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CASE STUDY

Environmental Impact of Petroleum Refinery Effluent on Groundwater Pollution: A Case Study of Maysan Refinery, Iraq

Impacto ambiental de los efluentes de las refinerías de petróleo en la contaminación de las aguas subterráneas: Estudio de caso de la refinería de Maysan, Iraq

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ABSTRACT

The study aimed to investigate the environmental impact of the refinery's wastewater on groundwater within the refinery and the surrounding area. Six different testing sites were chosen to measure the concentrations of groundwater pollutants according to their distance from the untreated oil effluent discharge lagoon. The study period lasted for six months, as the testing work began in April and ended in September 2023. The results showed a clear effect of untreated petroleum effluent on the properties of groundwater, as the concentrations of petroleum effluent (oil and grease, TOC, phenol) and heavy metals (Ni, Cd, Pb) exceeded the permissible limits, as well as related parameters (TDS, EC, Cl, SO4) according to WHO specifications. As for the concentrations of the parameters (BOD, COD), there was no clear effect of the effluent on them, and on the contrary, their values began to increase at the testing sites far from the refinery. The groundwater was greatly affected by a distance of 5 km from the effluent collection lagoon (testing sites: GW1, GW2, GW3, and GW4), and it was not suitable for human use until after it was treated. As for the remaining of the distance (testing sites:GW5, GW6) to the nearest residential area (from 5 km to 9 km), the groundwater was limited to use for irrigation according to WQI guidelines. The study recommends that, in order to reduce pollution of refinery effluent, the responsible administration should use regular wastewater networks, construct a treatment plant for this effluent, and discharge the treated effluent to the nearest water source.

Keywords: Refinery Effluent; Petroleum Pollutants; Oil and Grease; TOC; Phenol; Heavy Metals; Groundwater Pollution.

RESUMEN

El objetivo del estudio era investigar el impacto ambiental de las aguas residuales de la refinería en las aguas subterráneas de la refinería y sus alrededores. Se eligieron seis lugares de ensayo diferentes para medir las concentraciones de contaminantes de las aguas subterráneas en función de su distancia a la laguna de vertido de efluentes petrolíferos sin tratar. El periodo de estudio duró seis meses, ya que las pruebas empezaron en abril y terminaron en septiembre de 2023. Los resultados mostraron un claro efecto del efluente de petróleo no tratado sobre las propiedades de las aguas subterráneas, ya que las concentraciones de efluente de petróleo (aceite y grasa, COT, fenol) y metales pesados (Ni, Cd, Pb) superaron los límites permitidos, así como los parámetros relacionados (TDS, CE, Cl, SO4) según las especificaciones de la OMS. En cuanto a las concentraciones de los parámetros (DBO, DQO), no se observó ningún efecto claro del efluente sobre ellas y, por el contrario, sus valores empezaron a aumentar en los lugares de ensayo alejados de la refinería. Las aguas subterráneas se vieron muy afectadas a una distancia de 5 km de la laguna de recogida de efluentes (lugares de prueba:GW1, GW2, GW3 y GW4), y no fueron aptas para el uso humano hasta después de ser tratadas. En cuanto al resto de la distancia (sitios de prueba: GW5, GW6) a la zona residencial más cercana (de 5 km a 9 km), el agua subterránea estaba limitada al uso para riego de acuerdo con las directrices de WQI. El estudio recomienda que, para reducir la contaminación de los efluentes de refinería, la administración responsable utilice redes regulares de aguas residuales, construya una planta de tratamiento para este efluente y vierta el efluente tratado a la fuente de agua más cercana.

Palabras clave: Efluente de Refinería; Contaminantes del Petróleo; Aceites y Grasas; COT; Fenol; Metales Pesados; Contaminación de Aguas Subterráneas.

INTRODUCTION

Groundwater is considered one of the most important natural resources in the lives of humans who live in arid and semi-arid areas that lack surface water in their regions. Groundwater is classified as a renewable natural resource and is exposed to human and natural influences. Protecting the quality of groundwater is a basic necessity to maintain the quality of that water. Despite the many measures taken by some countries and organizations responsible for protecting the environment, various pollutants still find their way into groundwater aquifers by penetrating soil particles, causing pollution.[1,2,3] The process of groundwater pollution is defined as the change occurring in the physical, chemical, or biological composition of that water, making it not meet the appropriate standards for use for industrial, agricultural, and human consumption purposes. Pollution of groundwater with effluent generated from factories, including oil fields and refineries, is a dangerous matter on all environmental, health, and economic levels.[4,5] Oil extraction and refining are complex processes that lead to many cases of leakage of oil waste into aquifers, surface water, and soil, causing pollution in all aspects of the environment.[5] Crude oil spills affect various aspects of the environment, such as air, water (surface and groundwater), and soil. The near-surface soil and groundwater system (critical zone) are characterized by a high level of heterogeneity, which increases the possibility of their contamination and changes in their physical, chemical and biological properties.[6,7] Therefore, most crude oil spills have become a continuous source of pollution in soil and groundwater systems.[8,9] Adsorption and dispersion processes form the basis of modeling crude oil contaminants in groundwater pollution.[10] Many studies have shown the impact of crude oil spills on the soil and their seepage into groundwater. Some researchers focused on assessing the quality of groundwater in the study area (Nigeria) with the aim of ascertaining the nature and extent of the effects of the oil spill on that water.[11] While others[12] studied the sources and extent of groundwater pollution and its consequences on human health and the environment, in addition to techniques for removing selected pollutants from groundwater. The study[13] explained, by analyzing samples of surface water and groundwater in the city of Samarra/Iraq, in terms of their containment of heavy metals, that this water is not suitable for drinking according to the WHO and the Water Quality Index (WQI), as all values are higher than 100 for surface water and groundwater. Another study[14] identified the physical characteristics of groundwater (temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity) and the influence of sampling location and tube well depth on its physical characteristics. The researchers[15] assessed the contamination of groundwater caused by industrial effluents and landfill leachate, especially heavy metals and hazardous anions like nitrate and sulfate. Many studies have indicated the possibility of using the water quality index (WQI) to evaluate the extent of surface water and groundwater pollution and their suitability for human, industrial, and agricultural uses. The study[16] determined the groundwater quality parameters at various sources in and around Dhaka city by using the water quality index (WQI). Other studies evaluated the groundwater quality for drinking and irrigation purposes using the GIS-based IWQI, EWQI, and HHR models. A total of 41 groundwater samples were collected from domestic wells in Suining city of the Sichuan Basin, which were used for analyzing the hydrogeochemical processes and suitability for irrigation and drinking purposes.[17] Also,[18] applied the WQI model to evaluate the physicochemical quality of groundwater at effluent discharge and administration areas of a WTF in Shama Municipality in Ghana. It also assessed the physicochemical quality of groundwater at different locations in a waste treatment facility using the WQI model.

Many scientific and applied studies have used the WQI classification to indicate the quality of groundwater and its suitability for human use due to its accurate results[17,18,19,20], so it was adopted in this study. Table 1 shows the WQI classification values.

Table 1. WQI Classification value[19,20]

Status	WQI value	Possible usages
Excellent	0-25	Drinking, Irrigation and Industrial
Good	26-50	Drinking, Irrigation and Industrial
Fair	51-75	Irrigation and Industrial
Poor	76-100	Irrigation
Very Poor	101-150	Restricted use for Irrigation
Unfit for Drinking	Above 150	Treatment required before use

The WQI is calculated by using the equation (1).[17,18,19]

$$WQI = \Sigma\, qn\, Wn \;/\; \Sigma\, Wn \qquad (1)$$

Where: qn = Quality rating of nth water quality parameter, Σ Wn= Unit weight of nth water quality parameter. The quality rating is calculated by using the equation (2).

$$qn = [(Vn - Vid) \;/\; (Sn - Vid)] \times 100 \qquad (2)$$

Where: Vn = Estimated value of nth water quality parameter at a given sample location, Vid = Ideal value for nth parameter in pure water. (Vid for pH = 7 and 0 for all other parameters), Sn = Standard permissible value of n th water quality parameter. The unit weight (Wn) is calculated by using the equation (3).

$$Wn = k \;/\; Sn \qquad (3)$$

Where: Sn = Standard permissible value of nth water quality parameter. K = Constant of proportionality and it is calculated by using the equation (4).

$$k = [\, 1 \;/\; (\Sigma\, 1/\, Sn=1,2..., n)] \qquad (4)$$

The study aimed to determine the effect of untreated petroleum effluent from the refinery on the properties of groundwater within the refinery and surrounding area and the suitability of that water for various human uses.

Study Area

Maysan Governorate is considered one of the governorates of southern Iraq, as it is located in the southeast of the country. We consider the city of Amara, located on the Tigris River, the main center of the governorate. It is about 320 km away from the city of Baghdad and about 180 km away from the city of Basra. According to the statistics of the Ministry of Planning in Iraq for the year 2021, the number of people in the governorate is about 1 202 175 capita. Figure 1 shows the location of Maysan Governorate on the map of Iraq.

A B

Figure 1. Locations of Maysan Governorate and the refinery a-Location of Maysan Governorate within the Map of Iraq b- Location of Maysan refinery (Google Earth)
Source: (https://maps.app.goo.gl/ex4QoL6uLra8f6vq9)

The Maysan refinery was chosen as a study area because it represents one of the most promising strategic projects in the Maysan Governorate and employs large numbers of technical personnel from the people of the governorate. The refinery's location coordinates were determined as latitude 31.922524 and longitude 47.43468. The production capacity of the Maysan refinery is about 40 thousand barrels per day, and it consists of four refining units. Each has a capacity of ten thousand barrels per day of gasoline, gas, oil, and other petroleum products.

The city of Al-Masharah is considered the closest population center to the refinery site and is about 12 km away from it, while the refinery is about 32 km away from the city of Amara. Although the refinery is classified as one of the important projects and modern technologies are used in the production process, it lacks regular sewage networks and a treatment plant for this waste, in addition to the refinery discharging waste to adjacent open areas, which causes harm to the environmental aspects (air, soil, and water) for residential areas near the refinery. Therefore, the Maysan refinery site was chosen as a study area, figure 2.

A B

Figure 2. Views of the Study Area and Testing Works a- Location of the Study Area b- View of the Testing Works

METHOD

Six different testing sites were chosen to measure the concentrations of groundwater pollutants inside the refinery and its surrounding areas according to their distance from the untreated oil effluent discharge lagoon (which has an area of about 0,5 square kilometers and a depth between 1 and 1,5 meters). A main testing site was chosen in the vicinity of the lagoon, 1 site inside the refinery, 3 sites within the area surrounding the refinery, 1 site in the nearest residential area (the city of Al-Masharah). The study period lasted for six months, as the testing work began in April and ended in September 2023.

Groundwater samples were subjected to laboratory analysis to determine their characteristics. Laboratory and field data were analyzed according to the specifications of WHO regulations[21] and standard methods for the examination of water and wastewater.[22] The Water Quality Index (WQI) was also calculated for the water samples to indicate their suitability for human use in accordance with WHO regulations.

RESULTS AND DISCUSSION

The effect of untreated petroleum effluent on groundwater was studied by collecting water samples from six boreholes at a depth ranging between 1,80 and 2,10 meters to follow the effect of the untreated oil waste collection lagoon on the properties of groundwater in the area surrounding the refinery.

Table 2 shows the concentrations of the most prominent major pollutants in the untreated effluent at the collection lagoon, while the results of table 3 show the results of laboratory analysis of groundwater at the test sites.

Table 2. Values of Refinery Petroleum Effluent Parameters

Analysis of Refinery Petroleum Effluent	
Value	**Parameter**
7,9-9,1	pH
32650 mg/l	TDS
340 mg/l	Turbidity
116 mg/l	BOD
408 mg/l	COD
196 mg/l	Oil and Grease

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162 mg/l	TOC
13 mg/l	Phenol
1,883 mg/l	Ni
3,927 mg/l	Cu
1,206 mg/l	Cd
1,116 mg/l	Pb
1,005 mg/l	Co
Nill	Remaining of the heavy elements

Table 3. Values of the Physical, Chemical, and Biological Parameters in the Groundwater of the Testing Sites.

Groundwater Parameters	Permissible Limits accord. to WHO Specifications	Testing Locations					
		GW_1	GW_2	GW_3	GW_4	GW_5	GW_6
pH	6,5-8,5	8,05	7,95	7,62	7,64	7,42	7,05
TDS (mg/l)	1000	24500	21650	20465	18455	20670	19885
EC (µS/cm)	400	3400	3120	2980	2620	2730	2315
Ni (mg/l)	0,07	0,610	0,460	0,295	0,118	0,094	0,021
Cu (mg/l)	2,0	0,12	0,09	0,062	0,022	0,012	0,026
Cd (mg/l)	0,03	0,051	0,044	0,031	0,026	0,021	0,018
Pb (mg/l)	0,01	0,694	0,588	0,487	0,423	0,127	0,082
Co (mg/l)	0,11	0,194	0,142	0,113	0,111	0,013	0,015
Oil and Grease(mg/l)	5,0	132,0	118,421	87,089	46,495	12,885	4,407
TOC (%)	2,0	115,0	93,200	55,540	19,641	23,713	4,095
Phenol(mg/l)	0,001	5,531	4,136	3,851	1,672	0,0	0,0
BOD (mg/l)	5,0	98,0	115,0	106,0	140,0	210,0	280,0
COD (mg/l)	10,0	295,0	320,0	332,0	390,0	430,0	550,0
Total Number of Bacteria (No./ml.)	500,0	$4 * 10^5$	$6 * 10^5$	$7 * 10^5$	$9 * 10^5$	$17* 10^5$	$20* 10^5$
Turbidity (NTU)	5,0	1090,0	890,0	742,0	682,0	385,0	224,0
SO_4 (mg/l)	250,0	795	684	473	234	272	206
Cl (mg/l)	250,0	332	302	307	238	241	176

Notes:

GW_1: A test site 5 meters away from the refinery effluent lagoon, towards the nearest surface water source (Al-Masharah River adjacent to the city).

GW_2: A test site 500 meters away from the refinery effluent lagoon, towards the nearest surface water source (Al-Masharah River adjacent to the city).

GW_3: A test site 1,0 km away from the refinery effluent lagoon, towards the nearest surface water source (Al-Masharah River adjacent to the city).

GW_4: A test site 2,0 km away from the refinery effluent lagoon, towards the nearest surface water source (Al-Masharah River adjacent to the city).

GW_5: A test site 5,0 km away from the refinery effluent lagoon, towards the nearest surface water source (Al-Masharah River adjacent to the city).

GW_6: A test site 9,0 km away from the refinery effluent lagoon (at the borders of the residential area), towards the nearest surface water source (Al-Masharah River adjacent to the city).

The concentrations of organic petroleum pollutants (Oil and Grease, TOC, and Phenol) present in the groundwater at the testing sites (GW1, GW2, GW3, and GW4) near the refinery indicate their high values, which gradually begin to disappear upon reaching the area (GW5, GW6) near the city of Al-Masharah, figure. 3.

It was also observed in previous test sites that this groundwater was contaminated with heavy metal elements (Ni, Cd, and Pb), as their concentrations exceeded the permissible limits, while the effect of the metal elements (Co and Cu) was slight or non-existent, as shown in figure 4.

What was mentioned previously can also be confirmed by comparing the data contained in tables (2 and 3), as it is noted that there is a leakage of untreated effluent pollutants into groundwater in addition to other indicators.

Figures 5 and 6 show the effect of untreated effluent on the concentrations of inorganic elements (TDS, Cl, SO4) and the values of turbidity and electrical conductivity (EC). It was observed that these concentrations increased at the testing sites inside and near the refinery and decreased at sites far from the refinery. As for the concentrations of the parameters (BOD, COD), there was no clear effect of the effluent on them, and on the contrary, their values began to increase at the testing sites far from the refinery.

Table 4 and figure 7 include analysis results that indicate an estimate of water quality (WQI) and its suitability for various uses. It appeared that this water is not suitable for human use at the sites (GW1, GW2, GW3, GW4) unless it is treated, while the analysis results for the two sites (GW5, GW6) indicate that it can be used exclusively for irrigation purposes.

Therefore, it can be concluded that the extent of the impact of the untreated effluent collection lagoon on the surrounding area can reach a distance of about 5 km to a high degree, while a lesser impact appears towards the nearest residential area, which is about 9 km away.

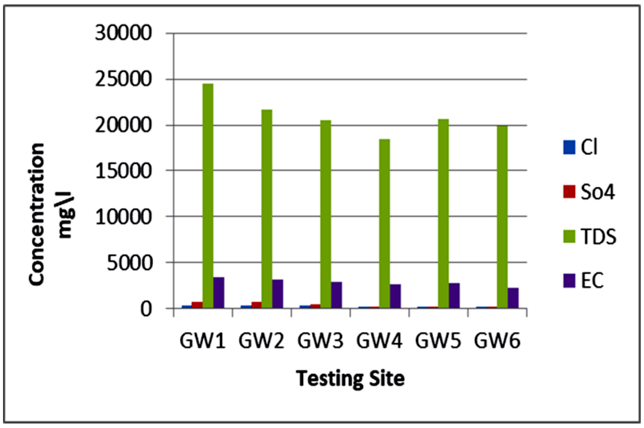

Figure 3. Values of Organic Petroleum

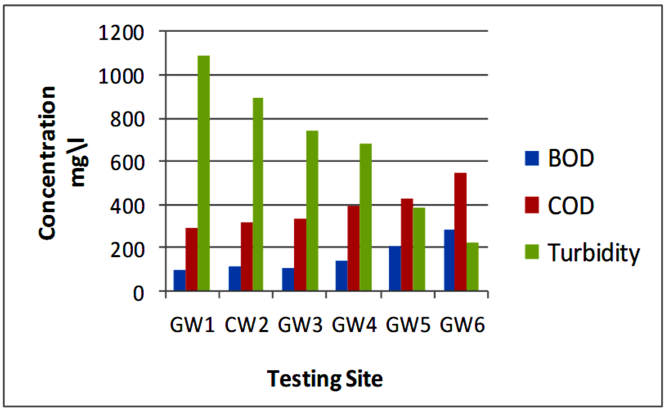

Figure 4. Values of Heavy Metal Pollutants Pollutants in the Testing Sites

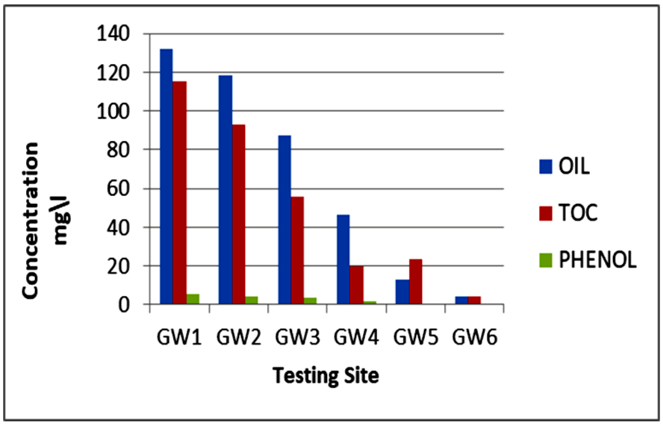

Figure 5. Values of Inorganic Petroleum Pollutants in the Testing Sites

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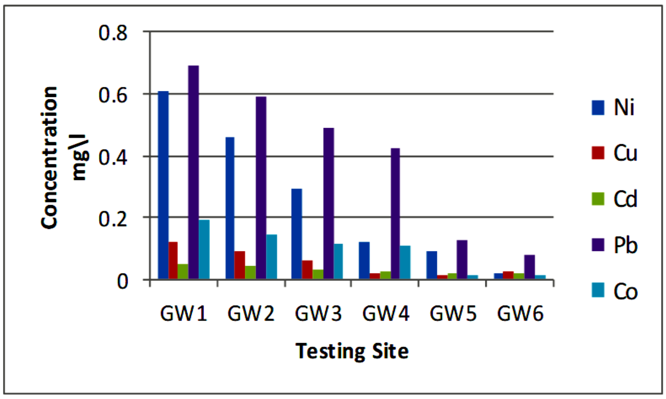

Figure 6. Values of BOD, COD, Turbidity in the Testing Sites

Table 4. WQI Values for Groundwater Quality at the Testing Sites

Testing Sites	WQI value	Comparison Limits	Status	Possible usages
GW1	623,35	Above 150	Unfit for Drinking	Treatment required before use
GW2	526,53	Above 150	Unfit for Drinking	Treatment required before use
GW3	433,36	Above 150	Unfit for Drinking	Treatment required before use
GW4	374,56	Above 150	Unfit for Drinking	Treatment required before use
GW5	116,959	101-150	Very Poor	Restricted use for Irrigation
GW6	78,993	51-75	Fair	Irrigation

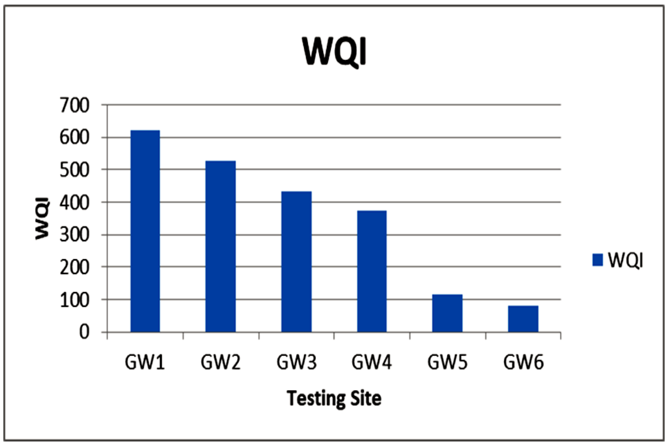

Figure 7. Water Quality Index of the Groundwater at the Testing Sites

CONCLUSIONS

Maysan Refinery was chosen as a study area because it represents one of the most promising strategic projects in Maysan Governorate. The study aimed to demonstrate the environmental impact of the refinery effluent on the surrounding area. The study showed the clear impact of untreated effluent on the properties of groundwater, as this groundwater was greatly affected by a distance of 5 km from the collecting effluent lagoon, and it was not suitable for human use until after it was treated, while the remaining distance to the nearest residential area (from 5 km to 9 km) was the groundwater that was not suitable to being used for drinking purposes and could only be used for irrigation.

The study recommends several points to reduce refinery effluent pollution, such as the use of regular

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wastewater networks, the construction of a treatment plant for these effluents, and the discharge of treated effluent to the nearest water source.

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