International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

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Assessment of surface water quality and groundwater in Wasit Governorate, Iraq

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International Journal of Science and Research Archive, 2025, 15(01), 1087-1105

Publication history: Received on 07 March 2025; revised on 16 April 2025; accepted on 18 April 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.1.1040

Abstract

The purpose of this research paper was to evaluate the quality of the Tigris River and surface water in the state of Wasit, Iraq, over the period of January to November 2024. Water samples were collected from five areas along the river and water from 5 wells. The collected water samples at each site have been sent to the Wasit Central Laboratory for physical, chemical, and microbiological testing. Water quality index was calculated from the collected water samples for assessing the water quality. The results indicated that the WQI of surface water in the Tigris River in the autonomous region ranges from 352.3 to 1106.5, which is 2.0 and 6.3 times larger than the WQI standard, ranging from 301.3, which is. The standard is large, 1.5 and 1.7 times more than WQI. Results indicated that the quality of groundwater is the best in comparison with river quality. Deterioration of water quality in the Tigris might be linked to the discharge of partially treated wastewater.

Keywords: Water Quality Assessment; Surface and Ground Water; WQI; Wasit Governorate; Iraq

1. Introduction

The MENA area comprises Iraq and is approximately 433,970 square kilometers large. As shown in Figure 1, the population of the region is about 32 million people. Almost 12 MENA countries are facing acute water scarcity. In fact, less than 500 cubic meters of renewable fresh water resources per capita, which is a basic need for human survival, are being supplied in these countries. The region's economic and social developments and political stability one cubic meter of water can provide drinking water to a person for a year, and the same amount can, when used for irrigation in dry climates, where only 1 kilogram of grain is reported to be produced. This is the region’s largest water consumer. Agriculture uses 66% of the water demand in the case of moving away from the sector. A 10% water transfer would mean that the national water supply in Jordan would increase by 40%[1, 2].

Turkey is 352 kilometers to the north, Iran is 1,458 kilometers to the east, Syria and Syria to the west are 605 and 181 kilometers, respectively, and Saudi Arabia and Kuwait are 814 and 240 kilometers to the south (Figure 1). Four regions make up the geography of Iraq (Figure 1). Only the north and northeast of Iraq are home to mountainous regions, which make roughly 5% of the country's total land. The Taurus-Zagrus mountain range includes this area. The second section, which makes about 15% of the entire territory of Iraq, is the plateau and mountain regions. The Mesopotamian lowlands to the south and hilly regions to the north encircle the region. The Tigris and Euphrates were the only two major rivers in the third region, the Mesopotamian plains. It makes up 20% of all of Iraq. From Samarra in the north to the Tigris River, the Hittite cities, the Euphrates River, and, in the south, the Gulf of Thailand, the plain extends. Jaseira and the Western Highlands are the remaining regions of Iraq, which make about 60% of the country's total area [3, 4, 5].

Iraq is believed to have significant water resources in comparison to other countries. Its annual per capita allotment was 6,029 square meters in 1995 and is expected to increase to 2,100 square meters by 2015. Dams are being constructed on the Tigris and Euphrates rivers and their tributaries outside the Iraqi border. The main causes of Iraq's

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water scarcity are inadequate water resource management and the consequences of climate change. The need for water in Turkey and Syria is increasing as marshes are being restored. The Tigris and Euphrates rivers will dry out by 2040. Additionally, it is projected that supply will reach 43 and 17.61 BCM in 2015 and 2025, respectively, whereas demand would be between 66.8 and 77 BCM at this time. This suggests that swift, deliberate, and decisive action should be the Iraqi government's top priority. One solution to the issue is to use water collection systems. Resolving these problems in Iraq requires careful management of water resources and the use of non-traditional techniques to increase water resources [6, 7, 8].

Figure 1 Wasit Governorate

Figure 2 Sampling points

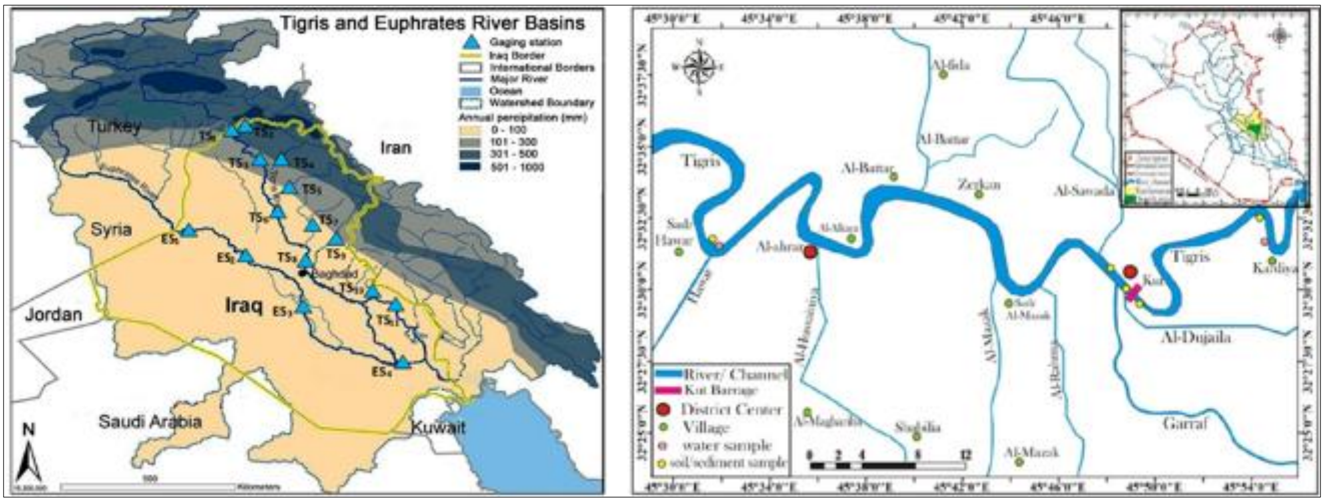

Figure 3 Tigris River, Wasit Governorate

The predominant climates are subtropical, semi-arid, and continental; the mountainous regions have a Mediterranean climate, with rain typically falling between December and February or between November and April; the average daily temperature in the winter is 16°C with nighttime lows of 2°C, and it may even snow; however, the summer months are extremely hot, with average temperatures rising above 45°C in July and August and dropping to 25°C at night (Fig. 1).

Although water is an essential component of the environment, groundwater and its quality have long been degraded due to both natural and man-made activities. The primary natural factors affecting water quality are hydrological, atmospheric, climatic, topographic, and geological factors; the main man-made factors include mining, livestock, and the generation and disposal of waste (industrial, municipal, and agricultural); anthropogenic activities include increased sediment runoff or soil erosion or heavy metal pollution as a result of changes in land use [9, 10, 11].

1.1. Physical parameters of water quality

This is an example of Inverted Reality: "a lazy person is nothing less than a dirty lake." The amount of suspended particles in water that prevents light from penetrating is measured by the Laziness Level Soil, silt, organic matter, plankton, water particles, and other elements in suspension are examples of this type of material.

Temperature affects the compounds' flavor, viscosity, solubility, fragrance, and chemical reactivity, including the processes of precipitation and chlorination. Temperature also affects the biochemical oxygen demand, or BOD. Additionally, it affects how heavy metals dissolved in water are absorbed. The majority of participants in research on the ideal drinking water temperature stated that the best outcomes occurred between 10 and 15°C [12, 13, 14].

Organic materials, particularly plants, and inorganic elements, such soil and rocks, are not suitable for a water color from an aesthetic standpoint due to the breakdown of organic materials (things are decomposing from sources), but not for health concerns [15, 16].

A variety of elements, including organic waste, inorganic compounds, and dissolved gasses, contribute to the water's unpleasant taste and odor, which is unacceptable from the standpoint of public health. These compounds may have household, agrarian, or natural origins [17, 18].

In water, solids are suspended or in solution. The various types of solids present in the water can be identified using a fiberglass filter. As their definition of the filtered material, the suspended solids will remain on the filter [15, 16].

This pH factor is one of the most fundamental water quality metrics. It is a number whose absolute value is the logarithm of the hydrogen ion concentration expressed as an exponent of ten. The strength of an acid or base is represented by this unitless integer. The question of how ac/alk the H2O molecule is is actually answered by this measurement. If there are too many hydrogen ions in the water, it becomes acidic; if there are too many hydroxy ions, it gets basic [17, 18].

The total of all titratable bases' ability to neutralize acids is the alkalinity of water. To determine the amount of soda powder needed to soften the water, for instance, to prevent corrosion in boiler feedwater pretreatment, the alkalinity of the water must be assessed. Generally speaking, hydroxide ions (OH), bicarbonate ions (HCO_3^-), and carbonate ions (CO_3^{2-}) or the combination of these ions and water determine the alkalinity of the water. The following equation indicates that there is a chance that OH^- and HCO_3^- ions will react. due to the fact that they combine to create CO_3^{2-} ions [18, 19].

Although groundwater, streams, and lakes naturally contain chloride, comparatively large quantities of chloride in fresh water (250 mg/L or more) could be a sign of wastewater contamination. Numerous sources, such as rocks, wastewater, and agricultural runoff, contribute to the entry of chloride into surface water [20, 21].

Wastewater and natural water both contain sulfate ions (SO_4^{2-}). Leaching of natural deposits of magnesium sulfate or sodium sulfate (Glauber's salt) is typically the cause of high sulfate concentrations in natural waterways. If Epson salt is ingested in large quantities in drinking water, it may have an unpleasant taste or an unintended laxative impact, although this does not represent a major health risk [15, 16].

Although iron (Fe) and manganese (Mn) do not cause health problems, But drinking water has a noticeably bitter taste even at very low concentrations [15, 16].

Hardness is a term used to describe the characteristics of mineral-rich water. Scale accumulation in hot water pipes and issues creating soap foam are caused by metals dissolved in water [19, 20].

A metric called chemical oxygen demand (COD) is used to quantify both biodegradable and non-biodegradable organic waste. Sulfuric acid, heat, and potassium dichromate—strong oxidizing agents—are used in this chemical test. In as little as two hours, results are available. For the same sample, the COD value is consistently greater than the BOD value [20, 21].

The existence or lack of life may be a helpful indicator of the quality of the water.] In natural waters, biologists can observe fish and insects. Additionally, the estimated species diversity index (SDI) is used to evaluate the quality of the water. Consequently, a body of water that has a balanced number of plant species is seen as a healthy system. Because of their tolerance to the particular pollution, certain species can be employed as markers of its existence [15, 16].

Because of their food and cell shape, bacteria are regarded as single-celled plants. The three fundamental cell forms of bacteria are bacillus, rod, and bacillus. Coccyx-shaped or spherical, with spirals A bacterial cell can proliferate and divide into two new cells in less than half an hour [15, 16].

Protecting water quality while attempting to enhance sanitation and water supply has proven to be quite challenging for developing nations recently. When faced with issues like nutrient overload and nutrient deficiencies in water sources, developed nations also find it difficult to maintain or enhance their water quality status and supplying a rising population with wastewater services [15, 17].

Large water quality data sets, which can be challenging to assess and synthesize, must be gathered and analyzed for water quality management. A number of tools have been created to assess data on water quality. One such technique is the Water Quality Index (WQI) model. The foundation of the WQI model is an integrated function that generates value by analyzing big datasets of water quality that fluctuate across time and space. To put it another way, a water quality index shows how good a source is. Water management and supply agencies find water appealing due to its ease of use [20, 21].

In general, WQI comprises four steps or components: The first step is to choose the relevant water quality metrics. Data on water quality are read second. and each water quality parameter's concentration is transformed into a single value dimensionless sub-index. Third, each water quality parameter's weighting factor is established. Fourth, a clustering algorithm uses sub-indices and weighting factors for all water quality measures to determine the final single water quality index. Numerous WQI models with various model architectures have been created. Classification and techniques The majority of the WQI model's elements were created using local customs and expert opinions. Consequently, a lot of models are sector-specific. Numerous scholars have examined the problem of uncertainty in WQI models. Any mathematical model will inevitably contain uncertainty, however the four stages of WQI can have an impact on the model's level of uncertainty [20, 21].

1.2. The most WQIs contain four main steps, namely:

- Selection of Water Quality metrics: Decide which water quality metrics to include in the evaluation.
- Parameter sub-index generation: A unit-less sub-index is created from the parameter concentration;

- Parameter Weight Assignment: Parameters are given weights according to their significance in the assessment.
- Water Quality Index Calculation Using Aggregation Function: The overall index is determined by combining the individual parameter sub-indices using weights. Water quality is frequently categorized using rating systems based on an overall index value [20, 21].

The primary goal of this study is to create a WQI model and evaluate the quality of the surface and groundwater in the state of Al-Wasid.

2. Material and Methods

Surface and ground water samples were collected from different 10 sites in Wasit governorate to evaluate the water quality (WQI) during the study period (Jan. to Nov. 2024).

The samples were kept in a sterile vial container after being previously cleaned with a non-ionic wash. Before being used, it was rinsed with deionized water after being cleaned with tap water and immersed in 5% HNO_3 for a whole day. Before loading samples, rinse the bags three times with sample water. At the sampling location, samples are appropriately recognized and tagged. After that, it is taken to a lab for examination. Every physical, chemical, and microbiological analysis was carried out in compliance with accepted practices for wastewater and water (APHA, 2023) [22].

3. Results and Discussion

The study aimed to evaluate the water quality of surface and ground in Wasit governorate, Iraq.

- **Tables (1 and 2):** indicate the minimum, maximum, average, and standard deviations of the results acquired during the study period (January to November 2024) for the physical, chemical, and microbiological analyses of the water samples that were collected. Tables 1 and 2 and Figures 4, 5, 6, 7, 8, and 9 illustrate how the Tigris River's surface water in the Wasit governorate is impacted by the discharge of partially treated effluent. Additionally, as shown in Table (2) and Figures (8, 9), the values of the microbiological and biological parameters demonstrated that the river samples that were taken did not meet the regulations.
- **Table (3):** demonstrate how the surface water quality measures are associated, the data revealed that the ammonia data had a substantial association (>0.75) with the microbiological parameters (TBC, TC, FC). This could be because wastewater is discharged into the river, as Table (3) shows.
- **Tables (4 and 5):** indicate the minimum, maximum, average, and standard deviations of the results acquired during the study period (January to November 2024) for the physical, chemical, and microbiological analyses of the water samples that were collected. Based on the data collected, the ground water in the Wasit governorate is displayed in Figures 10, 11, 12, 13, 14, and 15 as well as Tables 4, 5. Additionally, as shown in Table (4) and Figures (14, 15), the values of the microbiological and biological parameters demonstrated that the samples taken from the well region did not meet the regulations. As illustrated in Figures (14, 15), the microbiological results demonstrated that the wastewater reached the ground water and that the ground water in the research region lacked a wastewater network.
- **Table (6):** demonstrate the correlation factors between the parameters of ground water quality, the results revealed a substantial (>0.75) connection between the microbiological parameters (TC, FC, and TBC) and the ammonia data. According to Table (6), the microbiological data demonstrated that the wastewater reached the ground water and that the ground water in the research area lacked a wastewater network.

Table 1 Physical and chemical analysis of surface water samples along of Tigris river during the study (min-max, avg and sd) (Jan. to Nov. 2024)

No.	Parameter	Unit	Tigris River (Al Waist Governorate)																			
			Site (1)				Site (2)				Site (3)				Site (4)				Site (5)			
			Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd
1	Temperature	^0C	11.2	30.5	27.4	13.2	11.1	30.4	27.2	12.8	11.3	30.3	27.1	11.4	10.9	30.6	27.5	11.1	11.4	30.2	27.1	10.6
2	pH	-	7.12	8.1	7.55	5.5	7.15	8.12	7.51	6.4	7.18	8.14	7.48	6.6	7.11	8.13	7.52	7.1	7.1	8.2	7.53	6.8
3	Colour	Hazen	55	90	75	8.1	60	85	75	7.7	60	80	70	8.6	50	85	75	7.9	55	80	70	8.3
4	Turbidity	NTU	14.2	46.2	31.2	21.1	18.3	53.1	34.1	23.4	17.4	46.2	24.6	19.6	20.1	44.1	29.2	23.4	16.2	48.4	32.1	21.1
5	DO	mg/l	6.1	7.2	6.6	31.2	5.8	7.1	6.5	33.8	6.2	7.6	7.1	41.2	5.7	6.7	6.3	26.4	5.6	6.8	6.4	23.8
6	TDS	mg/l	733	1122	912	33.2	814	1184	924	28.2	884	1210	1187	38.4	911	1360	1180	23.1	944	1480	1210	19.8
7	TSS	mg/l	7.2	31.3	19.8	19.1	12.3	33.8	22.4	18.4	12.1	29.2	21.8	19.8	13.5	33.6	24.6	17.1	11.4	33.2	23.1	14.8
8	COD	mg/l	5.8	11.2	7.7	13.2	6.4	13.1	8.4	11.1	6.2	14.1	8.4	15.1	5.4	9.9	7.3	11.4	5.4	10.2	7.8	15.2
9	BOD	mg/l	3.3	7.7	5.2	11.3	4.1	8.4	6.3	9.3	4.6	7.9	5.8	13.2	3.2	6.6	4.6	9.8	3.5	7.1	5.8	13.6
10	Hardness	mg/l	198	224	208	17.2	206	228	218	18.6	212	234	220	19.2	242	268	254	14.8	244	274	260	15.4
11	Ca	mg/l	44	47.2	45.6	17.1	45.6	49.6	47.2	18.4	45.6	48.8	47.2	19.1	51.2	59.2	55.2	14.6	52	61.6	58.4	15.4
12	Mg	mg/l	21.4	25.8	22.9	17.3	22.4	25.3	24.3	18.6	23.8	27.3	24.8	19.3	27.7	29.2	28.2	14.7	27.7	29.2	27.7	15.6
13	Sulphate	mg/l	124	168	141	31.2	139	168	151	26.2	146	187	167	36.2	161	212	184	22.6	178	242	211	21.1
14	Chloride	mg/l	84	114	98	29.6	94	124	102	24.8	94	138	122	31.1	98	148	132	21.1	98	174	130	20.1
15	Ammonia	mg/l	0.1	0.4	0.2	13.2	0.12	0.46	0.26	14.1	0.15	0.42	0.31	14.2	0.2	0.48	0.31	14.6	0.28	0.48	0.36	14.2
16	Alkalinity	mg/l	178	198	184	11.2	180	202	188	14.2	184	212	204	11.6	188	218	210	9.6	190	224	212	15.1
17	Fe	mg/l	0.02	0.06	0.03	5.5	0.03	0.08	0.05	6.2	0.03	0.06	0.04	4.3	0.07	0.09	0.08	6.6	0.03	0.05	0.04	2.6
18	Mn	mg/l	0.01	0.02	0.01	1.2	0.01	0.03	0.02	1.6	0.01	0.03	0.02	2.1	0.02	0.06	0.04	3.1	0.02	0.06	0.03	1.1
19	Cd	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
20	Cu	mg/l	0.012	0.018	0.015	3.2	0.01	0.02	0.012	2.2	0.015	0.019	0.017	3.5	0.06	0.08	0.07	2.1	0.013	0.021	0.017	4.2
21	Cr	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
22	Zn	mg/l	0.1	0.23	0.15	4.5	0.12	0.28	0.19	3.8	0.13	0.24	0.18	2.8	0.14	0.21	0.16	1.8	0.15	0.24	0.19	3.6

23	Pb	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
24	As	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
25	Se	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
26	Ni	mg/l	0.014	0.018	0.016	4.2	0.01	0.015	0.012	3.2	0.018	0.024	0.02	2.6	0.012	0.021	0.018	3.1	0.011	0.015	0.013	2.2

Table 2 Microbiological analysis of surface water samples along of Tigris river during the study (min-max, avg and sd) (Jan. to Nov. 2024)

No.	Parameter	Unit	Tigris River (Waist Governorate)																			
			Site (1)				Site (2)				Site (3)				Site (4)				Site (5)			
			Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd
1	Total bacterial count	CFU/ml	900	4800	2200	32.1	1300	11200	6500	39.2	2100	11800	7200	41.2	1800	12100	8100	41.2	2400	15400	9200	43.2
2	TC	CFU/100ml	200	600	450	28.2	320	1800	900	33.4	440	3400	2800	39.2	550	4100	3200	33.5	600	3400	2400	38.1
3	FC	CFU/100ml	15	66	35	26.1	21	84	62	31.1	24	110	90	33.4	40	115	84	31.1	50	145	105	34.1

Table 3 Correlation matrix of surface water samples along of Tigris river during the study

	T	pH	Colour	Turbidity	DO	TDS	TSS	COD	BOD	TH	Ca	Mg	SO_4	Cl	NH_3	Alk	Fe	Mn	Cu	Zn	Ni	TBC	TC	FC
T	1.0																							
pH	0.1	1.0																						
Colour	0.5	0.8	1.0																					
Turbidity	-0.7	0.1	-0.2	1.0																				
DO	0.2	0.7	0.5	-0.4	1.0																			
TDS	0.1	-0.2	-0.2	0.5	-0.6	1.0																		
TSS	-0.4	0.2	0.0	0.9	-0.5	0.8	1.0																	
COD	0.1	0.9	0.9	0.0	0.6	-0.5	0.0	1.0																

BOD	0.4	0.9	0.9	0.1	0.5	0.1	0.3	0.8	1.0															
Hardness	-0.1	-0.6	-0.6	0.5	-0.8	0.9	0.6	-0.8	-0.4	1.0														
Ca	-0.1	-0.6	-0.6	0.4	-0.8	0.9	0.6	-0.8	-0.4	1.0	1.0													
Mg	-0.1	-0.5	-0.6	0.5	-0.7	0.9	0.6	-0.8	-0.4	1.0	1.0	1.0												
SO_4	0.2	-0.4	-0.4	0.4	-0.7	0.9	0.6	-0.6	-0.2	1.0	0.9	0.9	1.0											
Cl	-0.1	-0.1	-0.2	0.7	-0.7	0.9	0.9	-0.3	0.1	0.8	0.8	0.8	0.9	1.0										
NH_3	0.3	-0.6	-0.4	0.2	-0.7	0.9	0.4	-0.7	-0.3	0.9	0.9	0.9	1.0	0.8	1.0									
Alk	0.1	-0.4	-0.5	0.4	-0.6	1.0	0.6	-0.7	-0.2	1.0	0.9	1.0	1.0	0.9	1.0	1.0								
Fe	-0.8	-0.3	-0.7	0.8	-0.5	0.5	0.7	-0.5	-0.4	0.7	0.6	0.7	0.4	0.6	0.3	0.6	1.0							
Mn	-0.1	-0.8	-0.8	0.4	-0.8	0.8	0.4	-0.9	-0.6	1.0	1.0	1.0	0.9	0.7	0.9	0.9	0.7	1.0						
Cu	-0.8	-0.4	-0.8	0.7	-0.4	0.4	0.5	-0.6	-0.5	0.6	0.6	0.6	0.3	0.4	0.3	0.5	1.0	0.6	1.0					
Zn	0.1	-0.3	-0.3	0.5	-0.7	1.0	0.7	-0.5	0.0	0.9	0.9	0.9	1.0	0.9	0.9	1.0	0.5	0.8	0.4	1.0				
Ni	0.3	0.6	0.3	-0.2	0.9	-0.1	-0.2	0.2	0.5	-0.3	-0.4	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.4	-0.1	-0.2	1.0			
TBC	0.4	0.0	0.0	0.3	-0.4	0.9	0.6	-0.4	0.2	0.8	0.7	0.8	0.9	0.8	0.8	0.9	0.3	0.6	0.1	0.9	0.1	1.0		
TC	0.1	-0.3	-0.4	0.5	-0.6	1.0	0.7	-0.6	-0.1	0.9	0.9	1.0	1.0	0.9	0.9	1.0	0.6	0.8	0.5	1.0	-0.1	0.9	1.0	
FC	0.1	-0.6	-0.5	0.3	-0.8	0.9	0.5	-0.7	-0.3	1.0	1.0	1.0	1.0	0.8	1.0	1.0	0.5	0.9	0.4	0.9	-0.4	0.8	0.9	1.0

Table 4 Physical and chemical analysis of ground water samples in Wasit governorate during the study (min-max, avg and sd) (Jan. to Nov. 2024)

No.	Parameter	Unit	Waist Governorate																			
			Site (1)				Site (2)				Site (3)				Site (4)				Site (5)			
			Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd
1	Temperature	^0C	11.2	33.1	27.4	13.2	11.3	32.1	27.1	17.1	11.4	32.8	27.8	16.2	11.2	33.4	27.9	15.1	11.3	33.2	27.7	14.2
2	pH	-	8.02	8.24	8.1	9.9	7.92	8.1	7.98	11.2	7.98	8.2	8	11.8	7.98	8.15	8.1	9.9	8	8.18	8.1	11.8
3	Colour	Hazen	5	5	5	-	5	5	5	-	5	5	5	-	5	5	5	-	5	5	5	-
4	Turbidity	NTU	0.3	0.5	0.4	3.3	0.28	0.52	0.41	4.2	0.34	0.58	0.44	5.1	0.41	0.6	0.45	6.1	0.44	0.59	0.52	5.2
5	DO	mg/l	1.2	1.8	1.4	4.1	1.4	2.1	1.7	7.1	1.5	2.2	1.8	6.2	1.7	2.6	1.9	4.5	1.6	2.8	2.2	3.6
6	TDS	mg/l	1410	1814	1654	39.2	1560	1910	1712	101	1601	1930	1733	93	1536	1915	1611	94	1680	1955	1740	89
7	TSS	mg/l	0.1	0.2	0.12	3.2	0.1	0.2	0.12	3.4	0.1	0.2	0.13	3.8	0.1	0.2	0.14	3.2	0.1	0.2	0.12	3.3
8	COD	mg/l	1.2	2.1	1.7	2.3	1.4	2.3	1.9	2.2	1.3	2.2	1.8	2.6	1.1	2.2	1.7	2.3	1.3	2.3	1.7	2.1
9	BOD	mg/l	0.7	0.9	0.8	1.2	0.8	0.9	0.84	1.3	0.6	0.8	0.7	1.4	0.7	0.9	0.8	1.6	0.8	0.9	0.83	1.2
10	Hardness	mg/l	330	412	392	31.2	380	440	410	33.1	388	430	416	40.2	366	460	420	41.2	410	470	440	43.2
11	Ca	mg/l	43.2	52.8	46.4	29.2	51.2	57.6	48	28.8	47.2	51.2	48.8	31.3	42.4	50.4	48.8	36.1	45.6	54.4	49.6	32.1
12	Mg	mg/l	54.0	68.1	67.1	28.8	61.3	72	70.5	29.6	65.7	73.5	71.5	29.9	63.2	81.2	72.5	33.8	72	81.2	76.9	31.4
13	Sulphate	mg/l	216	238	221	31.2	220	236	228	26.1	194	208	202	21.1	168	194	177	16.1	184	212	194	23.6
14	Chloride	mg/l	128	166	148	24.1	120	160	142	23.2	128	168	158	19.5	112	148	134	15.2	144	182	164	19.6
15	Ammonia	mg/l	0.1	0.4	0.3	12.1	0.1	0.4	0.35	11.2	0.3	0.6	0.45	16.1	0.26	0.38	0.3	9.6	0.26	0.45	0.34	16.2
16	Alkalinity	mg/l	180	202	188	13.1	190	214	194	21.1	184	196	188	14.2	184	196	190	13.2	182	202	190	14.2
17	Fe	mg/l	0.28	0.33	0.3	11.1	0.32	0.39	0.36	14.5	0.35	0.42	0.38	11.3	0.34	0.46	0.38	14.8	0.33	0.48	0.41	16.1
18	Mn	mg/l	0.21	0.36	0.28	13.8	0.24	0.42	0.38	11.3	0.36	0.48	0.42	14.5	0.28	0.56	0.42	9.6	0.26	0.34	0.3	15.2
19	Cd	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
20	Cu	mg/l	0.015	0.023	0.017	3.8	0.017	0.032	0.021	12.1	0.013	0.019	0.017	3.5	0.018	0.026	0.021	6.6	0.014	0.028	0.022	4.6
21	Cr	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
22	Zn	mg/l	0.15	0.23	0.19	3.2	0.18	0.28	0.23	8.4	0.18	0.28	0.24	4.8	0.19	0.33	0.26	4.8	0.21	0.28	0.24	8.3

23	Pb	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
24	As	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
25	Se	mg/l	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0	0.001	0.001	0.001	0.0
25	Ni	mg/l	0.01	0.02	0.015	1.2	0.013	0.017	0.015	3.4	0.014	0.017	0.015	3.2	0.016	0.021	0.018	3.1	0.014	0.019	0.017	2.8

Table 5 Microbiological analysis of ground water samples in Wasit governorate during the study (min-max, avg and sd) (Jan. to Nov. 2024)

No.	**Parameter**	**Unit**	**Waist Governorate**																			
			Site (1)				**Site (2)**				**Site (3)**				**Site (4)**				**Site (5)**			
			Min	**Max**	**Avg**	**Sd**	**Min**	**Max**	**Avg**	**Sd**	**Min**	**Max**	**Avg**	**Sd**	**Min**	**Max**	**Avg**	**Sd**	**Min**	**Max**	**Avg**	**Sd**
1	Total bacterial count	CFU/ml	320	1200	620	15.2	211	750	550	19.2	114	248	189	11.3	315	780	512	31.2	455	1550	840	16.6
2	TC	CFU/100ml	55	180	94	13.1	74	196	114	21.3	15	72	54	13.1	65	211	116	26.6	71	177	143	19.2
3	FC	CFU/100ml	8	14	11	14.2	18	28	22	19.6	3	11	9	11.2	8	19	14	21.3	15	34	24	17.8

Table 6 Correlation matrix ground water samples in Wasit governorate during the study

	T	pH	Turbidity	DO	TDS	COD	BOD	TH	Ca	Mg	SO_4	Cl	NH_3	Alk	Fe	Mn	Cu	Zn	Ni	TBC	TC	FC
T	1																					
pH	-0.3	1																				
Turbidity	-0.1	0.4	1.0																			
DO	0.1	-0.1	0.8	1.0																		
TDS	0.6	-0.2	0.6	0.7	1.0																	
COD	0.7	-0.6	-0.4	-0.3	0.4	1.0																
BOD	-0.3	-0.3	0.1	0.0	0.2	0.4	1.0															
TH	0.7	-0.3	0.5	0.6	1.0	0.5	0.3	1.0														
Ca	0.6	-0.8	-0.5	-0.2	0.4	0.9	0.3	0.4	1.0													
Mg	0.5	-0.1	0.7	0.8	1.0	0.2	0.2	1.0	0.2	1.0												
SO_4	0.1	-0.3	-0.9	-0.9	-0.4	0.6	0.2	-0.4	0.6	-0.6	1.0											
Cl	0.4	0.5	0.3	-0.1	0.5	0.4	0.2	0.5	0.1	0.5	0.1	1.0										
NH_3	0.4	0.2	0.7	0.8	0.7	-0.3	-0.4	0.6	-0.3	0.7	-0.8	0.2	1.0									
Alk	0.3	-1.0	-0.4	0.1	0.2	0.6	0.3	0.3	0.8	0.1	0.3	-0.5	-0.2	1.0								
Fe	0.6	-0.3	0.5	0.8	0.7	0.1	-0.3	0.7	0.2	0.7	-0.7	-0.1	0.8	0.3	1.0							
Mn	0.7	-0.1	0.2	0.5	0.5	0.0	-0.7	0.5	0.1	0.5	-0.5	0.0	0.8	0.1	0.9	1.0						
Cu	-0.7	-0.5	-0.1	0.2	-0.3	-0.3	0.4	-0.3	-0.1	-0.3	-0.1	-0.8	-0.4	0.5	-0.1	-0.4	1.0					
Zn	0.3	-0.2	0.8	0.9	0.9	0.1	0.4	0.9	0.1	0.9	-0.7	0.3	0.6	0.2	0.7	0.3	0.0	1.0				
Ni	0.2	-0.3	0.7	1.0	0.6	-0.2	-0.1	0.6	0.0	0.7	-0.8	-0.3	0.7	0.3	0.9	0.6	0.3	0.8	1.0			
TBC	-0.6	0.5	0.6	0.2	0.1	-0.3	0.6	0.1	-0.5	0.3	-0.3	0.5	0.0	-0.5	-0.3	-0.6	0.1	0.4	0.0	1.0		
TC	-0.6	-0.2	0.2	0.1	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	-0.5	0.2	-0.3	-0.8	0.7	0.3	0.0	0.7	1.0	
FC	-0.1	-0.5	0.0	0.0	0.3	0.5	1.0	0.3	0.5	0.2	0.3	0.2	-0.5	0.5	-0.2	-0.6	0.4	0.4	-0.1	0.4	0.8	1

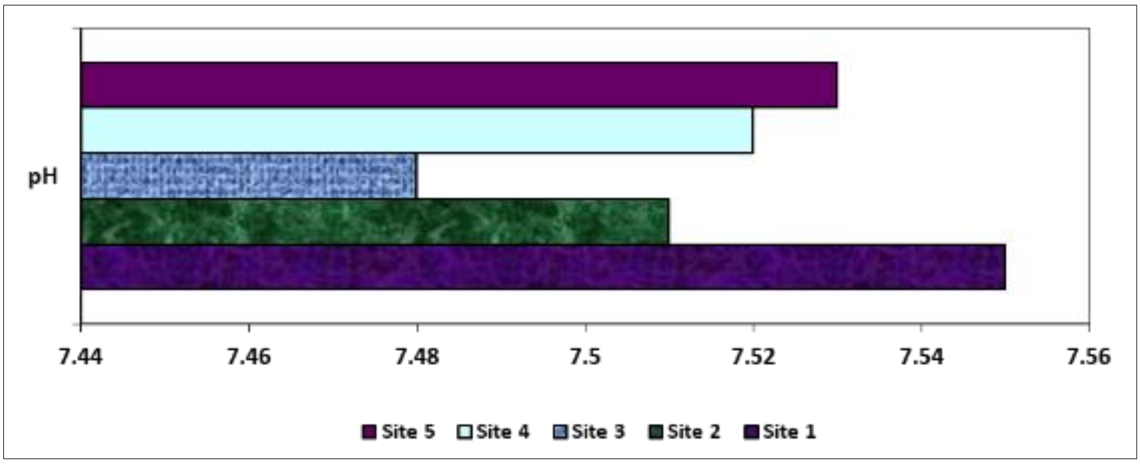

Figure 4 Average values of pH of surface water samples along of Tigris River during the study

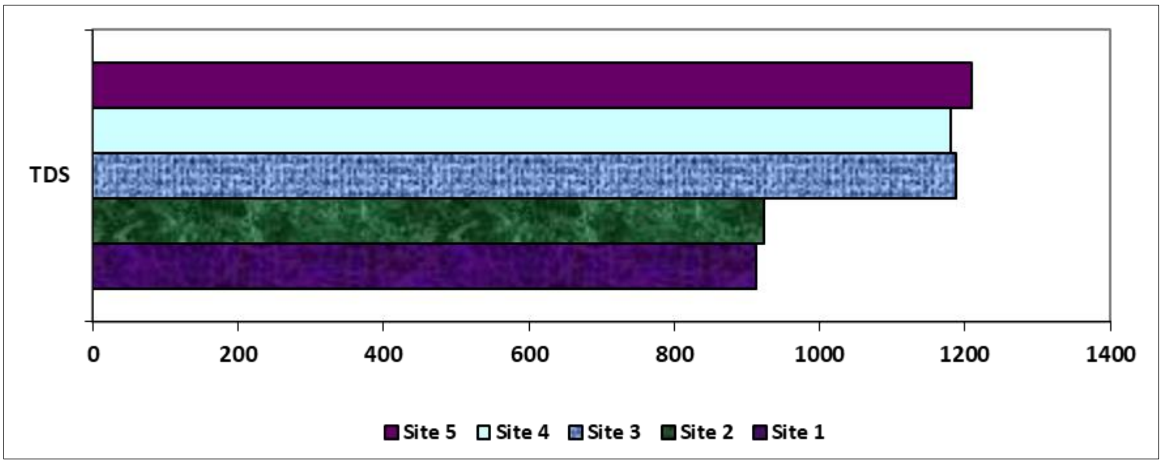

Figure 5 Average values of TDS in mg/l of surface water samples along of Tigris River during the study

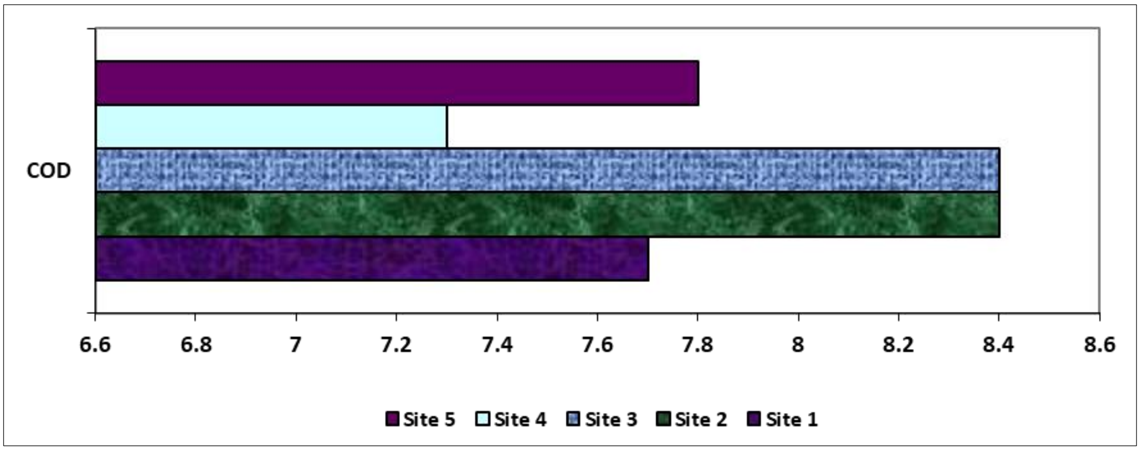

Figure 6 Average values of COD in mg/l of surface water samples along of Tigris River during the study

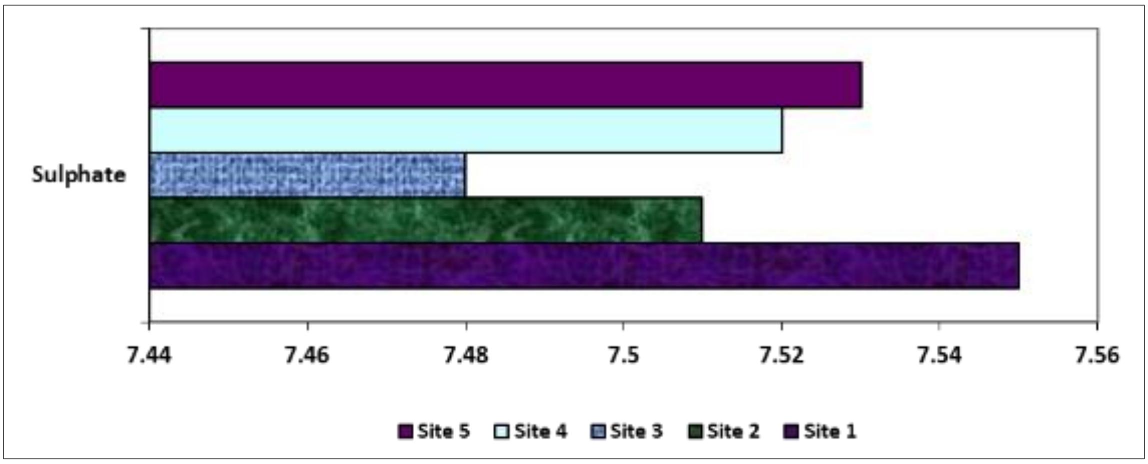

Figure 7 Average values of Sulphate in mg/l of surface water samples along of Tigris River during the study

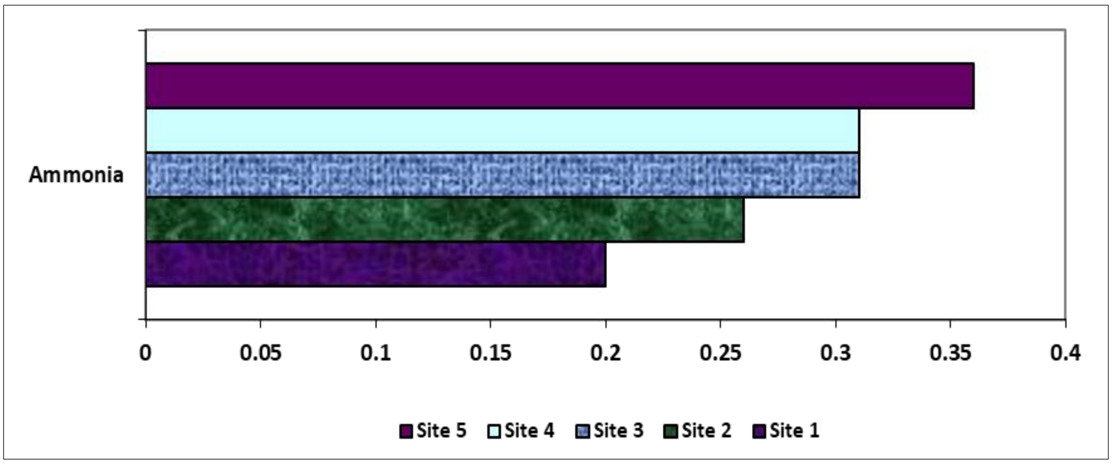

Figure 8 Average values of ammonia in mg/l of surface water samples along of Tigris River during the study

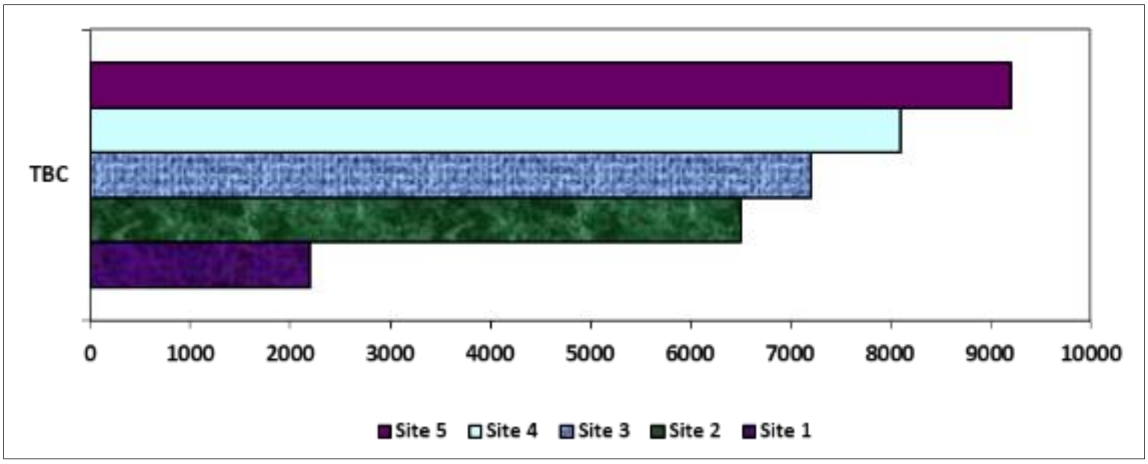

Figure 9 Average values of total bacterial count in CFU/100 ml of surface water samples along of Tigris River during the study

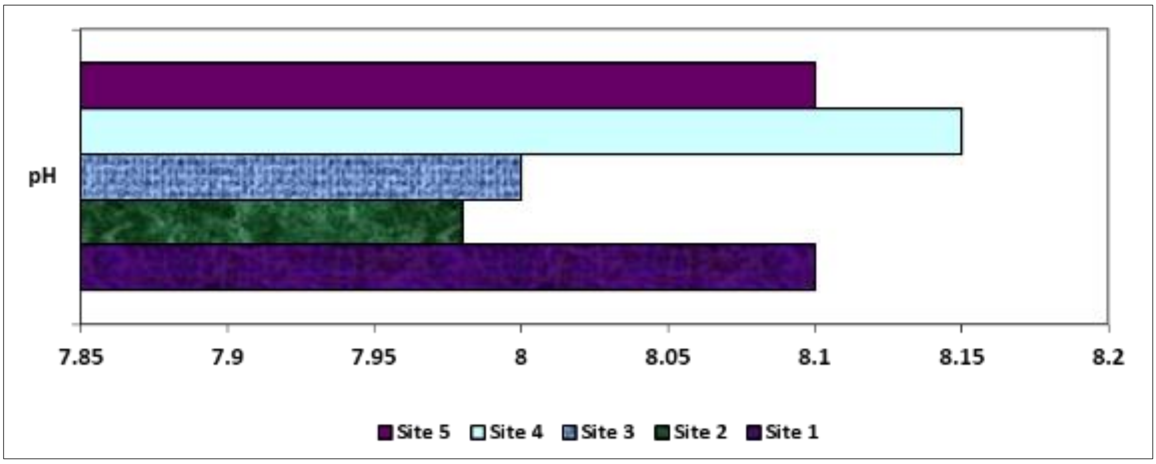

Figure 10 Average values of pH of ground water samples in Wasit governorate during the study

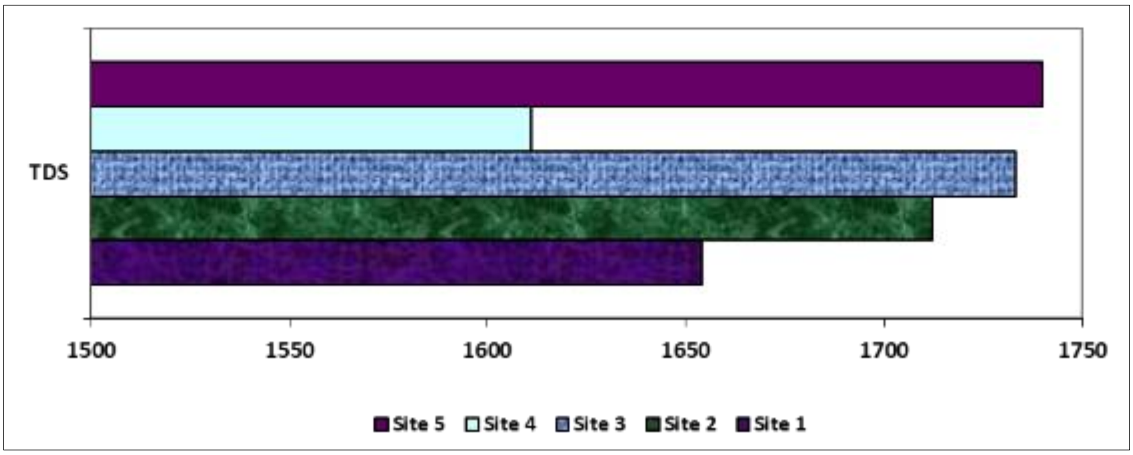

Figure 11 Average values of TDS in mg/l of ground water samples in Wasit governorate during the study

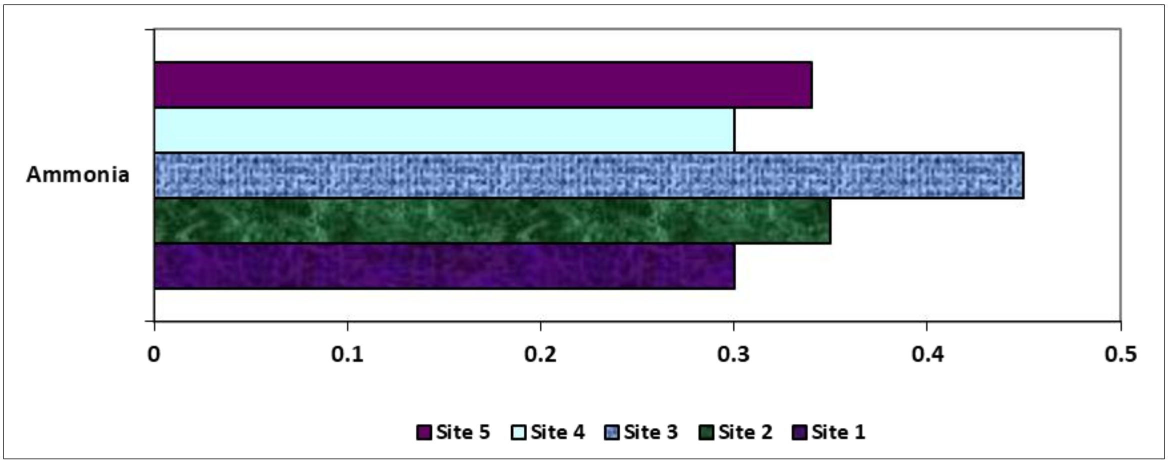

Figure 12 Average values of ammonia in mg/l of ground water samples in Wasit governorate during the study

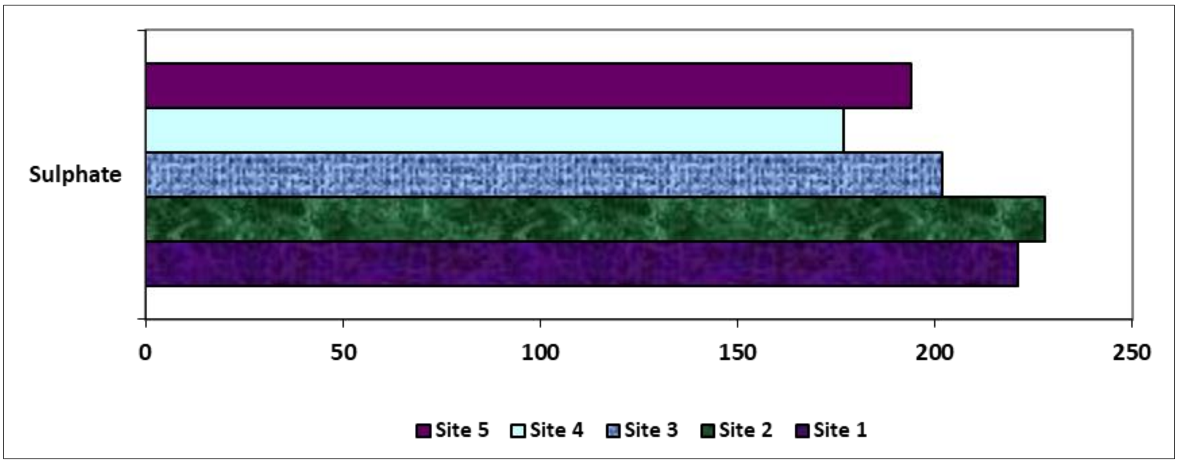

Figure 13 Average values of sulphate in mg/l of ground water samples in Wasit governorate during the study

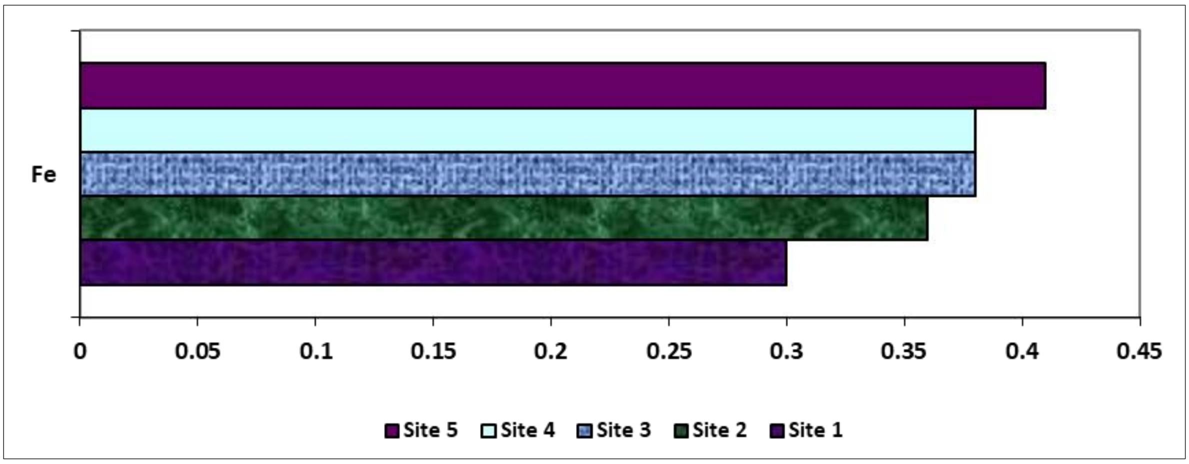

Figure 14 Average values of Fe in mg/l of ground water samples in Wasit governorate during the study

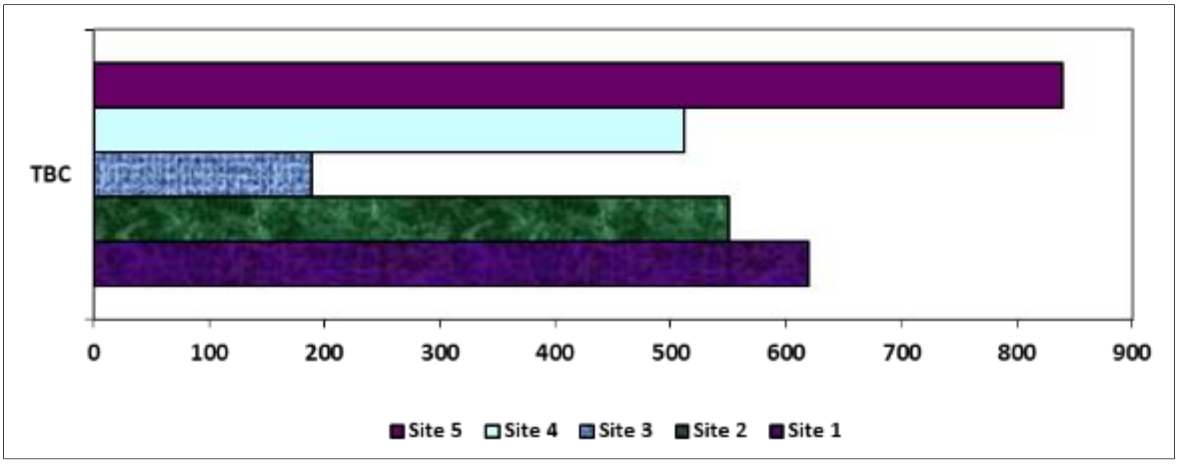

Figure 15 Average values of TBC in CFU/100 ml of ground water samples in Wasit governorate during the study

3.1. Water Quality Index (WQI)

- **Table (7):** As demonstrated in Table (7), the WQI calculation based on the guideline values (max permitted limits) for the surface water samples taken from the Tigris River in the Wasit governorate ranged from 352.3 to 1106.5.

As shown in Table (7) and Figure (16), the WQI of the collected water samples ranged from 2.0 to 6.3 times higher based on the WQI of standard parameters values. This could represent the discharge of partially treated and untreated wastewater to the river.

Table 7 Water quality assessment of Surface water of Tigris River and ground water in Wasit Governorate, during the period of study.

No.	Parameter	Unit	Quality Assessment Weight	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
1	TDS	mg/l	0.1	91.2	92.4	118.7	118	121	100
2	Sulphate	mg/l	0.05	7.05	7.55	8.35	9.2	10.55	12.5
3	Hardness	mg/l	0.1	20.8	21.8	22	25.4	26	50
4	Ammonia	mg/l	0.1	0.02	0.026	0.031	0.031	0.036	0.05
5	Chloride	mg/l	0.05	4.9	5.1	6.1	6.6	6.5	12.5
6	Fe	mg/l	0.1	0.003	0.005	0.004	0.008	0.003	0.03
7	COD	mg/l	0.1	0.77	0.84	0.84	0.73	0.78	0.5
8	BOD	mg/l	0.1	0.52	0.63	0.58	0.46	0.58	0.01
9	TBC	CFU/ml	0.1	220	650	720	810	920	0.01
10	FC	CFU/100ml	0.2	7	12.4	18	16.8	21	0.02
WQI				352.3	790.8	894.6	987.2	1106.5	175.6
Ratio = WQI for site/WQI for standard parameter				2.0	4.5	5.1	5.6	6.3	

- **Table (8):** As demonstrated in Table (8), the WQI calculation based on the guideline values (max permitted limits) for the ground water samples collected in the Wasit governorate ranged from 266.5 to 301.1.

Table (8) and Figure (17) show that the WQI of the collected water samples ranged from 1.5 to 1.7 times higher than the WQI of standard parameters. This could imply that the well's region lacked a wastewater network.

Table 8 Water quality assessment of ground water samples in Wasit governorate during the study

No.	Parameter	Unit	Quality Assessment Weight	Site 1	Site 2	Site 3	Site 4	Site 5	Standard
1	TDS	mg/l	0.1	165.4	171.2	173.3	161.1	174	100
2	Sulphate	mg/l	0.05	7.05	7.55	8.35	9.2	10.55	12.5
3	Hardness	mg/l	0.1	22.1	22.8	20.2	17.7	19.4	50
4	Ammonia	mg/l	0.1	0.03	0.035	0.045	0.03	0.034	0.05
5	Chloride	mg/l	0.05	7.4	7.1	7.9	6.7	8.2	12.5
6	Fe	mg/l	0.1	0.03	0.036	0.038	0.038	0.048	0.03
7	COD	mg/l	0.1	0.17	0.19	0.18	0.17	0.17	0.5
8	BOD	mg/l	0.1	0.08	0.084	0.07	0.08	0.083	0.01
9	TBC	CFU/ml	0.1	62	55	18.9	51.2	84	0.01

10	FC	CFU/100ml	0.2	2.2	4.4	1.8	2.8	4.8	0.02
WQI				266.5	268.4	230.8	249.0	301.3	175.6
Ratio = WQI for site/WQI for standard parameter				1.5	1.5	1.3	1.4	1.7	

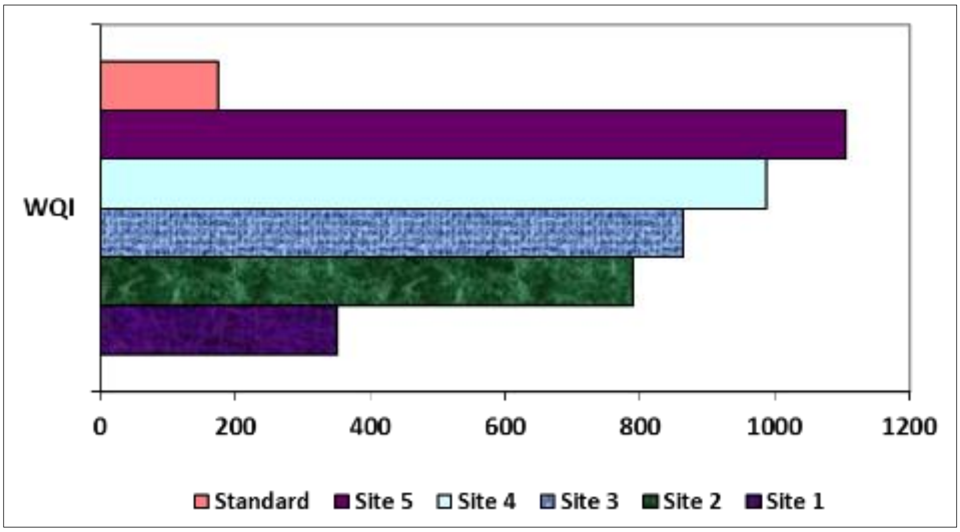

Figure 16 WQI of Surface water of Tigris River and ground water in Wasit Governorate, during the period of study

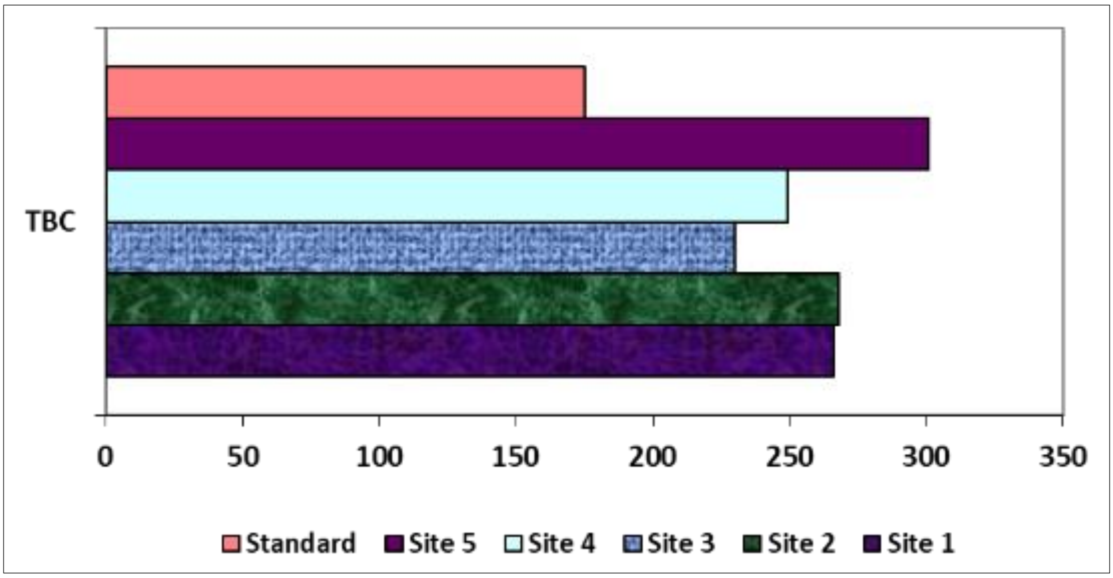

Figure 17 WQI of ground water samples in Wasit governorate during the study

4. Conclusion

- The current study's findings demonstrated that the Tigris River's surface water in the Al-Wasit governorate is impacted by the discharge of inadequately treated wastewater.
- The data indicated a substantial association (>0.75) between the microbiological parameters (TBC, TC, and FC) and the surface water quality indicators, which could be caused by wastewater discharge into the river.
- The microbiological and biological parameter values of surface water samples taken from the Tigris River did not meet the required standards.

- Additionally, the microbiological and biological parameter values of ground water samples did not meet the required standards.
- The findings indicated a good association (>0.75) between the microbiological parameters (TC, FC, and TBC) and the ground water quality metrics, namely the ammonia data.
- The microbiological results demonstrated that the wastewater reached the ground water and that the ground water in the studied area lacked a wastewater network.
- Based on the maximum allowable limits (guideline values), the WQI for the surface water samples taken from the Tigris River in the Al-Wasit governorate ranged from 352.3 to 1106.5.
- The WQI of collected water samples ranged from 2.0 to 6.3 times higher than the WQI of standard parameters, which could indicate that partially treated and untreated wastewater was discharged into the river.
- Based on the maximum allowable limits (guideline values), the WQI for the ground water samples that were taken in the Al-Wasit governorate ranged from 266.5 to 301.1.
- The WQI of the water samples that were obtained ranged from 1.5 to 1.7 times higher than the WQI of standard parameters. This could indicate that the area where the well was located lacked a wastewater network.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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