syndrome. With the possibility of afflicting the elderly and patients with this disease, as well as many cancerous diseases such as stomach, pancreas and rectum cancer, as well as the occurrence of abortion cases in pregnant women (Talaat *et al.*,2019). The results presented in table 4 showed the relative rise in the values, as their rates ranged between (0.79 to 10.9) ppm, these high values have a risk to public health when there are organic compounds and animal excreta that are a source of secondary amines formation (RNHR) due to bacterial actions that interact with nitrites to form nitrous amines compounds that have a stimulating effect for cancer and genetic mutations (Al-Saffawi, 2018c). All samples studied are within the limits appropriate for all uses.

As for orthophosphates, Sodium Tri-Polyphosphate Sodium STPP ($Na_5P_3O_{10}$) used in the manufacture of detergents is more common in the manufacture of detergents, which gradually decomposes in water into orthophosphate. High concentrations of phosphates (more than 10 ppm) in drinking water cause vomiting and diarrhea in humans and animals[25]. The average concentration of orthophosphate ions ranged among (0.11 to 3.52) ppm, and this relative increase in the values of water for some wells is due to the leakage of sewage tanks into it. Generally, the concentrations are low compared to other negative ions, which is due to the high ability of phosphates to adsorb on the surfaces of minutes and precipitation in the form of calcium phosphate as in the following equation (Al-Mashadany, 2019):

$$3Ca^{+2} + 2PO_4^{-3} \longrightarrow Ca(PO_4)2$$

Bacterial properties

Faecal coliform bacteria, including E. coli, are found naturally and in large numbers in the intestines of humans and animals. It can be used as successful indicators to ensure that there is recent faecal contamination of water and warn of the presence of health risks from its use (Al-Saffawi and Al-Taay, 2013), and the results indicated that the averages of faecal coliform ranged between (328 to 1496). cell. 100 ml^{-1}, This confirms that the well water may be polluted as a result of wastewater seepage into it

Table (4): Results of physical, chemical and bacterial properties of groundwater (ppm).

Wells		Parameters	T °c	pH	TDS	Turb*	DO	BOD_5	PO_4	NO_3	F. C**
Al-Mothana Qaurter	1	*min.*	20.0	7.33	1016	6.20	4.92	2.00	0.03	0.79	150
		max	24.0	7.98	1084	28.9	7.70	7.00	0.41	3.54	1986
		meam	22.3	7.70	1045	15.2	5.97	4.70	0.19	2.38	625
		± Sd	1.05	0.22	18.54	7.68	1.07	1.49	0.14	0.72	676
	2	*min.*	21.0	7.30	926	0.15	2.08	2.00	0.02	3.16	64.0
		max	24.0	7.98	991	0.64	3.87	5.00	0.29	4.16	921
		meam	22.6	7.69	953	0.39	3.40	3.50	0.12	3.72	328
		± Sd	1.08	0.21	24.1	0.20	0.92	1.02	0.08	0.33	313
	3	*min.*	21.0	7.30	1120	0.49	2.92	2.00	0.03	8.44	154
		max	24.0	7.86	1181	19.0	6.90	4.00	0.29	10.3	1733
		meam	22.9	7.59	1168	5.19	4.88	2.80	0.11	9.15	651
		± Sd	0.90	0.20	29.79	5.45	1.10	0.87	0.07	0.47	476
	4	*min.*	20.0	7.34	226	2.00	6.02	1.00	0.02	0.39	219
		max	24.0	7.95	481	4.80	7.32	4.00	0.55	6.59	866
		meam	22.1	7.73	265	3.40	6.10	1.90	0.26	1.23	582
		± Sd	1.38	0.18	68.2	0.87	1.95	1.14	0.18	1.65	293
Al-Zohoor Qaurter	5	*min.*	20.0	7.14	534	0.54	2.60	8.00	2.21	1.10	170
		max	25.0	7.95	589	2.22	4.95	17.0	3.52	3.54	613
		meam	22.6	7.53	554	1.21	3.73	11.7	2.90	2.39	375
		± Sd	1.87	0.34	16.8	0.48	0.66	3.32	0.44	0.73	145
	6	*min.*	21.0	7.24	890	0.40	5.23	1.00	0.14	1.67	132
		max	25.0	7.99	1327	8.30	7.82	3.00	0.60	3.24	756
		meam	23.3	7.66	1114	1.93	6.59	1.70	0.30	2.46	391
		± Sd	1.29	0.24	130.0	2.44	0.71	0.78	0.16	0.37	189
	7	*min.*	21.0	7.53	1194	0.27	5.00	1.00	0.16	8.55	101
		max	24.0	7.96	1559	1.13	7.03	5.00	0.33	10.9	921
		meam	22.3	7,82	1373	0.64	5.94	2.30	0.22	9.17	394
		± Sd	0.96	0.12	47.0	0.58	0.60	1.19	0.06	0.56	261
Al-Sideq Qaurter	8	*min.*	21.0	7.38	809	0.12	3.02	1.00	0.03	8.53	400
		max	25.0	7.99	840	0.80	6.30	3.00	0.33	10.7	1433
		meam	23.6	7.80	820	0.33	3.62	1.70	0.20	9.23	970
		± Sd	1.16	0.17	9.78	0.24	1.05	0.64	0.09	0.51	511
	9	*min.*	22.0	7.34	650	0.11	3.08	1.00	0.02	9.20	189
		max	24.0	7.94	995	1.11	6.00	3.00	0.41	10.8	2420
		meam	23.5	7.74	697	0.41	4.02	1.50	0.16	9.66	775
		± Sd	0.70	0.19	86.8	0.29	0.81	0.67	0.12	2.20	710
	10	*min.*	22.0	7.44	964	0.15	3.96	1.00	0.08	3.26	579
		max	24.0	7.98	1254	7.20	6.82	3.00	0.51	10.3	2419
		meam	22.9	7.79	1073	2.15	5.99	1.50	0.21	7.30	1296
		± Sd	0.51	0,16	67.5	2.39	0.73	0.67	0.15	2.20	724
Al-Hadba Q.	11	*min.*	22.0	7.37	795	0.10	3.13	2.00	0.02	7.26	271
		max	24.0	7.92	1361	4.51	4.43	4.00	0.42	9.88	2420
		meam	23.6	7.71	1091	0.33	3.37	2.60	0.15	8.61	1407
		± Sd	0.66	0.17	190.2	0.18	0.43	0.92	0.14	0.58	871
	12	*min.*	22.0	7.40	762	0.10	2.90	1.00	0.03	7.99	345
		max	24.0	7.98	1514	1.41	4.50	10.0	0.31	10.5	2419
		meam	23.5	7.74	983	0.72	3.51	3.30	0.16	9.33	1496
		± Sd	0.66	0.17	260	0.66	0.53	2.93	0.10	0.58	830

*NTU ** cell. $100ml^{-1}$

from the cavities that may occur in the geological layers, these results are consistent with the results of (Talaat *et al.,* 2019; Al-Sardar and Al-Saffawi, 2019) in their studies of groundwater in Mosul city and its vicinity.

Assessment of groundwater for drinking

The uses of the water quality model NSFWQI explains the interference effects of different properties and finding a single value that expresses water quality for different uses, which facilitates classification, control and management of water sources continuously.

The NSFWQI model is one of the most universal models used for great accuracy in the weight of each of the characteristics, which is reflected in the accuracy on the results of water quality assessment (Hamdan *et al* 2018; Sharifinia *et al.*,2019), and the results of the model shown in table 5 indicate that All studied water wells are of the category (medium quality) for drinking purposes and civil uses, and this relative deterioration is mainly due to higher concentrations of total soluble salts, nitrate ions, and fecal coliform bacteria, which negatively influenced the sub-index values (Qi) as shown in table 6.

Conclusions & Recommendations

The studied well water was characterized by the rise of most of the studied criteria, especially the values of total dissolved salts, nitrate ions and the total number of faecal coliform bacteria with a low concentration of dissolved oxygen in water, which leads to a relative deterioration in its quality for drinking and domestic purposes, as it was 100% of the NSFWQI values from the medium quality water category for drinking and domestic uses. Therefore, we recommend periodic monitoring of these water sources with the use of some simple and easy techniques when needed to eliminate contaminants from well water and reduce the number of bacteria and make them suitable for use as a technology of freezing and slow thawing or solar radiation treatment technology (Al-Saffawi and Talaat, 2018; Al-Hamdany, 2018).

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