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Evaluation of the efficiency and quality of the water of the unified Al Aziziyah-AI Hafariya project - Wasit Governorate

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Abstract

This study aimed to evaluate the efficiency and quality of water in the unified Al-Aziziyah–Al-Hafariya water treatment project in Wasit Governorate. Bacteriological parameters, including Total coliform, Fecal coliform, and *Escherichia coli*, as well as selected heavy metals (Cadmium, Zinc, and Chromium), were analyzed at different stages of water treatment. The results showed that river water exhibited the highest levels of bacterial contamination, with Total coliform, Fecal coliform, and *E. coli* reaching 1100, 463, and 1.6 MPN (Most Probable Number)/100 mL, respectively. A progressive reduction in bacterial counts was observed through sedimentation and treatment stages, with complete removal of *E. coli* in both final treated water and distribution network samples. Similarly, heavy metal concentrations were highest in river water and gradually decreased during treatment. Chromium showed the most noticeable reduction, while Cadmium and Zinc remained within low concentration ranges throughout the treatment process. The findings indicate that the water treatment plant is effective in significantly reducing both microbial and chemical contaminants, producing water that meets acceptable safety levels for distribution. However, continuous monitoring is recommended to ensure sustained water quality.

Keywords: Water quality, Bacteriological contamination, Heavy metals, *Escherichia coli*, Water treatment

Introduction

Water quality assessment has become an increasingly important issue worldwide due to its direct impact on public health, environmental sustainability, and socio-economic development. Access to safe drinking water is considered a fundamental human right; however, the deterioration of water resources due to anthropogenic activities continues to pose significant challenges, particularly in developing countries. Surface water systems are highly vulnerable to contamination from municipal wastewater, agricultural runoff, and industrial effluents, which collectively contribute to the degradation of water quality [1,2]. In Iraq, rivers such as the Tigris and its branches, including Al-Gharraf River, represent the primary sources of drinking water. These water bodies are increasingly subjected to environmental stress due to rapid population growth, urbanization, and insufficient wastewater treatment infrastructure. Several studies have reported that water quality in southern Iraq is declining, with increasing levels of physicochemical and biological pollutants [3]. Moreover, spatial and seasonal variations in water quality have been observed, particularly in downstream regions where pollution loads accumulate [4,5].

Bacteriological contamination is one of the most critical indicators of water quality, as it directly reflects the presence of pathogenic microorganisms that can cause waterborne diseases. Indicators such as Total coliform, Fecal coliform, and *Escherichia coli* are widely used to assess microbial safety in drinking water systems. Previous investigations in Wasit Governorate and other Iraqi regions have revealed that these indicators frequently exceed permissible limits, particularly during warmer seasons, indicating inefficiencies in water treatment and disinfection processes [6,7,8]. Furthermore, the persistence of microbial contamination in distribution networks suggests possible secondary contamination due to pipe leakage, biofilm formation, or inadequate residual chlorine levels [9]. In addition to microbiological pollution, heavy metal contamination represents another major environmental concern due to its toxicity, persistence, and bioaccumulative nature. Metals such as Cadmium (Cd), Lead (Pb), Chromium (Cr), and Nickel (Ni) can enter water systems through industrial discharge, agricultural inputs, and natural geological processes. Exposure to these metals poses serious health risks, including neurological disorders, kidney damage, and carcinogenic effects [10,11]. Studies conducted in Wasit Governorate have reported elevated concentrations of heavy metals in both surface and groundwater, often exceeding national and international standards, particularly in areas influenced by industrial and agricultural activities [12].

The performance of water treatment plants plays a crucial role in mitigating both microbial and chemical contamination. Conventional treatment systems, which typically include coagulation, sedimentation, filtration, and disinfection, are widely used in Iraq. However, their efficiency is highly dependent on operational conditions, maintenance, and source water quality. Several studies have indicated that many treatment plants in Iraq operate at suboptimal efficiency, with insufficient removal of turbidity, organic matter, and microbial contaminants [13]. In some cases, treated water still fails to meet drinking water standards, highlighting the need for system optimization and technological upgrades. Recent advancements in water treatment technologies, such as membrane filtration, adsorption using activated carbon, and advanced coagulation techniques, have demonstrated higher efficiency in removing both pathogens and heavy metals. Membrane-based processes, including ultrafiltration and reverse osmosis, have shown superior performance in microbial removal compared to conventional methods [14]. Similarly, adsorption techniques and natural coagulants have proven effective in reducing heavy metal concentrations in contaminated water systems [1]. Despite these advancements, their application in many developing regions remains limited due to economic and technical constraints.

Therefore, continuous evaluation of existing water treatment plants is essential to ensure their effectiveness in improving water quality and protecting public health. The Al-Aziziyah–Al-Hafariya water treatment project represents a key component of the water supply system in Wasit Governorate, serving a large population that depends on its output for daily consumption. Given the environmental pressures affecting water sources in the region, it is necessary to assess the performance of this project in terms of both bacteriological and chemical parameters. Accordingly, the present study aims to evaluate the efficiency of water treatment processes in the Al-Aziziyah–Al-Hafariya project by investigating the reduction of bacteriological indicators (Total coliform, Fecal coliform, and *Escherichia coli*) and selected heavy metals (Cd, Zn, and Cr) across different treatment stages. This evaluation will provide insights into the effectiveness of the treatment system and its ability to produce safe and potable water in accordance with health and environmental standards.

Materials and Methods

Bacteriological Examinations

All bacteriological analyses were conducted using the multiple tube fermentation technique and the Most Probable Number (MPN) method, following standard procedures described by the American Public Health Association (15).

Study Design and Sampling Strategy

This study was conducted as a cross-sectional analytical investigation to evaluate water quality across different stages of the Al-Aziziyah–Al-Hafariya water treatment plant. Water samples were collected from four main points: raw river water, sedimentation stage, final treated water, and distribution network. A total of 24 samples were collected during the study period from September 2025 – February 2026. At each sampling point, samples were collected in triplicate to ensure analytical reliability. Sampling was carried out periodically. All samples were collected in sterile containers, transported to the laboratory under cooled conditions (4°C), and analyzed within (6–12 hours) of collection.

Sampling Procedure

Water samples were collected from four specific locations representing different stages of the treatment process: (1) raw river water intake, (2) sedimentation basin, (3) final treated water outlet, and (4) distribution network. Sampling was conducted during the period from September 2025 – February 2026, covering multiple sampling events. At each site, 3 samples were collected in triplicate using sterile, labeled polyethylene bottles. All samples were collected following standard sampling procedures to avoid contamination. Immediately after collection, samples were preserved in iceboxes at approximately 4°C and transported to the laboratory within (2–4 hours). Bacteriological analyses were performed within (6–12 hours) of collection to ensure sample integrity, while samples for heavy metal analysis were acidified with nitric acid (HNO_3) and stored at 4°C until analysis.

Total Coliform Detection

Total coliform bacteria were detected using the multiple tube fermentation method according to APHA (2017, 9221E) as follows:

Presumptive Test:

Ten milliliters of each water sample were inoculated into tubes containing 10 mL of double-strength Lauryl Tryptose Broth. The tubes were gently shaken to ensure proper mixing and incubated at 35 ± 0.5°C for 24 ± 2 hours. Tubes showing turbidity and gas formation were recorded as positive. Tubes without visible growth were further incubated for an additional 48 ± 3 hours, after which the results were recorded and interpreted using standard MPN tables for drinking water.

Confirmed Test:

Positive tubes from the presumptive test were gently mixed, and a loopful of culture was transferred aseptically into tubes containing Brilliant Green Lactose Bile Broth. The tubes were incubated under the same conditions, and positive results were confirmed based on gas production.

Fecal Coliform Detection

Fecal coliform bacteria were detected according to APHA (15, 9221E).

A loopful from confirmed positive coliform tubes was transferred into tubes containing EC (Escherichia coli medium) Medium. The inoculated tubes were incubated in a water bath at 44.5 ± 0.5°C for 24 ± 2 hours within 30 minutes of inoculation. Tubes showing turbidity and gas production were considered positive, and results were expressed as MPN/100 mL.

***Escherichia coli* Detection**

Detection of *Escherichia coli* was carried out according to APHA (15, 9221F). Positive fecal coliform tubes were inoculated into EC-MUG (*Escherichia coli*–4-methylumbelliferyl-β-D-glucuronide) medium and incubated at 44.5 ± 0.5°C for 24 ± 2 hours. Positive samples were identified using a UV lamp (365 nm), where fluorescence (blue-green color) indicated the presence of *E. coli*. Results were calculated using MPN tables and expressed as MPN/100 mL.

Heavy Metals Analysis

The concentrations of heavy metals, including Cadmium (Cd), Zinc (Zn), and Chromium (Cr), were determined according to the American Public Health Association (APHA, 2017). Water samples (50 mL) were digested using concentrated nitric acid (HNO_3, 65%) on a hot plate at 80°C. An initial volume of 5 mL of nitric acid was added, followed by an additional 1 mL after partial digestion, and heating was continued until complete dissolution was achieved. The digested samples were cooled, filtered if necessary, and the final volume was adjusted to 50 mL using deionized water. Metal concentrations were measured using an Atomic Absorption Spectrophotometer (AAS), and results were expressed in mg/L. Calibration curves were established using standard solutions of known concentrations for each metal. Analytical blanks were included to account for background contamination, and all measurements were performed in triplicate. Quality control procedures included calibration verification, repeatability checks, and the use of standard reference materials. The detection limits for Cd, Zn, and Cr were within the measurable range of the instrument.

Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to evaluate significant differences among water treatment stages. When significant differences were detected, mean comparisons were performed using the Least Significant Difference (LSD) test at a significance level of $P \leq 0.05$. Results are presented as mean ± standard error (SE). Statistical analyses were conducted using (insert software, e.g., SPSS version XX). Where applicable, degrees of freedom (df), F-values, and exact P-values were considered to assess statistical significance. All measurements were performed in triplicate to ensure reliability of the results.

Results

Bacteriological Analysis

The bacteriological results are summarized in Table (1) and illustrated in Figure (1). The results revealed significant differences in bacterial contamination levels across the different stages of water treatment. River water showed the highest counts of Total coliform, Fecal coliform, and *Escherichia coli*, with values reaching 1100, 463, and 1.6 MPN/100 mL, respectively. A marked reduction was observed in sedimentation water, where the values decreased to 202.5, 202.5, and 0.18 MPN/100 mL, respectively. This decline continued in the final treated water, with bacterial counts dropping to 18 for Total coliform, 10.33 for Fecal coliform, and complete absence (0) of *Escherichia coli*, indicating high treatment efficiency. Similarly, distribution network water maintained low bacterial levels, recording 12.8, 8.5, and 0 MPN/100 mL, respectively. These results are clearly visualized in Figure (1), which demonstrates the progressive reduction in bacterial counts throughout the treatment process. The Least Significant Difference (LSD) values were 548.2, 351.6, and 1.35 for Total coliform, Fecal coliform, and *E. coli*, respectively. The observed differences between river water and subsequent treatment stages exceeded the corresponding LSD values for Total coliform and Fecal coliform, indicating statistically significant reductions following treatment. However, the differences among sedimentation, final treated water, and distribution network were comparatively smaller and, in some cases, did not exceed the LSD values, suggesting limited statistical significance between these stages. In contrast, the reduction in E. coli from detectable levels in raw water to complete absence in the final stages clearly exceeded the LSD value, confirming a significant removal across the treatment process.

Table (1): Bacteriological parameters of water at different treatment stages (MPN/100 mL)

Water Type	Total coliform	Fecal coliform	*Escherichia coli*
River water	1100 a	463 a	1.6 a
Sedimentation water	202.5 b	202.5 ab	0.18 b
Final treated water	18 b	10.33 b	0 c
Distribution network	12.8 b	8.5 b	0 c

LSD	548.2	351.6	1.35

Values are presented as mean ± standard error. Different superscript letters within columns indicate significant differences at P ≤ 0.05 according to LSD test.

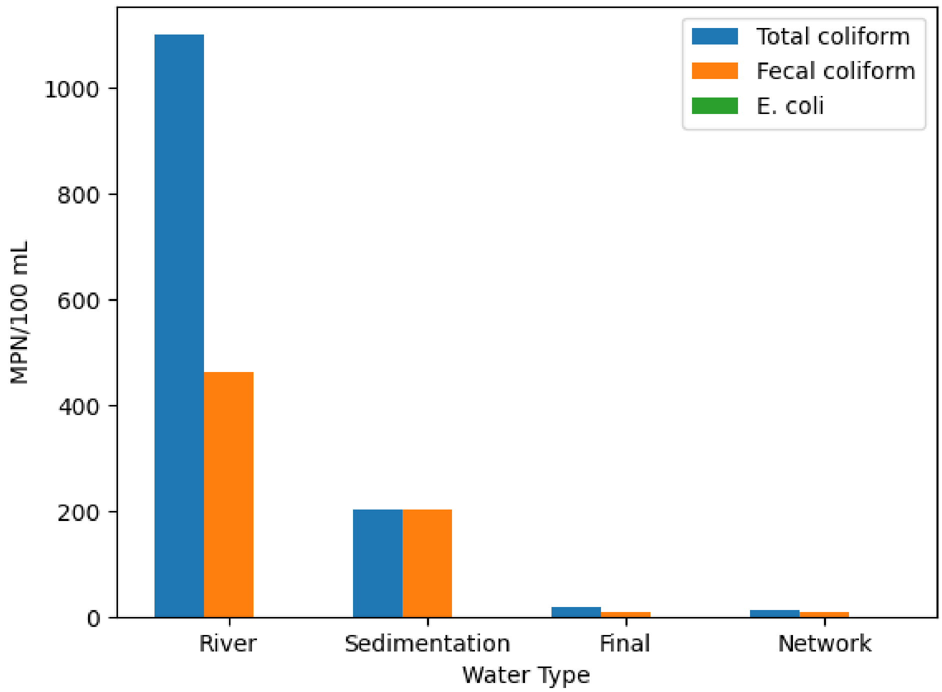

Figure (1): Bacteriological parameters at different water treatment stages

Heavy Metals Analysis

The concentrations of heavy metals are presented in Table (2) and illustrated in Figure (2)**.** The results showed that river water contained the highest concentrations of Cadmium (Cd)**,** Zinc (Zn)**,** and Chromium (Cr)**,** with values of 0.008, 0.010, and 0.072 mg/L, respectively. In sedimentation water, the concentrations decreased to 0.002, 0.009, and 0.032 mg/L, respectively. Further reduction was observed in final treated water, where values reached 0.004, 0.008, and 0.014 mg/L, indicating the effectiveness of treatment processes in reducing heavy metal contamination. In the distribution network, the concentrations were 0.003, 0.008, and 0.025 mg/L, respectively, showing slight variation but generally maintaining low levels. These trends are clearly represented in Figure (2), which highlights the reduction of heavy metal concentrations throughout the treatment stages. The LSD values were 0.006, 0.020, and 0.038 for Cd, Zn, and Cr, respectively. The observed differences in heavy metal concentrations across treatment stages were generally small. For Cadmium and Zinc, the variations between stages were minimal and, in most cases, did not exceed the corresponding LSD values, indicating no statistically significant differences. In contrast, Chromium showed relatively larger differences between river water and treated stages, some of which exceeded the LSD value, suggesting statistically significant reduction. However, these differences should be interpreted with caution due to their limited magnitude and potential analytical variability.

Table (2): Heavy metals concentrations in water at different treatment stages (mg/L)

Water Type	Cadmium (Cd)	Zinc (Zn)	Chromium (Cr)
River water	0.008 a	0.010 a	0.072 a
Sedimentation water	0.002 a	0.009 a	0.032 b

Final treated water	0.004 a	0.008 a	0.014 b
Distribution network	0.003 a	0.008 a	0.025 b
LSD	0.006	0.020	0.038

Values are presented as mean ± standard error. Different superscript letters within columns indicate significant differences at P ≤ 0.05 according to LSD test.

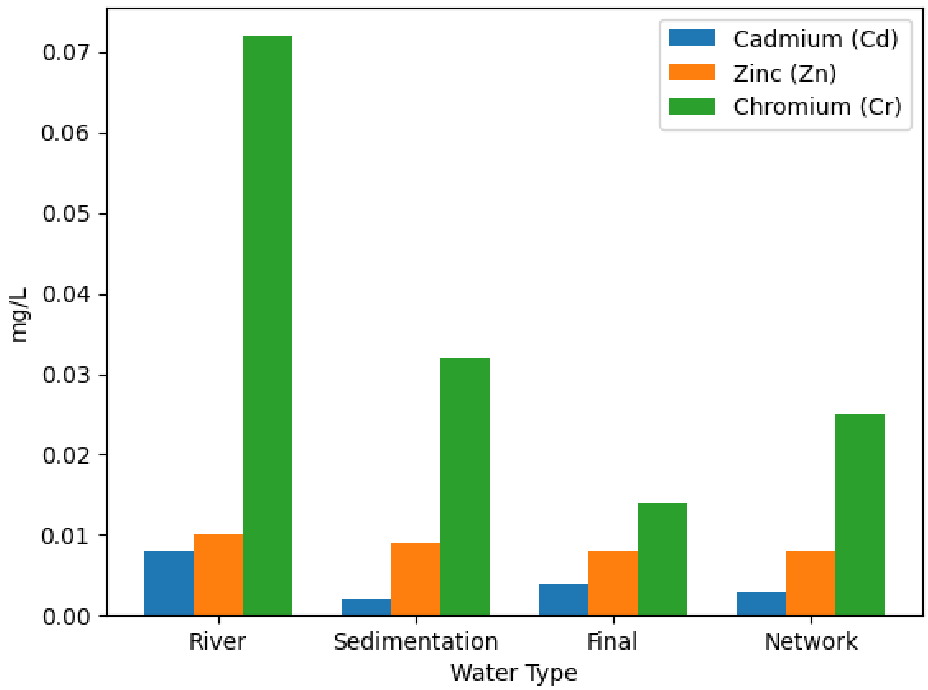

Figure (2): Heavy metals concentrations at different water treatment stages

Discussion

Bacteriological Parameters

The present study demonstrated a clear and progressive reduction in bacteriological indicators, including Total coliform, Fecal coliform, and *Escherichia coli*, across the different stages of water treatment. The highest contamination levels were recorded in river water, followed by a gradual decline in sedimentation and final treated water, with complete elimination of E. coli in the final stages. This trend reflects the overall effectiveness of the treatment processes, including coagulation, sedimentation, filtration, and disinfection. However, the specific contribution of individual processes, particularly chlorination, cannot be conclusively determined due to the absence of operational data such as residual chlorine levels, contact time, and turbidity. The elevated bacterial load observed in raw water can be attributed to contamination from domestic wastewater discharge and agricultural runoff, which are common sources of pollution in Iraqi surface waters. Similar findings have been reported in previous studies, where untreated water sources exhibited high levels of coliform bacteria due to anthropogenic activities [6].

Further comparison with studies conducted in Wasit Governorate indicates that bacterial contamination can reach extremely high levels in influent water, with total plate counts exceeding 10^8 CFU/100 mL, while removal efficiencies in some conventional systems may not exceed 64.5% [16]. This variation suggests that treatment performance is influenced by multiple operational and environmental factors.

The observed reduction in bacterial counts in the present study indicates an overall improvement in microbial water quality. The complete removal of E. coli in the final treated water suggests effective disinfection under the conditions applied in this system. However, the persistence of low levels of Total and Fecal coliform indicates that complete microbial removal was not fully achieved. This may be associated with several factors, including potential limitations in disinfection efficiency or possible recontamination within the distribution system. Similar observations have been reported in other studies, where contamination in distribution networks was linked to pipe leakage, biofilm formation, and inadequate infrastructure conditions [9,17]. Additionally, studies conducted in Baghdad reported the presence of pathogenic bacteria even after treatment, indicating variability in disinfection efficiency among different systems [8].

On the other hand, advanced treatment technologies have demonstrated significantly higher removal efficiencies. Membrane filtration systems have been shown to achieve removal rates exceeding 99% for microbial contaminants, including complete elimination of E. coli [18]. Similarly, biofilm-based systems such as Moving Bed Biofilm Reactors (MBBR) have achieved high bacterial removal efficiencies under optimized conditions [16]. These findings highlight the potential for improving microbial water quality through technological advancements.

Heavy Metals

The results of heavy metal analysis revealed a gradual decrease in the concentrations of Cadmium (Cd), Zinc (Zn), and Chromium (Cr) across the treatment stages. This trend indicates that the applied treatment processes contributed to reducing metal contamination, although complete removal was not achieved.

The selection of Cd, Zn, and Cr in the present study was based on their environmental relevance and their frequent detection in surface water systems in Iraq, particularly in areas affected by agricultural and industrial activities. These metals are commonly used as indicators of heavy metal pollution due to their toxicity and persistence. However, it is acknowledged that other metals such as Pb and Ni may also contribute to water contamination and should be considered in future investigations for a more comprehensive environmental assessment.

The presence of heavy metals in raw water is primarily associated with industrial discharge, agricultural activities, and natural geological processes. Previous studies conducted in Wasit Governorate have reported elevated concentrations of heavy metals, particularly cadmium and lead, in surface water [11]. These findings are consistent with the current results, confirming that surface water sources are vulnerable to heavy metal pollution. Further evidence from regional studies indicates that heavy metal contamination is widespread in Iraq. Investigations on groundwater in eastern Wasit have reported elevated concentrations of Pb and Cd exceeding permissible limits [19]. Similarly, studies on river water have shown increasing concentrations of heavy metals downstream due to cumulative pollution loads [20].

The observed reduction in metal concentrations during treatment can be attributed to conventional processes such as coagulation, sedimentation, and filtration, which facilitate the removal of metals associated with suspended particles. However, dissolved metals are generally more resistant to removal using conventional treatment methods. Previous studies have demonstrated that traditional systems may have limited efficiency in removing certain metals, particularly when present in dissolved forms [21]. In some cases, treatment processes may influence metal concentrations due to the addition of treatment chemicals such as alum during coagulation. This phenomenon has been reported in previous studies, where certain metal concentrations increased after treatment [21]. Although variations in heavy metal concentrations were observed among treatment stages, some of the differences were relatively small and should be interpreted with caution. The statistical significance indicated by LSD values does not necessarily reflect substantial environmental or practical differences. Therefore, the results should be considered within the context of analytical variability and methodological limitations.

Advanced treatment technologies have demonstrated higher efficiency in removing heavy metals. Adsorption techniques, particularly using activated carbon, have achieved removal efficiencies exceeding 90% for various metals [20]. Similarly, membrane technologies have shown high effectiveness in removing dissolved heavy metals, making them promising approaches for improving water quality [22].

Treatment Efficiency and Comparative Analysis

Overall, the results of the present study indicate an improvement in water quality across the different stages of treatment, reflected by the reduction in both bacteriological and chemical contaminants. However, a comprehensive evaluation of treatment efficiency requires additional operational data, including parameters such as residual chlorine, turbidity, and hydraulic conditions, which were not assessed in the present study.

Comparative analysis with studies conducted in Iraq reveals considerable variation in treatment efficiency among different plants. Some treatment plants exhibit reduced performance due to factors such as inadequate maintenance, outdated infrastructure, and suboptimal operational conditions. For example, studies conducted in Basra reported limited removal efficiency for turbidity and microbial contaminants, indicating operational constraints [23]. In contrast, other studies have demonstrated that high efficiency can be achieved under optimized conditions. A study conducted in Erbil reported an overall treatment efficiency exceeding 99%, highlighting the importance of proper system management and operational practices [23]. These variations emphasize the importance of continuous monitoring, maintenance, and optimization of treatment processes. Additionally, the integration of advanced technologies, such as membrane filtration and adsorption systems, may enhance the removal efficiency of both microbial and chemical contaminants and contribute to improved water quality.

Conclusion

The results of this study demonstrated that the Al-Aziziyah–Al-Hafariya water treatment system contributes to improving water quality by reducing both bacteriological contamination and selected heavy metal concentrations. A clear decrease in Total coliform, Fecal coliform, and *Escherichia coli* was observed across the treatment stages, with complete removal of E. coli in the final treated water and distribution network. In addition, the concentrations of heavy metals (Cd, Zn, and Cr) showed a general reduction after treatment.

Overall, these findings indicate an improvement in water quality within the treatment system. However, further assessment including additional physicochemical and microbiological parameters is recommended to confirm full compliance with drinking water standards.

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