JAEHR
Journal of Advances in Environmental Health Research
J Adv Environ Health Res, 2023; 11(4): 246-252. doi: 10.34172/jaehr.1310
http://jaehr.muk.ac.ir

Original Article

Probabilistic Risk of Nitrates to Human Health Via Drinking Water: A Case Study of Water Supply for Dandan Station and its Quarters in Mosul, Iraq

Zahraa Anmar Mohtfer[1], **Abdulazeez Younis. T. Al-Saffawi**[1*]

[1]Department of Biology, College of Education for Girls, Mosul University, Mosul, Iraq

Article history:
Received: August 16, 2022
Accepted: January 2, 2023
ePublished: December 3, 2023

***Corresponding author:**
Abdulazeez Younis. T. Al-Saffawi,
Email: alsaffawia2025@uomosul.edu.iq

Abstract

Background: The primary objective of this study was to assess the nitrate ion concentration in drinking water and determine the potential health risks associated with nitrate contamination for humans.

Methods: A total of 100 water samples were collected from ten sites, including the Dandan water supply station and adjacent residential neighborhoods on the right side of Mosul city between September 2021 and February 2022.

Results: The results of the study revealed that the concentration of nitrate ions ranged between (0.95-3.614 mg/L). Based on the study's results, all of the analyzed water samples fell within the international drinking water quality standards set by the World Health Organization. The concentrations of nitrate ions corresponded to low values of both chronic daily intake (CDI) and hazard quotient (HQ or QI), which ranged from 0.05162 to 0.18164 mg/kg/day and 0.03226 to 0.11357, respectively. Consequently, the hazard index (HI) for this study remained within safe limits for drinking water. The study also revealed that infants and individuals within the age group of 21 and older were the most susceptible to potential nitrate-related health risks, while the age group of 16 to 18 exhibited the lowest susceptibility to such risks.

Conclusion: The study recommends the use of examined water for drinking due to its safe and healthy nitrate ion concentration. It further suggests the continuation of periodic assessments of drinking water supply stations to ensure ongoing consumer safety, as no potential health risks, including cancerous and non-cancerous risks, were identified.

Keywords: HHR_{NO3}, Water supply, Dandan station, Mosul city, Water quality

Please cite this article as follows: Mohtfer ZA, Al-Saffawi AYT. Probabilistic risk of nitrates to human health via drinking water: a case study of water supply for dandan station and its quarters in Mosul, Iraq. J Adv Environ Health Res. 2023; 11(4):246-252. doi:10.34172/jaehr.1310

Introduction

Freshwater resources, both surface and underground, are vital and indispensable for providing water for drinking, irrigation, and industrial purposes. They account for only 2.5% of the planet's surface water, with a significant portion existing in the form of ice and snow, making it less accessible for human use.[1] In recent decades, the world has witnessed the effects of climate change and declining rainfall, particularly in arid and semi-arid regions like Iraq.[2] Iraq faces a compounded issue as its surface water sources are limited, and the Tigris and Euphrates rivers, along with their tributaries, originate in neighboring countries that control the flow of these rivers. The construction of dams and water storage projects in Turkish territories has led to a significant reduction in the volume of water reaching Iraq, often disregarding international laws concerning shared international waters. In 2004, the combined discharge of the Euphrates and Tigris rivers amounted to 81.5 billion cubic meters, but this decreased to a 38.11 million cubic meters annually in 2005. Reports suggest that the Tigris and Euphrates rivers in Iraq could face the risk of drying up if neighboring countries persist in constructing dams and water projects.[3-5]

During dry seasons, the flow of the Tigris river within Iraq significantly decreases due to increased human activities. This surge in water consumption leads to a notable increase in the discharge of municipal, agricultural, and industrial wastewater into the river through numerous estuaries on both sides. This deterioration in water quality raises the likelihood of health risks for consumers who rely on the Tigris River as a source of raw water for water supply stations in Iraq, including Mosul. These risks encompass an elevated presence of bacteria, viruses, parasites, as well as toxic substances such as heavy metals, nitrate ions, fluorides, among others.

Hence, it is crucial to conduct regular studies and perform periodic checks on water sources and water supply stations to safeguard the health of consumers.[6,7]

Of the most common methods of assessing drinking water in the world for hazardous substances are the approaches proposed by the US Environmental Protection Agency (EPA).[8] They are the most important method for estimating the degrees of potential risks of drinking water pollutants such as nitrates and heavy metals. The methods also provide scientific guidance and recommendations for drinking water supply stations.[9-11]

Nitrate ions are naturally prevalent which can enter the human body. Approximately 85% of nitrate intake in humans is attributed to vegetables, while the remaining percentage is obtained from drinking water.[12] The quantity of water consumed by individuals varies depending on factors such as age, environment, and seasons. In Mosul city, summer temperatures can increase above 45 °C, leading to increased daily consumption of drinking water. This, in turn, results in a higher intake of nitrates into the digestive system.[13] The US EPA[14] has established maximum limits for nitrate levels in drinking water, with a standard of 10 ppm for NO3-N or 50 ppm of NO3. Hence, routine and systematic monitoring of public water supplies, including nitrate ions, is essential. Elevated nitrate levels pose a heightened risk of Blue Baby Syndrome, particularly for infants and the elderly.[15] Researches indicate an association between long-term exposure of pregnant women to elevated nitrate concentrations and adverse impacts on both the fetus and newborns[16], as well as hindering fetal development within the mother's womb and increasing the risk of miscarriage. Exposure to oxidative stress is one of the putative mechanisms for spontaneous preterm birth.[17-19] Beyond its carcinogenic effects resulting from nitrate reduction when entering the mouth to form nitrite ions, nitrates can potentially interact with amines and amides in the digestive system, leading to the formation of N-nitrosamine compounds (NOCs), as illustrated in the equation 1[20]:

$$R_2NH\ (\text{amines}) + NO_2 \rightarrow R_2N{-}N{=}O\ (\text{nitrosamine}) \qquad (1)$$

most of which have carcinogenic and mutagenic properties, contributing to conditions such as leukemia, stomach, colon, rectal cancers, oral ulcers, and genital issues, as well as increased risks of sudden death, birth defects, and miscarriages in pregnant women.[21,22] Fortunately, the presence of ascorbic acid, polyphenols, and other compounds in high concentrations in most vegetables serves to inhibit the formation of NOC compounds, providing protection for human health against these serious diseases.[22,23] Therefore, this study aimed to estimate both the nitrate ion concentrations and the associated health risks in the drinking water supply of the Dandan water station and its connected neighborhoods on the right side of Mosul city.

Materials and Methods

The Study Area

The study area is located to the west of Tigris River in the south of Mosul. The station was established in the mid-20th century to provide water to the neighborhoods of Al-Dandan, Jawsaq, Al-Dawas, Al-Nabi Sheet, Al-Sijin, Bab Al-Jadid, Bab Al-Beidh, Al-Akeedat, and others, with a daily production capacity of 45 000 cubic meters. The geology of the study area is characterized by the presence of the Al-Fatha formation containing gypsum ($CaSO_4{\cdot}2H_2O$), anhydrite ($CaSO_4$), and dissolved evaporation salts in the water. This composition increases the likelihood of erosion and damage to the water supply network pipes, leading to potential contamination of drinking water. This is primarily due to pressure imbalances within the pipes and the infiltration of sewage, especially in the context of the growing trend of directly connecting water pumps to the network pipes.[13-24] Figure 1 and Table 1 summarize the characteristics of the studied area.

Methodology

In this study, ten sites were chosen for water sample collection, encompassing both untreated raw water from the Tigris River (pre-treatment) and treated water (post-treatment). Additionally, samples were collected from the surrounding residential neighborhoods of the station. This data collection occurred over the period spanning from September 2021 to February 2022, with ten replicates taken at each site. The samples were collected using clean polyethylene bottles from the specified sites after opening the water tap for several minutes before filling the bottles. Then, the samples were placed in a cooler box and away from the light.

The concentration of nitrate ions was determined by ultraviolet spectroscopy method at wavelengths of 220 and 270 nm according to previous studies.[25,26]

Calculate the Potential Risks of Nitrates to Human Health

The risks of drinking water were estimated by applying the model indicated by the US EPA. It serves as a valuable and effective tool for evaluating the health risks associated with nitrates for consumers of drinking water. The calculations for assessing these risks are based on the equations provided by previous studies.[27-30] It is as follows (equations 2 and 3):

$$CDI = \frac{Ci \times IR \times EF \times ED}{BW \times AT} \qquad (2)$$

$$QI_{\text{Nitrate}} = HI = \frac{CDI}{\text{RfD oral}} \qquad (3)$$

where CDI is chronic daily intake and HI nitrate is equal to HQ. Also, Ci is nitrate concentration for aqueous samples, IR is the daily rate of drinking water (l. day-1), EF is frequency of exposure to nitrates according to age (day and years), ED is nitrate exposure period (years), BW

Figure 1. Satellite Image of the Dandan Water Plant and Residential Quarters (the right side of the Tigris River, south of Mosul city)

Table 1. Characteristics of Dandan Water Supply Plant and the Residential Quarters on the Right Side of Mosul City

Sites	Latitude	Longitude	Altitude	Uses
S1	36°33′54″ N	43°14′65″ E	231 m	Drinking and domestic uses
S2	36°33′50″ N	43°14′47″ E	213 m	
S3	36°33′12″ N	43°14′25″ E	240 m	
S4	36°33′13″ N	43°14′02″ E	240 m	
S5	36°32′87″ N	43°13′75″ E	235 m	
S6	36°33′40″ N	43°13′66″ E	246 m	
S7	36°33′35″ N	43°13′05″ E	246 m	
S8	36°33′06″ N	43°12′90″ E	232 m	
S9	36°32′75″ N	43°13′57″ E	235 m	
S10	36°32′71″ N	43°14′65″ E	213 m	

is body weight for each age group (kg), AT is mean time (day), and RfD is reference dose for Nitrate (1.6 mg/kg/d).

These factors are extracted based on previous evidence.[10,31,32]

Results and Discussion

The results revealed that the hazard quotient values of the Dandan station are higher in infants compared to other age groups. The values ranged between 0.08561 and 0.10694, as illustrated in Table 2. The increase in the values is due to the high values of CDI, which ranged between (0.13698 – 0.17110 mg/kg/d). These values are notably lower than the values reported in a prior study[22] concerning the human health risks associated with nitrates in the water sources of Al-Manara village, located to the north of Mosul city. In that study, the HI and CDI values for infants ranged between 0.4942 to 0.5432 and 0.7907 to 0.8691 mg/kg/d, respectively. However, our findings were relatively similar to those found in another study[15] which investigated the sources of drinking water in the village of Abu Wajna, located to the west of Mosul city. In that study, the values ranged between 0.0466 to 0.1125 for HI and 0.0746 to 0.1800 mg/kg/d for CDI. Similarly, in the age group of >21 years, there is higher values of CDI among females compared to males. These CDI values for females ranged between 0.07413 to 0.13288 mg/kg/d, resulting in a HQ value of 0.08305. In contrast, the CDI values for males did not surpass 0.05299 in this age group.

In regard to the remaining age groups examined, the HI values ranged from 0.0226 to 0.07180. Notably, the age group (16 to 18) exhibited comparatively lower susceptibility to nitrate-related risks in comparison to other age groups, with the CDI and HI values fluctuating within the range of 0.05245 to 0.09253 mg/kg/d and 0.03278 to 0.05783, respectively. This finding is supported by Al-Bhar and Al-Saffawi's study,[22] which also identified the age group (16-18) years as the least affected by nitrate exposure. In general, the risk quotient values for the age groups were as follows: Infant >)6 to 11(> (>21- Females) > (18 to 21) > (>21- Males) > (11 to 16) > (16 to18).

Limited research has been conducted in Iraq. Some studies have been conducted by the University of Mosul. Our study's findings show similar results to those reported in previous studies[33] involving water supply stations in the old Al-Yasir, Al-Zohour, Al-Saheroon, and the residential neighborhoods on the left side of Mosul. In this context, the values did not exceed risk quotient values (0.0480, 0.0256, 0.0307) and the CDI of nitrates (0.0768, 0.0441, 0.0492 mg/kg/d). The age group (16 to 18 years) exhibited lower susceptibility to nitrate-related risks compared to the other studied age groups, with consecutive risk quotient

Table 2. Results of chronic daily intake (mg/kg/d) and risk quotient (HI) values of nitrates in drinking water

Cohorts	Sites	Infants	6-11	16-11	18-16	21-18	>21	
							Females	Males
CDI	S1	0.148	0.093	0.068	0.056	0.072	0.080	0.069
HI		0.092	0.058	0.043	0.035	0.045	0.050	0.043
CDI	S2	0.182	0.115	0.084	0.068	0.088	0.098	0.085
HI		0.114	0.072	0.052	0.043	0.055	0.061	0.053
CDI	S3	0.137	0.087	0.063	0.052	0.066	0.074	0.064
HI		0.086	0.054	0.040	0.032	0.055	0.046	0.040
CDI	S4	0.164	0.104	0.757	0.062	0.080	0.089	0.077
HI		0.103	0.065	0.473	0.039	0.050	0.056	0.048
CDI	S5	0.162	0.103	0.075	0.061	0.079	0.088	0.076
HI		0.102	0.064	0.047	0.038	0.049	0.055	0.047
CDI	S6	0.169	0.155	0.113	0.093	0.119	0.133	0.115
HI		0.106	0.097	0.071	0.058	0.074	0.083	0.072
CDI	S7	0.149	0.094	0.069	0.056	0.072	0.080	0.069
HI		0.093	0.059	0.043	0.035	0.045	0.050	0.043
CDI	S8	0.146	0.093	0.067	0.055	0.071	0.079	0.068
HI		0.091	0.058	0.042	0.034	0.044	0.049	0.043
CDI	S9	0.139	0.088	0.064	0.052	0.067	0.075	0.065
HI		0.087	0.055	0.040	0.033	0.042	0.047	0.041
CDI	S10	0.171	0.108	0.079	0.064	0.083	0.093	0.080
HI		0.107	0.067	0.049	0.040	0.052	0.058	0.050

HI, hazard index; CDI, chronic daily intake.

(HI) values not exceeding (0.0221, 0.0126, 0.0141).

Our findings were similar to the found health risks associated with nitrates in the water sources of Abu Wajna village, located to the northwest of Mosul city, where they reported a range of HI values from 0.125 to 0.0147.[15] These values were notably lower than those reported in Al-Manara village, located to the northeast of Mosul city, in which the risk quotient value was as high as 0.5432.[22]

Overall, the risk quotient values for all studied age groups remained within safe limits as recommended by the US Environmental Protection Agency ($HI = HQ \geq 1.0$).[8,15] Exceeding these recommended limits can lead to severe health implications for consumers.[34,35] Research has shown that nitrite and nitrate compounds have the potential to cross the placental barrier within the pregnant mother's womb, affecting fetal health. Furthermore, a strong correlation has been established between elevated nitrate concentrations (≥ 10 mg/L) and the risk of premature birth, birth defects, and spontaneous abortion.[16,36] Additionally, research has highlighted a significant association between high nitrate levels and certain types of cancer, such as breast cancer in women, as well as cancer of the rectum, bladder, and pancreas, particularly in individuals with diets rich in amines and those who smoke. However, the consumption of fruits and vegetables rich in antioxidants has been found to inhibit the formation of nitrosamine compounds, thereby offering protection against various health risks. The decrease in the values of the CDI of nitrates and the risk quotient (HI) are mainly due to the decrease in the concentration of nitrate ions as shown in Table 3 and Figure 2, which did not exceed the permissible limits for drinking according to international standards.[37] The raw water values at Site 1, sourced from the waters of the Tigris River, ranged from 0.696 to 3.601 mg/L, with an average of 2.072 ± 0.887 mg/L.

The increase in concentrations can be attributed to the unprocessed discharge of sewage water from Mosul through numerous estuaries on both sides of the river. These estuaries contain organic materials, which undergo a transformation where microorganisms convert amino acids into ammonium ions through the action of the deaminase enzyme. Subsequently, these ammonium ions are oxidized aerobically to nitrate by Nitrosomonas bacteria in a process known as nitrification, as demonstrated by the equations 4 and 5[38,39]:

$$R - NH_{2\ \text{Organic matter}} \longrightarrow NH_4^+ + OH^- \quad (4)$$

$$NH_4^+ + O_2 \longrightarrow 2H_2O + NO_3^- + 2H^+ \quad (5)$$

Table 3 and Figure 2 also highlight the notably high nitrate concentrations, particularly at sites (4, 5, 6, 10). This elevation in nitrate levels may be attributed to the contamination of the drinking water supply with sewage and septic tank effluents, potentially resulting from the direct connection of water pumps to the network pipes. Such connections increase the risk of contamination in the event of pipe breaks at connection sites, with

Table 3. The Concentration of Nitrate Ions in the Water Supply of Dandan Station and its Neighborhoods (mg/L)

Sites	Replicators									
	2021							2022		
	7/11	22/11	28/11	5/12	12/12	15/12	22/12	2/1	16/ 1	20/2
S1	2.282	1.557	1.991	3.601	2.105	1.643	2.87	0.696	2.294	2.529
S2	2.622	2.505	2.176	2.29	2.211	1.564	1.559	0.901	2.141	2.148
S3	1.453	1.454	2.188	2.294	2.799	1.741	3	0.95	2.188	1.557
S4	2.295	2.364	2.199	2.283	2.635	1.623	2.905	1.658	2.223	2.262
S5	1.991	2.049	2.164	2.611	3.416	1.147	3.548	1	2.094	2.786
S6	2.517	2.019	2.105	1.434	3.614	1	3.469	2.776	2.082	2.77
S7	1.721	1.98	2.004	2.214	2.482	1.505	1.803	1.972	2.141	1.972
S8	1.639	2.166	2.517	2.341	1.721	1.47	1.717	1.458	2.223	1.799
S9	2.411	2.282	1.557	2.164	2.552	1.388	1.967	1.065	2.188	1.738
S10	6.196	2.258	2.141	2.211	1.885	0.885	2.541	1.576	2.023	2.305

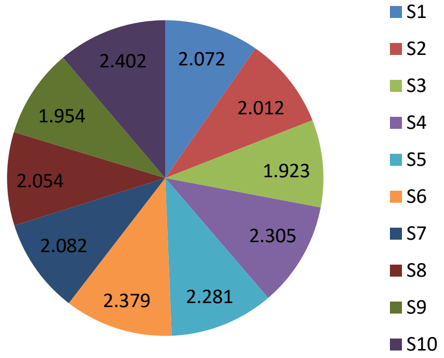

Figure 2. Average Concentration of Nitrate Ions in Water Supply of Dandan Station and its Neighborhoods (mg/L)

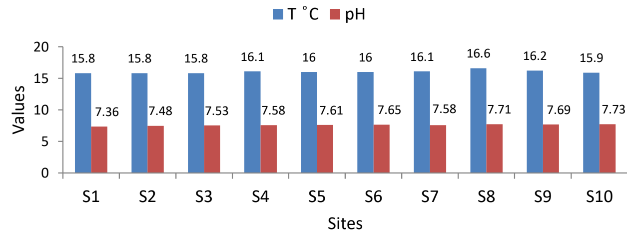

Figure 3. Water Temperature and pH Values for the Water Supply of Dandan Station and its Neighborhoods

concentrations reaching as high as 3.614 mg/L and an average of 2.402 mg/L. A decrease in the pH of the aquatic environment can slow down the nitrification process due to reduced growth and activity of nitrifying bacteria. Because the ideal pH for Nitrosomonas and Enterobacteriaceae ranges from 7.5 to 8.5, most nitrification processes may stop when the pH falls below 6.0. The speed of these reactions is influenced by water temperature, with slower rates observed when the temperature falls below 20 °C or rises above 40 °C. Regarding the studied water temperature displayed in Figure 3, it fluctuated between 15.8 and 16.6 °C, which directly affected the growth and activity of nitrifying bacteria. Additionally, the pH levels remained close to the relatively ideal state.[33]

These findings were similar to the study by Al-Hamadany et al,[24] which investigated the water quality of the old Al-Yaser station and its associated neighborhoods, yielding a nitrate concentration of 3.16 mg/L. Additionally, our results are consistent with the nitrate concentration reported by Al-Dulaimi and Younes[40] for the Tigris River, which amounted to 2.78 mg/L. When comparing the nitrate ion concentrations in our study with other regions around the world, it becomes evident that certain water resources exhibit significantly higher concentrations. For example, in the Guanzhong Basin and Xinzhou Basin of China, as well as in the provinces of Mahbubnagar and Nalgonda, nitrate concentrations have been reported to reach as high as 90, 44, 504, 880 mg/L, respectively.[10,29,33]

Generally, the consumption of nitrates at low concentrations, whether through drinking water or nitrate-rich vegetables, triggers the activation of nitrate ions, converting them into nitrites and subsequently into nitrogen oxide. This process plays a crucial role in the regulation and reduction of systolic blood pressure, contributing to the prevention of various cardiovascular diseases.[41,42]

Conclusions and Recommendations

This is one of the few rare studies in Iraq that has examined the potential health risks associated with nitrates. Our findings revealed that the nitrate level in the drinking water supplied to Dandan station was significantly below the global permissible limits. The risk quotient values for nitrates were low for all age groups and below the dangerous levels to human health. We found that the infant group was the most who affected by nitrate, followed by children aged 6-11, while the youth group (18 to 21years) was less affected by the nitrate. As a result, this study recommends the use of the examined water for drinking purposes due to its healthy and safe nitrate ion concentrations. No potential health risks, whether related to cancer or non-cancerous conditions, have been identified. It is further suggested to continue conducting periodic assessments of drinking water supply stations to ensure the ongoing safety of consumers.

Acknowledgments
The researchers express their appreciation to the University of Mosul, particularly Prof. Qusay Kamal Al-Din Al-Ahmadi and the Deanships of the College of Education for Pure Sciences and the College of Education for Girls, for their unwavering support and provision of all research requirements. We would also like to extend our appreciation to our colleagues for their invaluable assistance and support throughout the research process.

Authors' Contribution

Conceptualization: Zahraa Anmar Mohtfer.
Data curation: Abdulazeez Younis. Abdulazeez Younis. T. Al-Saffawi.
Formal analysis: Abdulazeez Younis. Abdulazeez Younis. T. Al-Saffawi.
Funding acquisition: Abdulazeez Younis. Abdulazeez Younis. T. Al-Saffawi, Zahraa Anmar Mohtfer.
Investigation: Abdulazeez Younis. T. Al-Saffawi.
Methodology: Abdulazeez Younis. T. Al-Saffawi.
Project administration: Abdulazeez Younis. T. Al-Saffawi.
Resources: Abdulazeez Younis. T. Al-Saffawi.
Software: Abdulazeez Younis. T. Al-Saffawi.
Supervision: Abdulazeez Younis. T. Al-Saffawi.
Validation: Abdulazeez Younis. T. Al-Saffawi.
Visualization: Zahraa Anmar Mohtfer.
Writing–original draft: Abdulazeez Younis. T. Al-Saffawi, Zahraa Anmar Mohtfer.
Writing–review & editing: Abdulazeez Younis. T. Al-Saffawi, Zahraa Anmar Mohtfer.

Competing Interests

The authors declare that they have no competing interest.

Ethical Approval

Not applicable.

Funding
This study was supported by College of Education for Pure Sciences and the College of Education for Girls.

References

1. Snousy MG, Morsi MS, Elewa AMT, Ahmed SAE, El-Sayed E. Groundwater vulnerability and trace element dispersion in the Quaternary aquifers along middle Upper Egypt. Environ Monit Assess. 2020;192(3):174. doi: 10.1007/s10661-020-8109-5.
2. Chen F, Yao L, Mei G, Shang Y, Xiong F, Ding Z. Groundwater quality and potential human health risk assessment for drinking and irrigation purposes: a case study in the semiarid region of north China. Water. 2021;13(6):783. doi: 10.3390/w13060783.
3. Al-Sallal TZ, Al-Saffawi AY. Sub-Index model to assess groundwater water quality for drinking and civil uses. Nativa. 2023;11(3):438-44. doi: 10.31413/nativa.v11i3.15910.
4. Al-Ansari N. The dangers of the water crisis in Iraq, causes and ways of treatment. Al Jazeera Center for Studies reports. 2018:1-9. [Arabic].
5. Mohtfer ZA, Al-Saffawi AY. Human health risks with fluoride ions via drinking water of Al-Daden water supply station in Mosul city, Iraq. HIV Nurs. 2022;22(2):1352-6.
6. Al-Assaf AY, Al-Saffawi AY. Quality assessment of Tigris river water by using (WQI) for drinking with in Nineveh Governorate. In: 9th Periodic Conference of the Center for Scientific Research Dams and Water Resources Mosul University; 2018. p. 189-200.
7. Givi M, Jahangiri-Rad M, Tashauoei H. Assessment of groundwater quality in the Jajrood river basin, Tehran, Iran: a coupled physicochemical and hydrogeochemical study. J Adv Environ Health Res. 2021;9(3):237-54. doi: 10.32598/jaehr.9.3.1221.
8. United States Environmental Protection Agency (USEPA). Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A), Interim Final. Washington, DC: USEPA; 1989.
9. Huang Y, Zuo R, Li J, Wu J, Zhai Y, Teng Y. The spatial and temporal variability of groundwater vulnerability and human health risk in the Limin district, Harbin, China. Water. 2018;10(6):686. doi: 10.3390/w10060686.
10. Zhang Q, Xu P, Qian H. Assessment of groundwater quality and human health risk (HHR) evaluation of nitrate in the Central-Western Guanzhong Basin, China. Int J Environ Res Public Health. 2019;16(21):4246. doi: 10.3390/ijerph16214246.
11. Yahaya TO, Oladele EO, Fatodu IA, Abdulazeez A, Yeldu YI. The concentration and health risk assessment of heavy metals and microorganisms in the groundwater of Lagos, Southwest Nigeria. J Adv Environ Health Research. 2020;8(3):225-33. doi: 10.22102/jaehr.2020.245629.1183.
12. Blaisdell J, Turyk ME, Almberg KS, Jones RM, Stayner LT. Prenatal exposure to nitrate in drinking water and the risk of congenital anomalies. Environ Res. 2019;176:108553. doi: 10.1016/j.envres.2019.108553.
13. Mohtfer ZA, Al-Saffawi AY. Using the organ model (OWQI) to evaluate Al-Dandan water supply station and its residential quarters, Mosul, Iraq. Int J Appl Sci Eng Rev. 2022;3(4):44-57. doi: 10.52267/ijaser.2022.3405.
14. United States Environmental Protection Agency (USEPA). Guidelines for Carcinogen Risk Assessment. Risk Assessment Forum. Washington, DC: USEPA; 2005.
15. Al-Saffawi AY, Awad MH. Human health risk (HHR) of Nitrates in the groundwater of Abuwajnah village, Tal Afar district Iraq. World J Pharm Life Sci. 2020;6(8):13-9.
16. Sherris AR, Baiocchi M, Fendorf S, Luby SP, Yang W, Shaw GM. Nitrate in drinking water during pregnancy and spontaneous preterm birth: a retrospective within-mother analysis in California. Environ Health Perspect. 2021;129(5):057001. doi: 10.1289/ehp8205.
17. Tarquini F, Picchiassi E, Coata G, Centra M, Bini V, Meniconi S, et al. Induction of the apoptotic pathway by oxidative stress in spontaneous preterm birth: single nucleotide polymorphisms, maternal lifestyle factors and health status. Biomed Rep. 2018;9(1):81-9. doi: 10.3892/br.2018.1103.
18. Coffman VR, Jensen AS, Trabjerg BB, Pedersen CB, Hansen B, Sigsgaard T, et al. Prenatal exposure to nitrate from drinking water and markers of fetal growth restriction: a population-based study of nearly one million Danish-born children. Environ Health Perspect. 2021;129(2):27002. doi: 10.1289/ehp7331.
19. Aung MT, Yu Y, Ferguson KK, Cantonwine DE, Zeng L, McElrath TF, et al. Prediction and associations of preterm birth and its subtypes with eicosanoid enzymatic pathways and inflammatory markers. Sci Rep. 2019;9(1):17049. doi: 10.1038/s41598-019-53448-z.
20. Bryan NS, van Grinsven H. The role of nitrate in human health. Adv Agron. 2013;119:153-82. doi: 10.1016/b978-0-12-407247-3.00003-2.
21. Shannon OM, Easton C, Shepherd AI, Siervo M, Bailey SJ, Clifford T. Dietary nitrate and population health: a narrative review of the translational potential of existing laboratory studies. BMC Sports Sci Med Rehabil. 2021;13(1):65. doi: 10.1186/s13102-021-00292-2.
22. Al-Bhar BM, Al-Saffawi AY. Health effects of nitrate concentrations in the groundwater of Al-Manara village, north-east of Mosul city, Iraq. Sci Arch. 2021;2(3):267-71.
23. Ward MH, Jones RR, Brender JD, De Kok TM, Weyer PJ, Nolan BT, et al. Drinking water nitrate and human health: an updated review. Int J Environ Res Public Health. 2018;15(7):1557. doi: 10.3390/ijerph15071557.

24. Al-Hamadany MA, Al-Saffawi AY, Al-Shaherey YJ. Assessment of drinking water quality using the NSFWQI model between source and consumer in Mosul city, Iraq. Sci Arch. 2021;2(4):324-9. doi: 10.47587/sa.2021.2409 .
25. American Public Health Association (APHA). Standard Methods for the Examination of Water and Wastewater. 20th ed. Washington, DC: APHA; 1998.
26. American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF). Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC: APHA, AWWA, WEF; 2017.
27. Shamsuddin AS, Syed Ismail SN, Abidin EZ, Ho YB, Juahir H. Contamination of nitrate in groundwater and evaluation of health risk in Bachok, Kelantan: a cross-sectional study. Am J Appl Sci. 2016;13(1):80-90. doi: 10.3844/ajassp.2016.80.90.
28. Qasemi M, Afsharnia M, Farhang M, Ghaderpoori M, Karimi A, Abbasi H, et al. Spatial distribution of fluoride and nitrate in groundwater and its associated human health risk assessment in residents living in Western Khorasan Razavi, Iran. Desalin Water Treat. 2019;170:176-86. doi: 10.5004/dwt.2019.24691.
29. Chen F, Yao L, Mei G, Shang Y, Xiong F, Ding Z. Groundwater quality and potential human health risk assessment for drinking and irrigation purposes: a case study in the semiarid region of north China. Water. 2021;13(6):783. doi: 10.3390/w13060783.
30. Zhang Q, Qian H, Xu P, Li W, Feng W, Liu R. Effect of hydrogeological conditions on groundwater nitrate pollution and human health risk assessment of nitrate in Jiaokou Irrigation District. J Clean Prod. 2021;298:126783. doi: 10.1016/j.jclepro.2021.126783.
31. Tian H, Liang X, Gong Y, Qi L, Liu Q, Kang Z, et al. Health risk assessment of nitrate pollution in shallow groundwater: a case study in China. Pol J Environ Stud. 2020;29(1):827-39. doi: 10.15244/pjoes/104361.
32. Thang NQ, Tho NT, Phuong NT. Nitrate, nitrite, and lead contamination in leafy vegetables collected from local market sites of Go Vap district, Ho Chi Minh City. Vietnam J Chem. 2021;59(1):79-86. doi: 10.1002/vjch.202000124.
33. Al-Hamadany MA. Acomparative Study of Algae Qualitative Distribution in Selected Aquatic Environments in Nineveh Governorate [thesis]. Mosul, Iraq: College of Education for Pure Science; 2022. [Arabic].
34. Wu J, Lu J, Wen X, Zhang Z, Lin Y. Severe nitrate pollution and health risks of coastal aquifer simultaneously influenced by saltwater intrusion and intensive anthropogenic activities. Arch Environ Contam Toxicol. 2019;77(1):79-87. doi: 10.1007/s00244-019-00636-7.
35. Paladino O, Seyedsalehi M, Massabò M. Probabilistic risk assessment of nitrate groundwater contamination from greenhouses in Albenga plain (Liguria, Italy) using lysimeters. Sci Total Environ. 2018;634:427-38. doi: 10.1016/j.scitotenv.2018.03.320.
36. Shamsuddin AS, Syed Ismail SN, Sham SM, Abidin EZ. Nitrate in groundwater and excretion of nitrate and nitrosamines in urine: a review. Int J Sci Basic Appl Res. 2014;15(2):176-91.
37. World Health Organization (WHO). Guidelines for Drinking-Water Quality. 4th ed. Switzerland: WHO; 2017. p. 631.
38. Al-Hamdany NA, Al-Shaker YM, Al-Saffawi AY. Application of nitrate pollution index (NPI) to evaluate the health safety of wells water for some quarters of the leftside of Mosul city, Iraq. Biochem Cell Arch. 2020;20(2):6063-8.
39. Zarama-Alvarado S. The challenges of dealing with nitrogen pollutants in groundwater. Rev Cient. 2018;3(33):230-42. doi: 10.14483/23448350.13545.
40. Al-Dulaimi GA, Younes MK. Assessment of potable water quality in Baghdad city, Iraq. Air Soil Water Res. 2017;10:1178622117733441. doi: 10.1177/1178622117733441.
41. Gee LC, Massimo G, Lau C, Primus C, Fernandes D, Chen J, et al. Inorganic nitrate attenuates cardiac dysfunction: roles for xanthine oxidoreductase and nitric oxide. Br J Pharmacol. 2022;179(20):4757-77. doi: 10.1111/bph.15636.
42. Li D, Nishi SK, Jovanovski E, Zurbau A, Komishon A, Mejia SB, et al. Repeated administration of inorganic nitrate on blood pressure and arterial stiffness: a systematic review and meta-analysis of randomized controlled trials. J Hypertens. 2020;38(11):2122-40. doi: 10.1097/hjh.0000000000002524.