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STUDY AND DISTRIBUTION OF MICROPLASTIC PARTICLES AND MICROBIAL CONTAMINATION IN SOME WELLS WITHIN THE CITY OF BAGHDAD / IRAQ

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ABSTRACT

The current study aims to evaluate microplastic levels and microbial pollution in the selected well water in Baghdad, 2026. In this study, 10 wells were examined chemically and biologically, and the study showed that microplastic levels ranged from 2 to 19 particles per litre across the wells. The highest levels of microplastics were observed at W5 due to its proximity to industrial and human activities, specifically near the landfill site. In comparison, the lowest level was recorded at W1 because it is located in an agricultural area and is not affected by general pollution. The variation in the average concentration of plastic particles, their types, and their distribution across different locations may be attributed to the nature of plastic particle decomposition and the accumulation of large amounts of plastic over time. Other contributing factors include the wells' proximity to pollution sources, landfills, and densely populated areas; whether the well is covered or open; and the impact of natural factors such as surface runoff from rainwater.

Also, the results of the microbial analysis showed clear variation in bacterial contamination in well water. Well W10 recorded the highest concentration of different types of bacteria, while Well W4 and W9 showed the least contamination. The contamination of Well W3 is attributed to its mixing with wastewater discharged from the Rustamiya station. The results of the variance analysis of the relationship between well locations and types of bacterial contamination (Coliforms, E. coli, and TPCs) show that the location clearly affects the number of bacterial species, particularly at W10, which differed significantly from the other locations examined. In comparison to sites W1, W8, W3, W9, W5, W4, W6, W2, and W7, the different sources of pollution caused the TPC contamination at this location to grow by 94.4%, 93.3%, 91.8%, 91.4%, 90.6%, 89.8%, 89.0%,

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87.8%, and 73.8%, respectively Finally, we recommend against drilling wells, especially those for human use, near human and industrial areas due to their potential to contaminate these wells.

Keywords: Microplastic, Microbial, Human activity, Baghdad, well water, and pollution.

1. INTRODUCTION

Groundwater is an important source of potable water, irrigation, industrial activities, drinking and domestic purposes. Rapid population expansion, urbanisation, industry, and agricultural practices increase its exploitation, decrease its availability, and make it more susceptible to water quality pollution (Vijay et al., 2011). Urban and industrial waste disposal and agricultural pesticide use may pollute groundwater with microplastic (MPs) particles (Adhikary et al., 2009). Thus, a thorough understanding of groundwater quality is necessary to support long-term sustainability initiatives as well as to guarantee its safe use. This entails evaluating the chemical compatibility of groundwater for various purposes in addition to estimating its availability (Al-Kutaisi and Al-Kubaisi, 2022). Numerous studies on groundwater quality have been carried out in several regions of Baghdad city (Al-Hiti, 1985; Ali, 2012; Alhassan etal., 2015. Al-Paruany etal., 2018; Al-Hadithi et al., 2019; Ali et al., 2025). MPs' pollution in groundwater has not been extensively studied. This study is the main investigation of Baghdad's groundwater.

Since 1970, plastic materials have been widely used worldwide. From 1.5 million tons in 1950 to 359 million tons in 2018, global production has increased. By 2050, it is anticipated that 33 billion tons of plastic will be produced (Singh et al., 2022). There are several types of plastic, such as Polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polyamide (PA) plastics. Plastic pollution is now seen as a major environmental issue (Waldschlager, 2021). It comes in various forms, including solid particles with regular or irregular shapes and polymeric matrix particles that range in size from 1 µm to 5 mm (Munhoz et al., 2023). Sediments, food products, oceans, bottled water, freshwater, wastewater, air, tap water, and aquatic species are just a few of the places where microplastics (MPs) have been discovered (Feld et al., 2021; Singh et al., 2022). MPs have a detrimental effect on organisms because of their tiny size, which makes it easy for them to penetrate food, water, and soil.

There are several direct and indirect ways microplastics enter inland water (groundwater and surface water). Two of the most common sources of microplastics in freshwater systems are urban runoff and untreated wastewater. Microplastics can also come from rural runoff in addition to urban garbage. Another significant source of microplastics in freshwater ecosystems is atmospheric deposition. According to studies, microplastics may be carried by the wind and end up in rivers, lakes, groundwater, and reservoirs, especially in areas near cities or industrial zones (Dris et al., 2016). Agricultural practices, sewage, land-fills, industrial effluent, and surface water interaction are the primary sources of microplastics in groundwater. Moreover, Septic tank systems, cracks,

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and vertical infiltration are the main transit routes. According to studies, the most prevalent plastic polymers in groundwater are polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) (Cole et al., 2011; Sha et al., 2022).

This poses a substantial risk not only to aquatic life but also to higher trophic levels, including humans, who rely on these water bodies for drinking water, agriculture, and fishery resources (Rochman et al., 2015). The health implications for humans are increasingly being studied, as microplastics have been detected in drinking water, seafood, and even human blood and placental tissue (Leslie et al., 2022).

Microplastics in groundwater pose serious health risks. When consumed, these particles can lead to endocrine disruption, inflammation, metabolic problems, and possibly even cancer. This can carry these particles into the human body, especially if they are between 1 and 5 µm in size, allowing them to migrate to organs like the spleen and liver. As of early 2026, the World Health Organisation (WHO) has not set any precise standards or numerical limits for microplastic concentrations in drinking water or groundwater (Prata et al., 2020; Minh et al., 2023).

Pathogenic microorganisms, including bacteria, viruses, and protozoa, can contaminate stormwater runoff from various sources such as sewer overflows, faulty septic systems, agricultural runoff, and wildlife faeces (Aromolaran et al., 2019). *Coli* (*E. coli*) and *coliform* are commonly used to assess microbial water quality.

Bacteriological contamination is one of the most significant threats to groundwater quality because it directly affects public health. The following are internationally recognised indicators of faecal pollution and microbial contamination of the drinking water: total coliforms, faecal coliforms, and Escherichia coli (WHO, 2017). The existence of these bacteria in drinking water is strongly associated with waterborne diseases, including diarrhea, typhoid fever, and other gastrointestinal infections, particularly among people who are at risk (Alwaeli et al., 2021). According to numerous field studies performed in Baghdad and other areas of Iraq, bacteriological contamination of the groundwater and drinking water sources has been reported, highlighting the effects of human activities and the lack of proper sanitation facilities on their quality (Hasan & Hussain, 2015).

Recent studies indicate that groundwater near the Earth's surface can be contaminated from numerous sources, including human activities that lead to the leakage of pollutants into wells from wastewater treatment plants and livestock farms, as well as faecal contamination. Pollution also results from the mixing of groundwater and sewage, particularly in villages and cities lacking modern sewage systems. Furthermore, groundwater is contaminated when agricultural land is irrigated with wastewater containing high levels of coliform bacteria and faecal coliform bacteria. The presence of total coliforms in well water indicates the potential for pathogenic bacteria, while the presence of faecal coliforms suggests the infiltration of wastewater into the wells. In both cases,

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this water must be disinfected before being given to animals or used by humans, as it can have serious health consequences (Alexander, 2002; Mench et al., 1994). The present study's primary goal is to determine the amounts and features of MPs and microbial contamination in groundwater on both sides of Baghdad.

1.1 Study Area

The research zone is located between 33˚ 14′-33˚ 16′ N and 44˚ 31′- 44˚ 33′ E, and ~~it~~ encompasses both the Karkh and Rusafa sides of Baghdad (Figure 1). The most important aquifers are generally Quaternary deposits (Pleistocene-Holocene) with water depths of 15 to 30 meters on both sides. Land-use environments include industrial, agricultural, and residential zones. Climate data from the Baghdad station (Baghdad International Airport) from 1990 to 2025 showed that the average annual temperature, average relative humidity, total annual rainfall, and total annual evaporation were 23.45%, 3300 mm, and 124 mm, respectively. The climate in the study area is semi-arid and arid.

Geologically, Pleistocene-Holocene Quaternary sediments are exposed across most of Baghdad. However, only the Injana Formation covers the exposed Pre-Quaternary rocks (Jassim and Goff, 2006). Table 1 lists the names, symbols and depths of soil sampling sites and wells in the research region.

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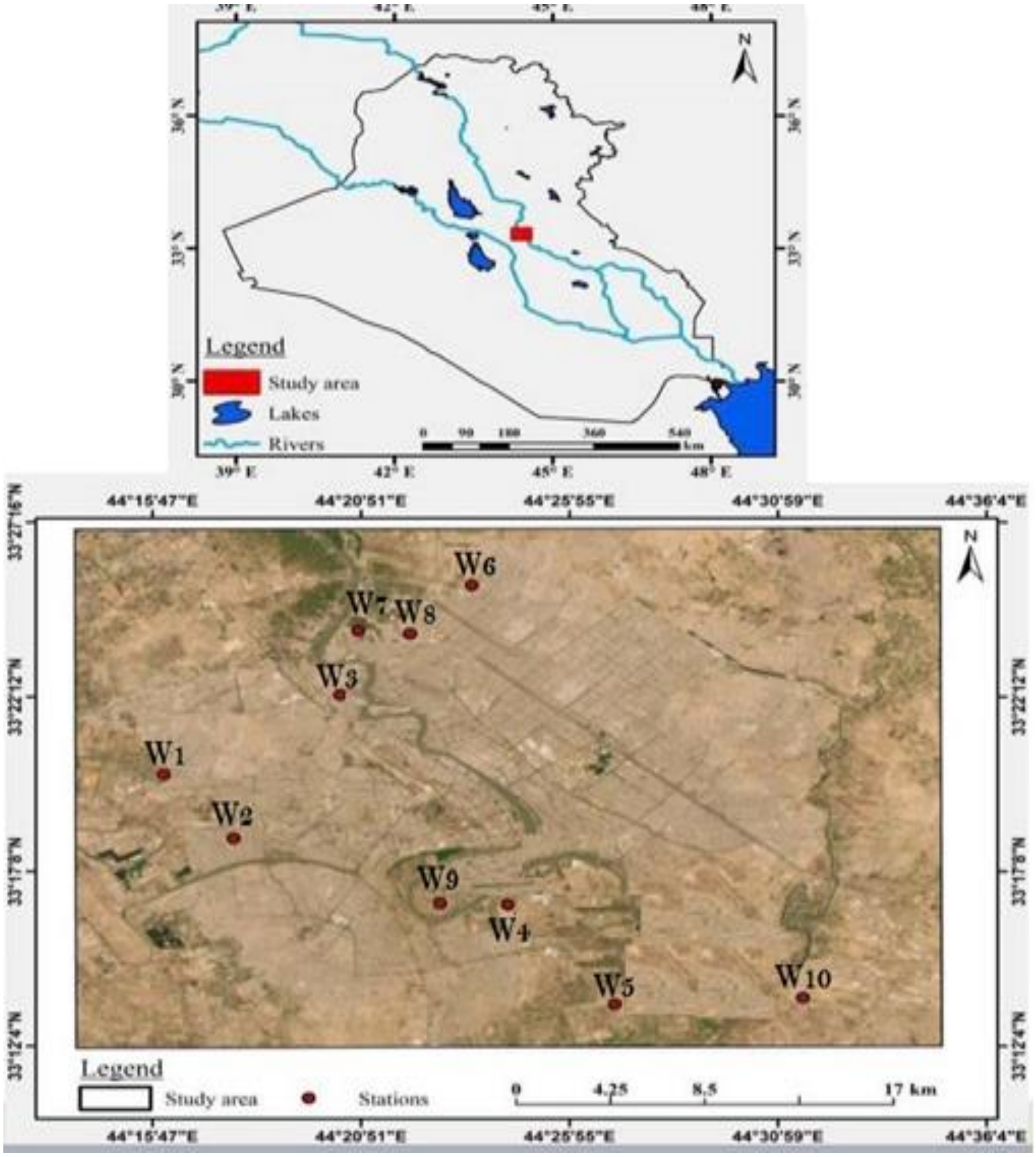

Figure 1: Map of the study area

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Table 1: The Name, symbol, and depth of wells in the study area.

Well Symbol	Well name	N	E	Depth of water	Well Symbol	Well name	N	E	Depth of water
W1	Al-Gazalia	33 22 32.2	44 17 35.0	3.5	W6	Qahira	33 13 15.3	44 32 50.1	5.2
W2	Al-Amirya	33 16 11.9	44 21 11.4	4.2	W7	Krayaat	33 23 29.4	44 23 24.7	3.7
W4	Atyifia	33 17 52.9	44 25 36.1	4.6	W8	Adiymia	33 20 35.1	44 22 17.5	4.6
W4	Dora	33 17 23.1	44 27 11.0	5	W9	Jadria	33 21 11.1	44 21 15.1	5.6
W5	Hor Rajb	33 15 11.2	44 26 42.3	5.7	W10	Daiyala bridge	33 22 17.4	44 7 27.2	4.9

2. METHODOLOGY

2.1 sampling

Ten well water samples were chosen from the districts of Rusafa and Karkh in 2026 to measure hydrochemical parameters, such as pH, total dissolved solids (TDS), electrical conductivity (EC), and cations (sodium, potassium, calcium, and magnesium) and Anions (chloride, sulfate, and bicarbonate). The samples were collected in 1-litre polyethylene containers. A 100 ml glass bottle was used for Microplastic and microbiological analysis. In the field, measurements were made of pH, TDS, and electrical conductivity. Before being sent to the lab for analysis, each sample was filled, the apertures were firmly shut, and it was placed in a sealed container. The quantity of duplicate samples and quality control measures used during the microplastic measuring and sampling processes have been described.

2.2 Measurements

1. For physico-chemical analysis, Samples were examined for pH, conductivity, EC, TDS, and nitrate ion. A pH and conductivity meter (WTW, Germany) was used to test the pH, conductivity, and TDS. A UV spectrophotometer (Dune, Germany) was used to measure the nitrate concentration.

2. Each sample had one millilitre of water extracted and put into Petri plates. The plates were then filled with 20 millilitres of nutritional medium. The suspension with the nutritional medium was then homogenised by gently shaking the plates. To prevent condensation on the bacterial colonies, the dishes were flipped after they had hardened. At 35°C, they were incubated. The Colony Forming Units (CFU), which are quantified in CFU per 100 millilitres of the initial sample, were used to count the visible colonies after 24 to 48 hours, according to the following equation (APHA, 2012):

(Reciprocal of clotting × Number of cells = Number of colonies).

The biological analyses included the following tests:

• Total plate count (TPC)

• Total coliform count (TC)

• E. coli bacteria

3. Plastic particles are studied using optical microscopy or scanning electron microscopy (SEM). To avoid interference, one-litre samples are collected in glass bottles and then filtered through filters with particle sizes ranging from 1 to 22 micrometres. -Hydrogen peroxide (H_2O_2) is used to eliminate organic pollutants and impurities. There are two phases to microplastic analysis. In the first step, the particles (fibres, pieces, and spheres) are identified and categorised using optical microscopy. Using SEM, the structure and particle sizes are ascertained in the second step.

3. RESULTS AND DISCUSSION

The results of physicochemical analyses of groundwater in some wells on both sides of Baghdad city are shown in Table 2.

Table 2: Physicochemical analyses of groundwater in some wells on both sides of Baghdad City.

wells	EC	TDS	pH	NO_3
W1	856	498	7.2	24
W2	2345	1342	7.5	21
W3	1410	899	7.3	17
W4	1765	1132	7.1	45
W5	2021	1276	6.8	48
W6	1432	876	7.3	36
W7	2765	1654	7	60
W8	3564	2165	7.2	65
W9	1654	1034	7.4	34
W10	1112	734	6.9	66

The spatial variation of pH, EC, and TDS in water samples of the studied wells in March 2026 was analysed. The lowest values of pH, EC, and TDS were 6.8, 856 µS/cm, and 498 ppm for well numbers W5, W1, and W1. The maximum values were 7.5, 3565 µS/cm, and 2156 ppm for well numbers W2, W8, and W8. In accordance with the WHO recommendation of 2500 µS/cm. Electrical conductivity (EC) values in wells W7 and W8 exceeded the WHO maximum limit, as EC affects water taste and is a measure of the total dissolved ions in groundwater samples. According to the WHO standard (1000 ppm), total dissolved solids (TDS) values ranged from 498 to 2165 ppm. The WHO maximum limit was exceeded by the wells W2, W4, W5, W7, W8, and W9. Distribution of EC and TDS in water samples in wells as shown in Figure 2

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The concentration of hydrogen ions in a solution is represented by pH. The permissible pH range, which is between 6.5 and 8.5 per the national standard, is within the WHO standard for all samples. (Figure 3).

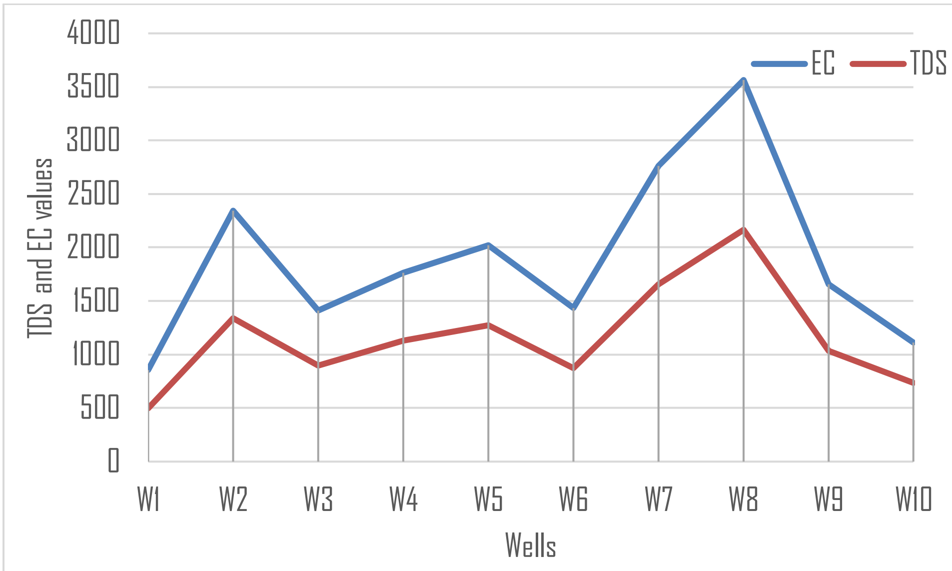

Figure 2: Distribution of EC and TDS in water samples in wells in March 2026.

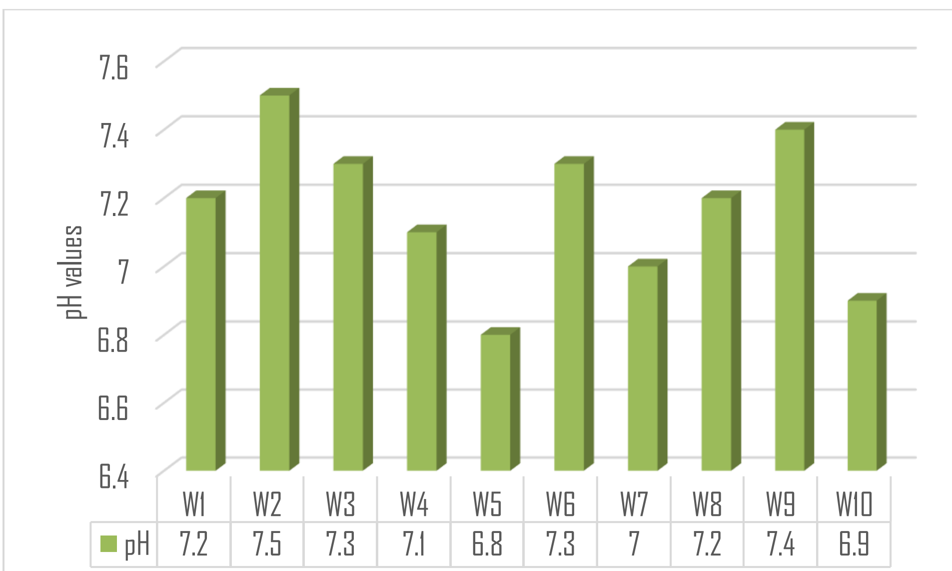

Figure 3: Distribution of pH values in water samples in wells in March 2026.

The Nitrate concentrations in the studied wells varied from 17 ppm to 66 ppm in March, 2026. It is noticed that 30% of the groundwater samples showed nitrate concentrations higher than the

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maximum permissible limit recommended by the World Health Organization WHO and IQS (50ppm). The high value of $NO_3{}^{1-}$ in the studied area may be due to fertilizer use and sewage seepage from the pits through the unsaturated zone, Figure 4.

Figure 4: Distribution of NO_3 concentration in water samples in wells, March, 2026.

3.1 Microplastics analysis in the study area

The term plastic refers to materials made from natural or synthetic materials. Plastic is used in many industries and can be recycled. A key characteristic of plastic is its slow decomposition rate, which causes numerous environmental and health problems. (Andrady et al., 2017) Microplastics comprise all plastic particles smaller than 5 mm. These particles exist either as primary plastic (i.e., synthetic primary plastic) or as secondary microplastic (which results from the decomposition of larger plastic waste). (Horton et al.,2016; Wright and Kelly,2017). In both forms, the plastic particles are spherical or have varying edges. The results of plastic concentration data from six locations over a single season are shown in Table 3.

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Table 3: Concentration of microplastics in the well water of the studied area

Sites	Type and concentration (Particle/l) in wet period		Total particle %	Sites	Type and concentration (Particle/l) in wet period		Total particle %
W1	circular	10	27	W6	circular	12	53
	parts	5			parts	10	
	Fibers	6			Fibers	13	
	Film	3			Film	11	
	Large pieces	3			Large pieces	7	
W2	circular	10	38	W7	circular	12	35
	parts	9			parts	6	
	Fibers	10			Fibers	7	
	Film	5			Film	5	
	Large pieces	4			Large pieces	5	
W3	circular	13	43	W8	circular	11	46
	parts	12			parts	13	
	Fibers	8			Fibers	10	
	Film	8			Film	8	
	Large pieces	2			Large pieces	4	
W4	circular	14	50	W9	circular	11	56
	parts	12			parts	19	
	Fibers	10			Fibers	10	
	Film	8			Film	14	
	Large pieces	6			Large pieces	2	
W5	circular	18	65	W10	circular	15	50
	parts	15			parts	13	
	Fibers	17			Fibers	13	
	Film	5			Film	9	
	Large pieces	10			Large pieces	8	

In this study, the concentration of microplastic particles ranged from 2 to 19 particles per litre in well water samples collected in Baghdad in 2026, with an overall average of 27 particles per litre. The results, shown in Table 3, indicate that the selected sites were contaminated with microplastic particles at varying levels due to differences in human and industrial activity and in the impact of climate. Site W5 recorded the highest concentration of microplastic particles in the selected well compared to the other wells, indicating that this site was directly affected by human activities or the proximity of plastic from waste accumulation near the well. The well at site W1 recorded the lowest concentrations, as it is an agricultural area far from industrial and human activities, and its impact is limited to the use of some plastic coverings in the studied agricultural area of Baghdad. In particular, the physical properties of plastic particles in the studied soils varied, including circular, irregular shapes, fibres, films, and large pieces smaller than 5 mm. Figure 5.

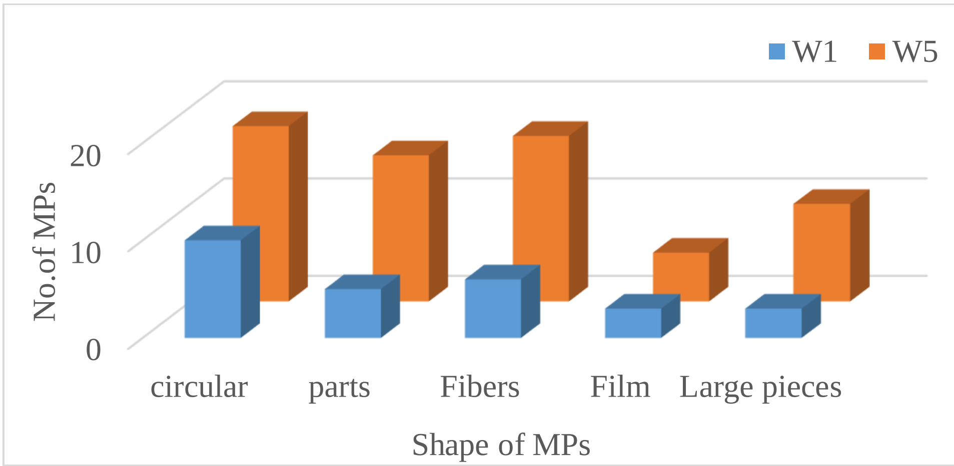

Figure 5: Shape and number of MPs in W1 and W5 in the studied area.

In this study, the presence, distribution, and prevalence of microplastics in well water in some areas of Baghdad, at multiple levels, may be concerning Figure 6. We recommend identifying the types of microplastics present in other areas of Baghdad, including polyethylene (PE), polyethylene terephthalate (PET), and nylon.

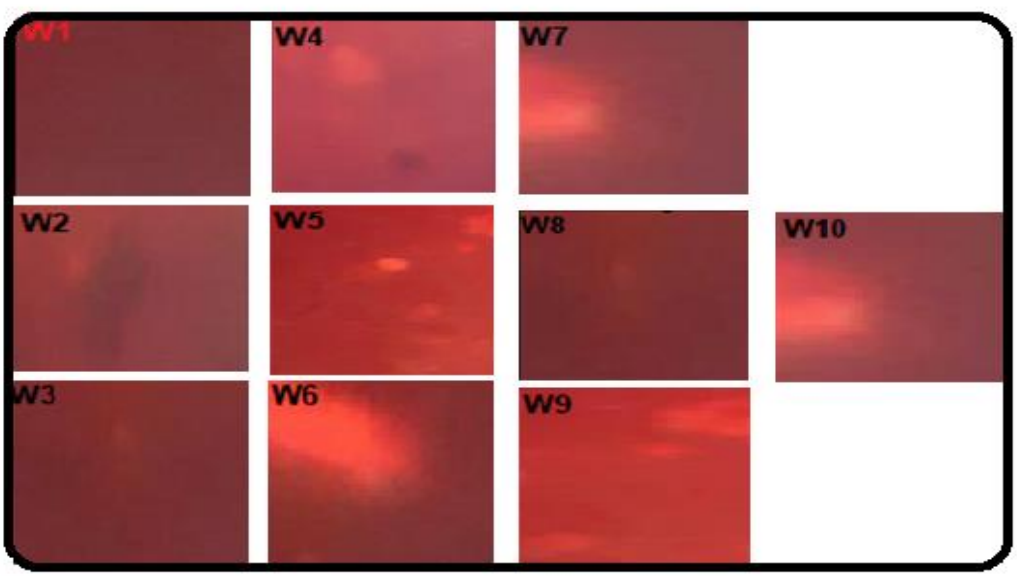

Figure 6: Occurrence of MPs in the well water of the study area.

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The analysis of variance (ANOVA) and the least significant difference (LSD) at the 5% level showed a significant effect of well locations on the average contamination levels of microplastic particles (circular, parts, fibres, film, and large pieces) (Table 4). The effect of location was evident in the microplastic contamination indicators. Sites W2, W8, and W10 showed a significant increase in the microplastic (circular) particle contamination index compared to the other sites, reaching 16.0, 18.0, and 15.0 particles, respectively. Sites W8 and W9 differed significantly from the other sites in the average concentration of fine particles, reaching 19.0 particles/L each. Well water contamination with fibre and large pieces was associated with sites W2, W8, and W10, respectively, where the average concentration in well water was significantly different from the other sites, reaching 13.0, 16.0, 15.0, and 10.0, 10.0, and 10.0 particles per litre, respectively. Meanwhile, site W9 showed a significant difference in film particle concentration compared to the other sites, with 14.0 particles per litre. The percentage increase in circular particle concentration at site W8 compared to the average concentration at sites W1, W3, W5, W7, and W9 was 33.3%, 44.4%, 27.8%, 38.9%, and 38.9%, respectively.

Table 4: Average microplastic content of studied well samples within the city of Baghdad

Wells	circular	parts	Fibers	Film	Large pieces
W1	D 11.0±1.45	F 5.00±1.05	C 6.00±1.14	D 3.00±0.75	EF 3.00±0.38
W2	BA 16.0±2.67	B 14.0±2.72	A 15.0±2.43	D 5.00±0.98	BA 10.0±1.34
W3	BDC 13.0±1.85	CBD 11.0±2.60	C 8.00±2.03	C 8.00±0.94	F 2.00±0.53
W4	BDC 13.0±1.20	CBD 11.0±2.07	BC 10.0±2.86	C 8.00±0.82	BCD 6.00±1.08
W5	D 10.3±1.00	ED 9.00±1.25	BC 10.0±2.90	D 5.00±0.63	EFD 4.00±0.83
W6	D 10.0±1.70	CD 10.0±1.46	BA 13.0±2.98	B 11.0±1.36	BC 7.00±1.09
W7	DC 12.0±2.06	FE 6.00±0.94	C 7.00±1.34	D 5.00±0.87	BCD 5.00±0.62
W8	A 18.0±2.23	A 19.0±3.18	A 16.0±2.03	C 8.00±1.33	A 10.0±1.46
W9	D 11.0±1.90	A 19.0±3.26	C 10.0±1.95	A 14.0±1.85	F 2.00±0.26
W10	BAC 15.0±2.04	CB 13.0±2.91	BA 13.0±2.03	CB 9.00±1.68	BA 10.0±1.08
mean	12.9	11.7	10.8	7.60	5.50
Range	10-18	5.00-19.0	6.00-16.0	3.00-14.0	2.00-10.0
$Lsd_{0.05}$	3.29	3.23	4.51	2.69	2.15

At well water sites W10 and W9, the concentration differed significantly from that at the other studied sites (W7, W6, W5, W3, W2, W1, and W10). The various pollution sources increased particle contamination at these sites by 73.7%, 26.3%, 42.1%, 52.6%, 47.4%, 68.4%, and 31.6%, respectively. The highest significant increase in the average levels of microplastic particles (fibres) and large pieces was observed at well W8, reaching 62.5%, 50.0%, 37.5%, 33.3%, 70.0%, 80.0%, 37.5%, and 56.3%, respectively, compared to the average levels of these two indicators in wells W1, W3, W5, and W7, respectively. The level of E. coli bacterial contamination can be ranked according to location as follows:

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The results shown in Table 5 indicate significant differences at the 0.05 probability level among the average film particles in the well water at different locations. The highest significant differences were observed in well W9, with averages of 78.6%, 64.3%, 42.9%, 64.3%, 21.4%, and 35.7%, compared to the average of these particles in wells at locations W1, W2, W3, W5, and W6. W10 and W10, respectively.

Furthermore, the results of the ANOVA table, using the least significant difference index at a probability level of 0.05 (Figure 7), indicated a significant dominance of total circular particles in the well water across all locations. The total concentration of these particles was 129 particulates/L, decreasing to 117, 108, 76, and 55 particulates/L for large pieces, film, fibre, and parts, respectively. The percentage increase in total circular particles across all well water locations was 9.30%, 16.3%, 41.1%, and 57.4% for circular particles compared to parts, fibre, film, and large pieces.

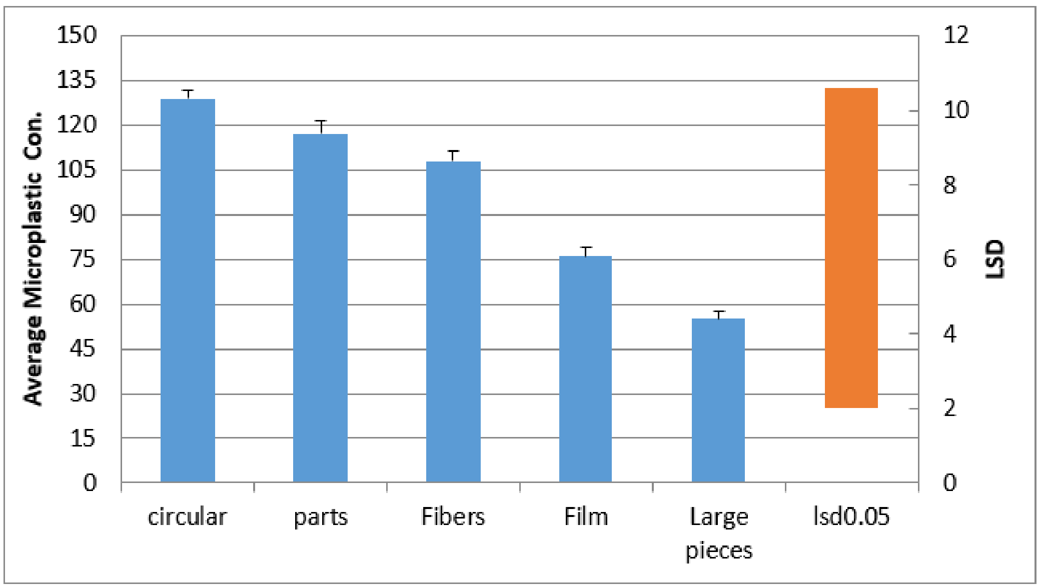

Figure 7: Total average concentration of microplastic particles in the water of the studied wells in Baghdad.

The variation in the average concentration of plastic particles, their types, and their distribution across different locations may be attributed to the nature of plastic particle decomposition and the accumulation of large amounts of plastic over time. Other contributing factors include the wells' proximity to pollution sources, landfills, and densely populated areas; whether the well is covered or open; and the impact of natural factors such as surface runoff from rainwater.

These results are consistent with those found by Rochman et al. (2019) and Hale et al. (2020). Statistical analysis using ANOVA in a study by Qais (2025) ~~on~~ assessing and diagnosing

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microplastic pollution in 36 wells across different areas of Mousal Governorate showed that most differences between well locations were statistically significant, confirming ~~the~~ variation in environmental impacts and pollution sources across regions. He also pointed to the morphological characteristics of the particles, where plastic fibres constituted the highest percentage at 31%, followed by fragments at 29%, thin films at 11%, and granules at 7%, while 12% were classified as having an unspecified shape.

The amount of plastic pollution can be ranked according to location as follows:

Large pieces < film < fiber < parts < circular.

The relationship between water depth and the total number of microplastics in the studied well water was investigated (Figure 8). The results showed a direct relationship between water depth and microplastics, with a coefficient of r=0.96. This is because a shallower water level increases the ability of small microplastic particles to reach and migrate to groundwater. This explains the varying numbers and types of microplastics present in the well water under study.

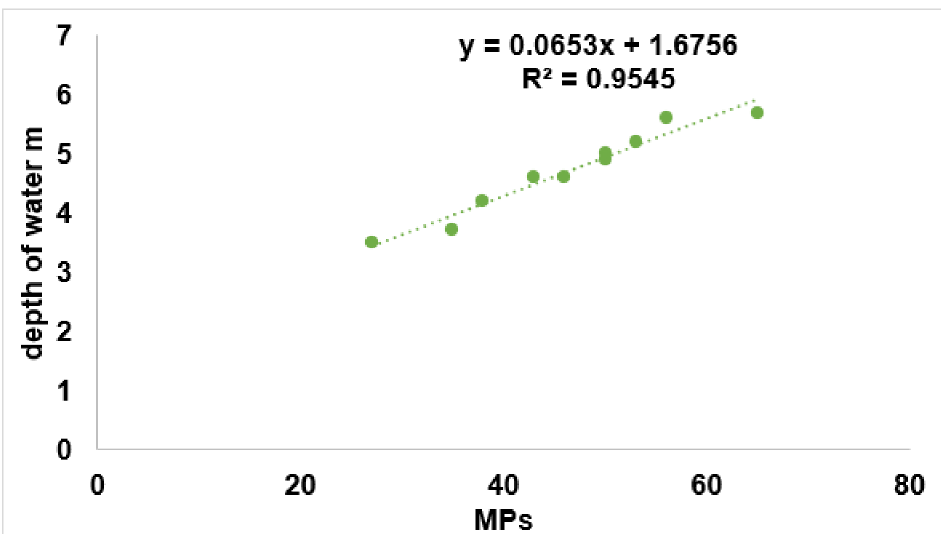

Figure 8: The relation between MPs and the depth of water in the well water of the studied area

The relationship between pH and the number of microplastic particles in the studied wells is shown in Figure 9. The results showed an inverse relationship with r= 0.0988. A higher well pH helps stabilise microplastic particles and reduce chemical reactions, thereby helping them to maintain their shape. Furthermore, the study found that the highest concentration of microplastic particles was in low-depth wells compared to high-depth wells, and that other factors, such as organic matter that binds to microplastic particles and promotes their accumulation, were also significant.

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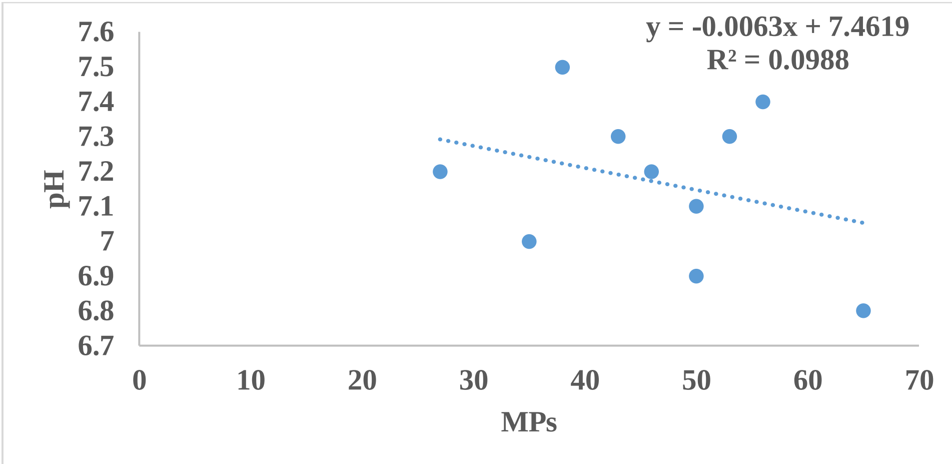

Figure 9: The relation between MPs and pH in the well water of the studied area

Table 5: Classification of Microplastics in water depends on Khant and Kim (2022).

Pollution degree	mg l^{-1} Conc.
Low pollution	<10
Moderate pollution	50-10
high pollution	100-50
Very high	>100

Based on the Khant and Kim 2022 classification, wells are classified by microplastic concentration index, the degree of pollution, and their source, as shown in Table 5. Comparing ~~the~~ microplastic concentrations at the studied well sites, we find that well sites W1, W2, W5, W4, W7, W8, and W10 have Moderate pollution levels, while levels at sites W5, W6, and W9 were very high during the study period.

3.2 Microbiological analysis in the study area.

The results for the total plate count, E. coli, and Coliform Bacteria in well water from the study area in March (wet period), 2026 are listed in Table 6.

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Table 6: Microbiological analyses of groundwater in some wells on both sides of Baghdad City.

wells	TPC	E.coli	Coliform
W1	34	26	-
W2	85	40	38
W3	32	13	15
W4	31	26	15
W5	50	23	24
W6	75	67	-
W7	32	25	-
W8	33	28	-
W9	31	23	
W10	600	342	210

The total bacterial counts in March ranged from 31 to 600 cells/ml. The results indicate bacterial contamination of the studied well water. The variation in bacterial contamination level is due to the proximity of these wells to pollution sources such as wastewater or sewage. Furthermore, soil is a major reservoir for microorganisms, including both pathogenic and non-pathogenic bacteria. (Jawetz etal.,2007). From the results above, wells W4 and W9 recorded the lowest counts, while well W10 recorded the highest. The increase in total plate count in well 10 was associated with a pollution source (sewage in Rustamiya). The variation in bacterial counts at the remaining sites is linked to variations in organic matter and oxygen levels, as well as variations in surrounding environmental conditions.

The results showed a clear variation in the number of coliform bacteria, ranging from 15-210 cells/ml. This variation in bacterial numbers may be attributed to differences in the concentrations of organic and inorganic materials available in the well water, and the results showed that well W10 in the Jisr Diyala area had high numbers, which is linked to sewage water. The increased concentrations in well W2 are due to the presence and impact of sewage activities. Bacteriological analysis revealed coliform bacteria in some of the studied wells at a rate of 50%. This indicates limited groundwater contamination in some areas of Baghdad. E. coli counts ranged from 13 to 342 cells/ml during the study period. This variation was associated with nutrient and salinity levels. The results showed that the wells contained large numbers of bacteria linked to sewage and livestock farming in some areas, as well as evidence of wastewater contamination. Bacteriological analysis revealed that E. coli was found in 100% of the samples from the study area. This indicates widespread groundwater contamination in Baghdad. Generally, the numbers of coliform and E. coli bacteria are high during the study period due to higher temperatures and increased population activity. The statistical analysis of bacteria in well water samples is shown in Table 7.

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Table 7: Statistical analysis of bacteria in well water samples in the study area

Wells	Mean TPC Bacteria ±SD	Mean E. coli Bacteria ±SD	Mean Coliform Bacteria ±SD
W1	F 45.0±3..76	E D 43.0±3.61	-
W2	C 98.0±6.13	D 45.0±5.00	C 42.0±4.31
W3	DEF 66.0±7.03	E 31.0±2.92	C 28.0±1.43
W4	DC 82.0±6.32	C 76.0±6.24	-
W5	DE 75.0±8.38	-	B 72.0±4.79
W6	DC 88.0±7.90	C 88.0±6.87	-
W7	B 210±12.3	B 200±14.3	-
W8	EF 54.0±2.45	D 50.0±6.10	-
W9	DF 69.0±4.35	D 55.0±6.53	D 10.0±1.01
W10	A 800±23.8	A 487±18.3	A 280±17.7
mean	158.7	119	86.4
Range	45-800	31.0-487	10.0-280
$Lsd_{0.05}$	22.7	13.0	16.7

The results of the variance analysis (Table 8) the relation between well locations and types of bacterial contamination (Coliforms, E. coli, and TPCs) indicate that the location of contamination clearly affects the number of bacterial species, particularly at location W10, which differed significantly from the other locations examined. In comparison to sites W1, W8, W3, W9, W5, W4, W6, W2, and W7, the different sources of pollution caused the TPC contamination at this location to grow by 94.4%, 93.3%, 91.8%, 91.4%, 90.6%, 89.8%, 89.0%, 87.8%, and 73.8%, respectively. The following is a ranking of the contamination levels by location based on the total number of TPC bacteria:

W10 > W1 > W8 > W3 > W9 > W5 > W4 > W6 > W2 > W7.

The number of E. coli contaminations of well water increased significantly, despite the variation in the most probable count of the bacteria in the well water. The highest most probable count of this bacterium in the well water at site W10 was 100ml/487, while the lowest most probable count was 100ml/31.0 in the well water at well W3. The percentage increase in the E. coli bacteria count at well W10 was (93.6, 91.2, 90.8, 89.7, 88.7, 84.4, 81.9, and 58.9%) compared to the count of this bacterium in wells W3, W1, W2, W8, W9, W4, W6, and W7, respectively. The amount of E. coli bacterial contamination can be ranked according to the locations as follows:

W10>W3>W1>W2>W8>W9>W4>W6>W7.

Table 8 indicates significant differences at the 0.05 probability level between the mean most probable (Coliform) counts of coliform bacteria in well water across different locations. The highest MP counts were observed in well W10 (96.4%, 90.0%, 85.0%, and 74.3%) compared to wells W9, W3, W2, and W5, respectively, in ascending order: **W10 > W9 > W3 > W2 > W5**

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The higher Coliform counts for different bacterial species in well W10 may be attributed to the contamination of the well water with wastewater at the Rustamiya station, as noted by Al-paruany (2016). The results of the ANOVA table, using the least significant difference index at a probability level of 0.05 (Figure 10), also indicated a significant dominance of the total TPC bacterial count in the well water, reaching 100 ml/1587, while the E. coli and Coliform counts were 100 ml/1057 and 100 ml/432, respectively. The percentage increases in the total TPC bacterial count across all well locations were 32.3% and 72.8% for the E. coli and Coliform counts, respectively. Meanwhile, the significant increase in the average E. coli bacterial count was 59.9%, compared to the average Coliform bacterial count.

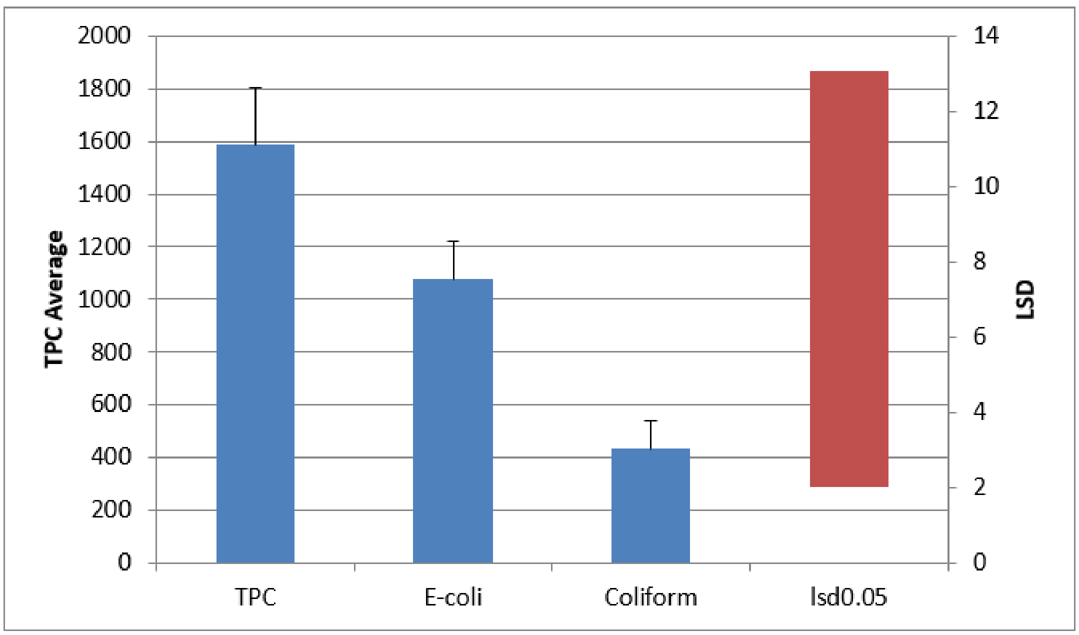

Figure 10: Average of squared values of the indices affecting the type of medium (location, season, and bacteria) on total biological pollution.

High TPC levels in groundwater do not always indicate the presence of serious pathogens, but they can suggest conditions that support the growth of harmful organisms. Monitoring TPC levels is crucial for maintaining water quality and ensuring its safety for consumption. The contamination of well water with these types of bacteria and their variation may be attributed to the different locations of the wells, their proximity to pollution sources, and the nature of the soil and its ability to leach these bacterial contaminants into the groundwater. These findings are consistent with those of Y.R. Humudat (2020) and Al-Naseri (2013). Hassan's (2015) study of microbial contamination in 10 wells in the Abu Ghraib area found that the water in these wells was microbially contaminated with a high microbial load (CPU), which negatively affected water quality. The study conducted by Supriya Kamboj, 2021, aimed at analysing the microbial load and health status of water across three locations in Punjab, found that the total microbial load (TPC) ranged from 3670 to 178330 cfu ml-1, and the total coliform bacteria ranged from 4.00 to 1100 ml-1 water. These results are consistent with the findings of Leslie G. Fell et al., 2025; Latchmore et al., 2020; and James et al., 2021, in their studies on the effect of location on bacterial pollution levels in wells. The results of the study conducted by Onuigbo A. C. et al. (2017) on E. coli at the site and across seasons in all wells showed that E. coli values decreased with increasing distance from pollution sources. Statistical analysis of their study revealed significant differences ($p < 0.05$) across locations and distances. The presence of bacteria in all wells was strongly affected by their proximity to pollution sources. The presence of bacteria in well water is influenced by climate cycles, with algal and bacterial growth increasing at higher temperatures and decreased growth at lower temperatures. Increased nutrient loading and surface runoff.

Our results indicate that the prevalence of waterborne diseases was higher during the study period, consistent with elevated microbial contamination. These results are consistent with those of FraserMah et al. (2017). In order to identify the source of pollution in the well water under study, the relationship between microplastic particles and the overall bacterial count was examined. A modest positive association in Figure 11 suggests that there are several sources of bacterial and microbial contamination in the wells under study. Additionally, it implies that the presence of bacteria in well water is either due to mixing with polluted water or to direct human activity, and that groundwater pollution does not necessarily imply that microplastic particles are entirely bacterial carriers.

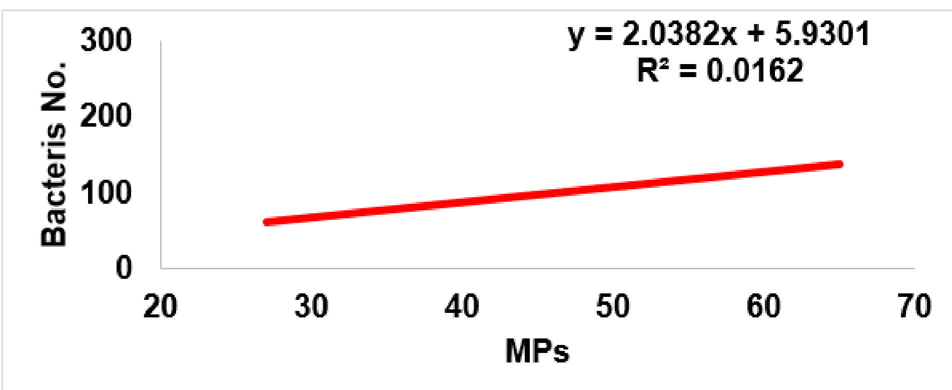

Figure 11: The relationship between MPs and TPC in the wells of the study area.

To classify well water based on a pollution index that relies on microplastic and bacterial contamination, the researcher proposed calculating the pollution index using the following equation: (Khant and Kim, 2022)

$$IGWp = \frac{SMP + SB}{2}$$

Where: IGWp=groundwater indicator

SMP= Microplastic degree

SB=bacteriological degree

Table 8: The classification of groundwater depends on MPs and the SB degree.

Microplastic degree		bacteriological degree		groundwater indicator	
1	1	<10	1	1-1.5	Clear water
1-10	2	10-100	2	1.5-2.5	Low pollution
11-100	3	100-1000	3	2.5-3.5	Moderate pollution
>100	4	>1000	4	3.5-4	High pollution

Applying the pollution index equation (Table 8), we find that the wells are moderately polluted with varying degrees of pollution.

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, 10 active wells were selected to study microplastics and bacteriological pollution in Baghdad in 2025. The results showed that microplastic pollution depends primarily on proximity to industrial and human activities. Well 10 recorded the highest microplastic concentration due to the mixing of its water with wastewater from the Al-Rustumiya sewage treatment plant. Well W5 recorded the lowest microplastic concentration because it is located in an agricultural area, and the effect was limited to bioplastics. In all studied wells, the amount of plastic pollution can be ranked according to location as follows: Large pieces < film < fibre < parts < circular.

The relationship between water depth and the total number of microplastics in the studied well water was investigated. The results showed a direct relationship between water depth and microplastics, with a coefficient of r=0.96. This is because a shallower water level increases the ability of small microplastic particles to reach and migrate to groundwater. Regarding bacteriological pollution, Well W1 also had the highest bacterial count across all types, while Well W5 had the lowest b. The increased bacterial pollution in Well W10 is attributed to mixing with sewage. The contamination of well water with these types of bacteria and their variation may be attributed to the different locations of the wells, their proximity to pollution sources, and the nature of the soil and its ability to leach these bacterial contaminants into the groundwater. The following is a ranking of the contamination levels by location based on the total number of TPC bacteria: W10 > W1 > W8 > W3 > W9 > W5 > W4 > W6 > W2 > W7. This study recommends avoiding

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the drilling of groundwater wells near landfills and industrial human activities. The study also recommends scientifically and securely lining wells to prevent mixing and subsequent secondary contamination.

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