Drinking Water Quality and Microbial Contamination in Mosul City, Iraq — A Comparative Study of Tap, Storage Tank, and Bottled Water

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Abstract

This research assessed physico-chemical and microbial properties of tap, stored, and bottled water in Mosul City, Iraq. The Water Quality Index (WQI) was calculated, and data were analyzed using SPSS.

Physio-chemical analysis indicated that tap water had turbidity of 0.68–3.92 NTU, pH level of 6.20–6.96 (Right Side) and 6.60–7.32 (Left Side), TDS content of 18–204 mg L^{-1} (Right Side) and 42 – 221 mg L^{-1} (Left Side) and a DO concentration between 6.20 and 8.89 mg L^{-1}; in the storage tanks similar chemistry was observed with slightly higher TDS concentrations from78 to221 mg L^{-1} along with lesser levels of DO ranging between 6.04 –8.98 mg L^{-1}. Bottled water was variable: turbidity 0.68–3.22 NTU, pH 6.60–7.21, and TDS 142–234 mg L^{-1}. The Water Quality Index (WQI) categorized tap water as good (42–48), stored tanks as poor (55–68), and bottled water as good to poor (35–65). Microbiological examination revealed *Aeromonas salmonicida* , *Stenotrophomonas maltophilia*, *Pseudomonas stutzeri*, Pseudomonas *fluorescens*, and *Acinetobacter haemolyticus* in bottled water. The Left Side had higher values of microbial contamination and WQI, which suggests that chemical parameters generally complied with WHO standards, whereas microbiological pollution in containers and bottled water extensively decreased the overall quality of water.

Keywords: Water Quality, Microbial Contamination, physio-chemical, bottled water, WQI,.

Introduction

Water is an indispensable necessity for human survival, wellbeing and socio-economic development, fulfilling a fundamental nutritional role by providing the main liquid for drinking as well as sanitation, hygiene and food production (25). However, it is because microbial pollution can contaminate and deteriorate the safety and quality of drinking water and cause adverse risks to public health, especially in regions with aged pipelines, inadequate treatment or distribution network maintenance (19). Waterborne diseases continue to be a major public health issue worldwide, with about 829,000 deaths due to diarrhoeal diseases associated with unsafe water reported annually by the World Health Organization (27). Microbial contamination of drinking water at times can be attributed to pathogenic bacteria including *Escherichia coli*, *Salmonella spp.*, *Pseudomonas aeruginosa*, and *Vibrio* *cholerae* (19–6); the organisms involve in causing gastrointestinal infections, cholera and other lethal diseases. These break-down products can find their way into water sources by human and animal excreta, sewer penetration, agricultural effluents, or improper practices of water manipulation and storage (20,4). *E. coli* has been used as a faecal contamination indicator and also for the overall microbial water quality (22). In urban areas, such as in the city of Mosul, households receive water from more than one source: tap water distributed by the main network for drinking, cooking or personal hygiene purposes; household storage tanks with locally stored rainwater (domestic tanks); and bottled water from shops. Each source has unique vulnerabilities. Bottled water is also considered to be safer than tap water, with recent research showing a presence of bacterial contamination in bottled water and casting doubts on its microbiological safety (8,18). Many pathogenic microorganisms are found in domestic storage tanks when not maintained ensuring good quality water (26,29). Moreover, the primary water supply network in Mosul has problems with leaks and pipe rusting; it is sometimes also subject to seepage from untreated sewage, which exacerbates the potential for microbial contamination (10). The evaluation of both physio-chemical and biological properties such as pH, turbidity, TDS (total dissolved solids), DO (dissolved oxygen) and WQI (water quality index), offers a larger spectrum on the water safety assessment regarding quality and bacteriological parameters (24,3). The objectives of the current project are to detect microbial contamination and to gain an overview about Ran-WQ in Mosul City including both main network (tapping water), domestic storage containers, and bottled water on both RS and LS of the city. It aims to evaluate the microbiological quality, safety of drinking water and make recommendations in-line with evidence on how to improve water management by analyzing the prevalence of pathogenic bacteria *E. coli*, *Pseudomonas spp*.

Materials and Methods

Sample Collection

Sixty water samples were randomly gathered from different sites at Mosul city (Figure 1), and it was sufficient to produce adequate statistical representation.

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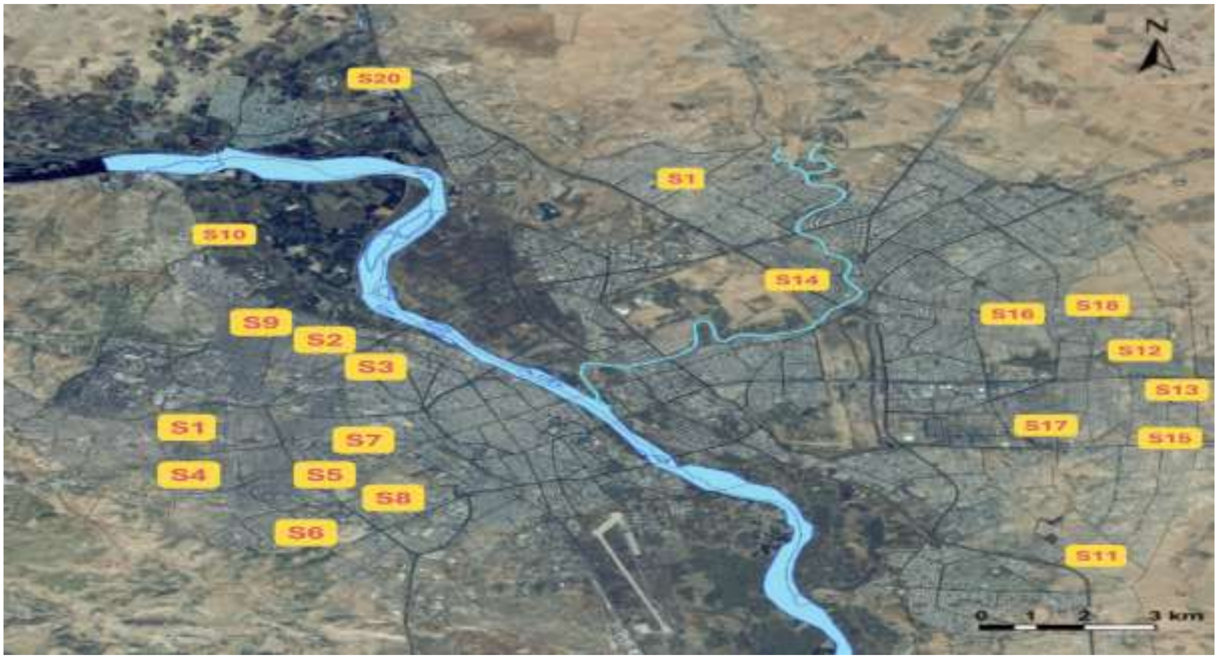

Figure 1. A map showing the locations of drinking water source sampling in the city of Mosul, Iraq. The sampling locations (S1–S20) represent different residential areas throughout the city.

Sample selection:

The sampling plan was based on environmental sampling criteria. Samples were obtained from tap water, household storage tanks, and bottled water. Sampling was conducted semimonthly from November 2024 to November 2025 using sterile airtight 250 ml glass jars to avoid contamination.

Water samples were collected from twenty districts across Mosul city, covering both the right and left sides (S1–S20).

During field visits, the sampling locations were precisely identified and recorded using mobile GPS applications. The coordinates obtained in the field were then used to place the sampling points (S1–S20) accurately on the map. This guaranteed that the actual positioning of the sites rather than estimated or manually designated locations, is reflected in the spatial distribution of the sites.

The detailed names of the sampling areas and their corresponding symbols are presented in Tables 1 and 2.

Physical and Chemical Analysis

Five primary water samples quality were evaluated: physiological-chemical.

- Turbidity (NTU): it was determined by turbidimeter after calibration.
- pH: pH readings taken by a digital pH meter.
- Electric Conductivity (EC, µS cm^{-1}): Measured by using a conductivity meter.
- DO (mg L^{-1}): Assessed with the Winkler method.
- TDS (mg L^{-1}): determined with a TDS meter.

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The selected parameters were used specially to assess the overall quality of the water and its drink- ability according to the WHO guidelines for drinking water quality; the Iraqi specifications were also considered (24,27,28).

Biological Analysis

1. Conventional Microbiological Tests

Classical methods where carried out with Nutrient Agar and MacConkey Agar for water samples cultivation, to show the presence of eventual bacteriological contaminants. The medium was made by dissolving 28 g of powder per liter of distilled water followed by autoclaving at 121°C for 15 min (11). Cultures were incubated and observed for growth, pigment, and hemolytic reaction for 24 hours at 37˚C.

2. Morphological and Microscopic Examination

Bacterial isolates were studied for the following:
- Characteristics of growth on both Nutrient Agar and MacConkey Agar
- Properties of the Gram stain to understand the shape, arrangement, and Gram reaction of the cells
- Microscopic morphology to differentiate the bacteria

The results of these studies helped to identify the bacteria (11).

Identification of Bacteria Using VITEK® 2

Bacterial isolates from the water samples were characterized at the species level using the automated VITEK® 2 System. The VITEK® 2 System:

- Conducts rapid biochemical tests.
- Predicts bacterial species based on metabolomic profiles.
- Delivers speedy, accurate results, simplifies the process, and reduces the labor needed for the task.

This method confirmed species, such as Pseudomonas spp., Acinetobacter spp., and other opportunistic pathogens, that occurred in both tap and bottled waters and acts as an alternative to the routine water quality examinations (7, 13).

Water Quality Index (WQI) Evaluation

The Water Quality Index (WQI) was employed as a single-value index to categorize the overall water quality represented by a sample in the study. It consolidated a range of ten physico-chemical water quality parameters into a single grouping:

- Good: WQI 0–50
- Poor: WQI 51–100
- Very Poor: WQI >100

It enabled the analysis of water quality pertaining to all water sources as well as their respective water quality variation. It also allowed the analysis of water quality from the Right Side and Left Side regions, whether water was sourced from the tap, storage tank, or bottled. Also, it allowed for the testing of hypotheses of water quality variation based on the site and the water source (24,25, 27).

The Water Quality Index (WQI) was calculated following the World Health Organization (WHO) guidelines for drinking water quality. The Iraqi classification system was also reviewed; however, due to the absence of a unified national WQI standard, the WHO criteria were adopted as the primary reference for evaluation. Although the Iraqi classification for drinking water was reviewed, it was not applied in this study because it lacks a unified national standard comparable to the WHO guidelines. Therefore, the WHO criteria were adopted as the main reference for evaluation.

Statistical Analysis

Physical-chemical and biological contents obtained were analyzed (means, SDs, min., max) using descriptive statistics and compared between water sources (tap, storage tanks, bottled water) as well as between Right side versus Left side of Mosul. t-tests and correlation analysis were used to determine whether added parameters had statistical significance or relationship with WQI. Data were analyzed using SPSS v25 and $p < 0.05$ was regarded as statistically significant (15,16).

Results

Physical and Chemical Characteristics of Drinking Water

Table 1 summarizes the physical and chemical properties of drinking water samples collected from the Right Side of Mosul city. Turbidity ranged between 0.68–3.92 NTU, pH values between 6.71–6.96, and TDS between 130–204 mg L^{-1}. All values complied with WHO standards, with slightly higher turbidity and TDS observed in storage tanks and bottled water.

Table 1: Physical and Chemical Properties of Water Samples in the Right Side of Mosul City

Area	Source	Turbidity (NTU)	pH	EC (µS cm^{-1})	Temp (°C)	DO (mg L^{-1})	TDS (mg L^{-1})
Al-Yarmouk S1	Tap	2.00	6.96	149	17.5	7.71	130
	Tank	1.68	6.91	149	17.8	7.16	178
	Bottled	3.92	6.90	221	17.6	7.95	194
Al-Najjar S2	Tap	2.37	6.82	202	17.4	8.18	182
	Tank	1.41	6.82	204	17.8	8.16	183
	Bottled	1.09	6.86	221	17.5	7.59	201
Al-Zanjali S3	Tap	1.38	6.80	204	17.5	7.69	184
	Tank	1.79	6.84	204	17.4	6.69	184
	Bottled	1.22	6.82	218	17.5	8.28	201
Al-Risala S4	Tap	1.78	6.71	200	17.6	7.80	182
	Tank	1.68	6.73	202	17.6	7.29	182
	Bottled	0.68	6.76	226	17.7	8.47	201
Al-Ma’alimin S5	Tap	1.90	6.91	207	17.6	8.89	182
	Tank	1.21	6.91	204	17.6	7.30	183
	Bottled	1.83	6.93	220	17.7	8.13	196
Tal Al-Ruman S6	Tap	0.93	6.84	206	17.7	8.34	180
	Tank	2.03	6.87	211	17.5	6.25	199
	Bottled	1.43	6.89	221	17.4	7.49	192
New Mosul S7	Tap	0.64	6.71	207	17.5	6.51	189
	Tank	1.69	6.73	209	17.8	7.92	189
	Bottled	1.37	6.76	219	17.4	8.75	199
the Shuhada S8	Tap	3.18	6.76	209	17.5	7.66	204
	Tank	1.61	6.95	209	17.4	7.82	186
	Bottled	0.65	6.20	18	17.5	8.86	182

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al-Rifa'i S9	Tap	2.46	6.91	204	17.4	6.20	183
	Tank	2.26	6.85	204	17.6	8.20	183
	Bottled	0.60	6.62	208	17.5	7.22	170
Hawi al-Kanisa (Church neighborhood) S10	Tap	2.14	6.85	204	17.6	7.91	182
	Tank	1.57	6.85	204	17.6	8.88	182
	Bottled	0.72	6.89	125	17.7	8.19	189

Table 2 shows the corresponding results for the Left Side of Mosul city. Turbidity values ranged from 0.68–3.22 NTU, pH ranged from 6.60–7.32, with one elevated value (9.97) recorded in a storage tank. Bottled water showed higher TDS values (422–423 mg L^{-1}) but still within WHO limits.

Table 2: Physical and Chemical Properties of Water Samples in the Left Side of Mosul City

Area	**Source**	**Turbidity (NTU)**	**pH**	**EC (µS cm^{-1})**	**Temp (°C)**	**DO (mg L^{-1})**	**TDS (mg L^{-1})**
Al-Shayma S11	Tap	1.13	6.99	218	17.8	8.87	196
	Tank	1.60	9.97*	218	17.4	8.31	196
	Bottled	0.68	7.21	244	17.6	8.31	422
Al-Khadraa S12	Tap	1.56	6.90	210	17.8	8.48	186
	Tank	2.84	6.89	217	17.5	8.70	195
	Bottled	0.97	6.60	246	17.5	8.72	423
Al-Quds S13	Tap	0.94	7.07	209	17.5	8.66	196
	Tank	0.86	7.05	211	17.5	8.38	188
	Bottled	1.28	7.07	224	17.4	8.44	203
Al-Muthanna S14	Tap	1.91	7.25	214	17.6	8.36	196
	Tank	1.62	7.02	211	17.6	8.47	189
	Bottled	3.22	7.18	139	17.6	8.87	128
Al-Intisar S15	Tap	1.61	7.09	206	17.6	8.86	179
	Tank	2.05	6.92	210	17.4	8.76	186
	Bottled	1.33	7.05	221	17.6	8.56	198
Al-Bakr S16	Tap	1.71	7.11	206	17.5	8.77	188
	Tank	1.63	6.96	210	17.5	8.14	188
	Bottled	1.41	7.03	216	17.5	8.60	199
Al-Mithaq S17	Tap	1.93	7.03	213	17.6	6.04	221
	Tank	1.84	6.87	207	17.3	6.81	184
	Bottled	1.62	7.08	112	17.6	8.89	196
Al-Samah S18	Tap	2.95	7.14	209	17.8	8.66	203
	Tank	1.08	6.84	207	17.9	7.97	188
	Bottled	1.05	7.03	219	17.7	8.01	199
Al-Hadbaa S19	Tap	2.88	7.07	212	17.5	8.92	188
	Tank	2.16	6.95	211	17.5	7.78	188

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	Bottled	1.24	7.02	221	17.4	8.48	201
Al-Malayeen S20	Tap	2.01	7.12	202	17.8	8.18	174
	Tank	1.86	7.14	204	17.4	8.93	185
	Bottled	1.52	7.32	91	17.5	8.98	178

* Exceeds WHO recommended pH range.

Comparative and Statistical Analysis

Table 3 compares the overall ranges of water quality parameters between the Right and Left Sides. All parameters were within WHO guideline limits, with relatively higher TDS observed on the Left Side.

Table 3: Comparison of Water Quality Parameters Between Right and Left Sides

Parameter	Right Side (Range)	Left Side (Range)	WHO Guideline
Turbidity (NTU)	0.68 – 3.92	0.68 – 3.22	< 5
pH	6.71 – 6.96	6.60 – 7.32 (9.97*)	6.5 – 8.5
TDS (mg L^{-1})	130 – 204	186 – 423	< 500
DO (mg L^{-1})	6.69 – 8.89	8.31 – 8.98	> 5

Table 4 presents the statistical comparison between the two sides. No significant differences were observed in turbidity and pH ($p > 0.05$), while EC, TDS, and DO showed significant differences ($p < 0.05$), reflecting localized distribution and storage effects.

Table 4: Statistical Summary and Significance Test Between Right and Left Sides

Parameter	Right Side (Mean ± SD)	Left Side (Mean ± SD)	p-value	Significance
Turbidity (NTU)	1.78 ± 0.74	1.42 ± 0.69	0.184	NS
pH	6.86 ± 0.09	7.03 ± 0.18	0.071	NS
EC (µS cm^{-1})	203 ± 26	224 ± 18	0.032	*
TDS (mg L^{-1})	186 ± 21	244 ± 37	0.018	*
DO (mg L^{-1})	7.82 ± 0.71	8.56 ± 0.42	0.009	*

Water Quality Index (WQI)

Table 5 classifies the studied water sources based on WQI values. Tap water was rated as Good, storage tank water as Poor, and bottled water ranged from Good to Poor.

Table 5: Water Quality Index (WQI) Classification

Water Source	WQI Range	Quality Class
Tap Water	42 – 48	Good
Storage Tanks	55 – 68	Poor
Bottled Water	35 – 65	Good–Poor

Biological Quality Assessment

Table 6 presents the bacterial species isolated from the studied samples. The detection of opportunistic and pathogenic bacteria, including in bottled water, indicates that the affected samples are microbiologically unsafe according to WHO standards.

Table 6: Identified Bacterial Species and Final Safety Status

Area	Isolated Bacteria	Safety Status
Al-Bakr	*Acinetobacter haemolyticus*	Unsafe
Al-Risala	*Aeromonas salmonicida*	Unsafe
Al-Samah	*Pseudomonas alcaligenes*	Unsafe
Al-Malayeen	*Stenotrophomonas maltophilia*	Unsafe
Tal Al-Ruman	*Aeromonas salmonicida*	Unsafe
Bottled Water	*Pseudomonas stutzeri*	Unsafe
Al-Quds	*Pseudomonas fluorescens*	Unsafe
Al-Intisar	*Pseudomonas alcaligenes*	Unsafe

Discussion

Quality assessment of drinking water in Mosul city indicated significant variation between sources (tap water, cisterns and plastic bottles) and between Right Side and Left Side i.e. the east (Lift side) of Mosul being significantly more contaminated than west (Right side). With the exception of few parameters most physico-chemical concentrations complied with WHO guideline limit (25,19,27).; however, microbiological analyses revealed presence of potentially pathogenic bacteria particularly in storage tanks and some bottled water samples. These findings are in line with other studies carried out in Iraq, which indicate household water is contaminated microbiologically despite acceptable chemical standards (19,6,26,29). At the national level, other studies in Iraqi cities yield similar findings. For example, Mansor et al. (20) stated that although the physico-chemical quality of tap water was generally good in many Iraqi cities, it showed a high level of bacterial impurities and Jumaa & Abdulqader (17) reported higher WQI values in some neighborhoods of Kirkuk as a consequence of microbial contents. Allawi & Ali (9) noted that Tigris River water for domestic use generally could sometimes be above safe microbial level, in particular in older areas. Further, a report from Basra (12) demonstrated that some of the main water treatment plants cannot always completely remove all bacterial contaminants, and this is consistent with our results of occasional non-potable isolates recovered from tap water. In the regional Arab setting, our findings are in agreement with those reported in Lebanon and Saudi Arabia. Fahes et al. (14) showed that among various Lebanese governorates, bacteria contamination was detected in tap and bottled water of the regions despite adherence to chemical parameters, as well as studies carried out in Yanbu (5), Saudi Arabia which revealed that urban water sources may meet physico-chemical standards although pathogenic bacteria are still present. Results of these analyses underscore the fact that chemical quality, alone, is not adequate to guarantee a safe drinking water. Worldwide, reports on the quality of bottled water show that microbial contamination is a major issue even in countries with controls (23). Further, international urban assessments of the Water Quality Index reveal source specific pollution trends and spatial variability. These findings suggest that integrating WQI and microbial analysis is warranted (21).

Conclusions

The results show impressive differences in both location and source-based water quality in Mosul City. Water from the City's Municipal Distribution Network tends to meet the chemical standards, but still poses a potential microbial threat. Further, domestic water storage, as well as some bottled water, may contain bacterial threats. These may be adequately addressed by routine cleaning. The Water Quality Index was demonstrably useful for an overall assessment of water quality and for appropriate recommendations. The results further indicate that there is need of comprehensive water monitoring schemes to measure both the physical-chemical parameters and the microbial safety of drinking water.

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