Simulation and Modeling of Water Treatment Plant with GPS-X Software for Health and Water Quality

Nabaa Abdul- Kareem [1*], Jabbar H. Al-Baidhani [1]

Abstract

Background: Waterborne diseases are infectious in nature, significantly impacting global health related to water quality and disease prevalence globally. In this study, GPS-X was used to design and simulate water treatment plants to determine the effectiveness of different mechanisms in water treatment. Method: The GPS-X water treatment software was utilized to evaluate raw and treated water performance at the Al-Kadhmaya Water Treatment Plant. Three scenarios were designed to assess the impact of varying flow rates and water parameters such as pH, alkalinity, turbidity, total dissolved solids (TDS), and total suspended solids (TSS) on the plant's performance. Results: The evaluation of the operational performance of the water treatment plant revealed that the concentrations of all contaminants in the effluent water consistently met the established Iraqi and WHO standards across all scenarios. This indicated the effectiveness of the plant's treatment processes in producing safe drinking water. The findings of this study held significance for water authorities, decision-makers in Iraq, and national and international environmental agencies, providing valuable information for improving water treatment practices and ensuring compliance with water quality standards. Conclusion: The study demonstrated the effectiveness of the GPS-X water treatment software in assessing the performance of the Al-Kadhmaya Water Treatment Plant. The results highlighted the plant's ability to consistently meet water quality standards, underscoring the importance of robust water treatment processes. These findings contributed to the body of knowledge regarding water treatment plant design and operation, offering insights that can inform decision-making processes to enhance water quality and ensure public health.

Keywords: Water Treatment Facilities (WTPs), GPS-X, Water Treatment Software, Water Quality, Water Management

Significance | This research determined the quality of the Water Treatment Plant using special software that verified the function of water treatment plants to ensure health safety.

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Introduction

Waterborne diseases, such as cholera, typhoid fever, and hepatitis A, are prevalent in regions with poor water quality, leading to significant public health issues. Addressing these diseases requires comprehensive strategies to improve water quality and to ensure safe drinking water in Baghdad, where water pollution is a concern. In Baghdad, inadequate service and substandard water quality disproportionately affect sanitation and water supply. The city's water resources management system has significantly deteriorated due to three decades of war and a lack of environmental awareness. While 91% of the population has access to drinking water, disparities exist between regions and urban and rural areas. In rural regions, only 77% of the population has access to safe drinking water sources, compared to 98% in urban areas. Additionally, 6.2% of the population lacks improved sanitation facilities. The scarcity of clean water and inadequate water management services pose significant public health risks, especially the potential for waterborne illnesses. Addressing these issues is crucial to

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preventing preventable health concerns from poor water management services (Mohammed & Abdulrazzaq, 2021).

Water resources are essential for humans and ecosystems, but due to factors such as industrialization, climate change, insufficient storage, and inadequate wastewater treatment before release, water treatment processes must ensure improvements in quality by removing various contaminants. This is essential to prevent health risks and ensure adequate and high-quality water for industrial, drinking, and other economic purposes. Meeting these quality requirements requires increased technological, chemical, and energy inputs, which raises the cost of water production and can adversely affect the environment. (Bârjoveanu et al., 2019)

The main objective of water treatment is to eliminate harmful microorganisms from polluted water and render it suitable for human consumption. This is accomplished by removing undesirable elements such as taste, odour, and impurities, including excess dissolved metals and debris. However, some chemicals used in the treatment process can be hazardous. The quality of raw water in Iraq varies significantly, leading to changes in the traditional water treatment system, typically involving screening, chemical coagulation, sedimentation, filtration, and disinfection. Regarding disposal, the backwash water and sludge generated by water treatment facilities pose a danger to the environment. As a result, it is essential to optimize chemical dosing and filter runs to reduce the waste produced by water treatment facilities. Furthermore, it is important to evaluate the operational status of the water treatment facilities and explore the most effective approach to ensure sufficient production of potable water with minimal imperfections and their management (Abukhanafer & Salman, 2018) .

The main challenges encountered by many developing nations involve protecting water bodies from pollution and ensuring the safety of drinking water and water sources (A. A. A. Abbas & F. M. Hassan*, 2018) . Monitoring the physicochemical and biological characteristics of water bodies and drinking water plants is essential for protecting aquatic life and public health. Additionally, the quality of raw water sources, such as rivers, lakes, and wells, is determined by a range of contaminants from various sources of pollution, as well as their physicochemical and biological characteristics (Hassan & Mahmood, 2018) .

Water resources have had significant impacts from climate change, population expansion, and heightened human activity. These factors provide major challenges for organizations responsible for providing drinking water, particularly in developing nations (H. Wang & Yu, 2014). There is an increasing interest in evaluating and improving water sources. A successful treatment method should meet specific criteria, such as easy installation, operation, and maintenance while requiring minimal investment and operational and maintenance costs. Additionally, it should demonstrate effectiveness in improving water quality (Khadse et al., n.d.) . It is performed to determine the factors that influence a plant's performance. The comprehensive performance evaluation programmed is an integrated approach useful for understanding the challenges and operational issues faced by drinking water treatment plants. It also provides information about the effectiveness of the work performed by the plant's units based on the chemical, physical, and biological properties of raw and treated water to assess the quality of pollutants removed (Chang et al.,2007). Therefore, in this study, we have studied the utilization of GPS-X software to facilitate the modeling and simulation of the Al-Kadhmaya Water Treatment Plant, allowing for comprehensive analysis and optimization of treatment processes under different scenarios. Monitoring and evaluating the performance of water treatment facilities (WTPs) is crucial to ensuring the effective production and management of safe, microorganism-free drinking water. This study determined the operational status of the Al-Kadhmaya Water Treatment Plant in 2022 using the GPS-X water treatment software.

Materials and methods

Area of Study and Data Collection:

Location and Description: The study area focused on the Tigris River, which divides Baghdad into Karkh and Rusafa, flowing from north to south. Seven water treatment facilities are situated along the Tigris River, with the Al Karkh water treatment facility positioned to the north of Baghdad.

Al-Kadhmaya Water Treatment Plant: This plant, located on the Karkh side of Baghdad, has a capacity of approximately 112,500 m3/day and serves the Karkh region with potable water. Data for the year 2022, from January 1st to December 31st, was collected from this facility.

Water Treatment Processes:

The water treatment process in Baghdad, particularly at the Al-Kadhmaya plant, involves a series of essential steps aimed at ensuring the availability of safe and potable drinking water for residents. Coagulation, flocculation, sedimentation, filtration, and disinfection are key processes employed, with operational data playing a crucial role in enhancing system performance. Continuous monitoring and optimization of these processes are essential for maintaining water quality and ensuring public health.

Coagulation and Flocculation: Chemical coagulants such as alum are added to neutralize or reduce the electrostatic charge of suspended solids. This facilitates particle aggregation through van der Waals forces, forming flocs. Rapid mixing during coagulation is followed by slower mixing during flocculation to create larger floc aggregates (Mhashhash et al., 2018). Chemical coagulants such as alum, ferric chloride, and polyelectrolyte have significantly improved the separation of dissolved solids or colloids from water, with variables like temperature, pH, and dosage impacting the process (Saritha et al., 2017). Flocculation follows coagulation, where small floc particles are transformed into larger aggregates through physical processes, requiring a detention period of 40 to 60 minutes for optimal performance (Nanjan Bellie & Sockan, 2008). The sedimentation stage then settles the floc particles that have not settled during flocculation, allowing cleaner water to be discharged. In the Al Kadhmaya plant, five sedimentation tanks aid in this process (Mhashhash et al., n.d.).

Sedimentation: Sedimentation tanks allow floc particles to settle, separating them from the water. Floc aggregates settle at the tank's base, while clarified water is collected from the upper receptacles.

Sand Filtration and Disinfection: Sand filtration removes larger suspended particles, and disinfection, typically using chlorine gas, eliminates pathogens. These processes ensure the production of safe and potable water. Sand filtration, another crucial step, targets the removal of relatively large suspended particles, enhancing water clarity. Two filtration processes are typically employed, with lighter and larger particles stratified at the top layers of the filter, facilitating better floc penetration (Al-Rawi, 2009). Moreover, sand filtration aids in the removal of bacteria and microorganisms, although disinfection remains essential for pathogen elimination (Clark et al., 2012). Disinfection involves the addition of chemical disinfectants like chlorine gas, ensuring the eradication of pathogens in water. Proper maintenance of pH and temperature during disinfection is crucial for its effectiveness (Mhashhash et al., 2018).

Operational data provided by the water treatment facility management, including flow rate, chemical dosage, and turbidity, are indispensable for system assessment and improvement (Table 1). Integrating this data enables thorough evaluation and enhancement of the treatment plant's performance, leading to overall operational efficiency.

Data Utilization and Software:

Hydromantis GPS-X Software: In this study, An academic license of GPS-X version 8.5 was used for mathematical modeling and simulation of the Al-Kadhmaya Water Treatment Plant. GPS-X provides a user-friendly interface for constructing plant models, inputting data, and performing simulations. GPS-X is a versatile tool utilized for modeling, simulating, optimizing, and managing water purification facilities (Hatch, 2022). It offers a user-friendly interface for constructing plant models, inputting data, and conducting simulations, with a wide array of unit processes available, covering both physical and chemical systems.

Various simulation software programs cater to water and wastewater treatment facilities, including SIMBA, AQUASIM, BioWin, and GPS-X (Abbasi et al., 2021). These tools aid in modeling, simulating, optimizing designs, and analyzing costs. GPS-X, specifically designed for water treatment, has been extensively studied by researchers worldwide to evaluate its capabilities in modeling individual components or entire treatment systems.

The GPS-X model incorporates multiple libraries of expressions and over 60 composite and state variables, including 24 kinetic and 30 stoichiometric input and output components (Mu'azu et al., 2020). Figure 2 illustrates the GPS-X interface, where users input raw water characteristics and operational parameters such as flow rates, chemical dosages, and temperature.

Mathematical algorithms and simulation techniques within GPS-X model the behavior of each component and process in the water treatment system, considering influent characteristics and operational parameters to calculate treatment unit performance and efficiency. Users design plant layouts by selecting icons from the Process Table, representing unit processes and control points, categorized into Raw Water Sources, Chemical Feed, Physical Treatment, and Disinfection.

Influent characteristics like flow rate, pH, alkalinity, total suspended solids (TSS), turbidity, color, nitrite (NO2), nitrate (NO3), and orthophosphate are entered into respective input fields, along with tank models specifying volume, depth, temperature, and chemical dosages.

Simulation calibration involves adjusting stoichiometric, kinetic, and other parameters to match simulation results with actual plant effluent closely. Figure 3 displays the layout of water treatment plants designed using GPS-X, illustrating component arrangement and configuration, facilitating effective planning, analysis, and optimization of treatment processes.

Figure 5 represents unit processes within the water treatment process, enabling detailed input of water characteristics. Overall, GPS-X provides a comprehensive platform for modeling, simulating, and optimizing water treatment facilities, aiding in efficient operation and management.

Model Layout and Design:

Plant Layout Design: The GPS-X software enabled the design of plant layouts, incorporating unit processes and control points. Icons representing different processes were arranged to depict the treatment plant's configuration.

Unit Process Input: Detailed characteristics of influent water, including flow rate, pH, suspended solids, turbidity, and chemical dosages, were inputted into the model to accurately reflect operational conditions.

Scenario Implementation: To assess the Water Treatment Plant's (WTP) response to different conditions, three scenarios were devised, each varying in water parameters, flow rate, and tank configurations. Selected scenarios were implemented to assess the plant's response under varying conditions, including changes in flow rate, influent concentrations, and operational parameters. Figure 4 showed the unit used in the water treatment process, with

Figure 1. Location of Al-Kadhmaya water treatment plant (courtesy google map)

Table 1. parameter of water quality in al-kadhmaya plant

parameter	**value**
Flow rate	69800 m^3/day
pH	7.8
turbidity	29 NTU
alkalinity	135 mg/l
TSS	34.7 mg/l
color	<5
Calcium as Ca	81.2 mg/l
Chloride as Cl	65.3 mg/l
Magnesium as Mg	30.7 mg/l
Nitrite as NO2	0.036 mg/l
Nitrate as NO3	1.61 mg/l
Orthophosphate as PO4	0.042 mg/l
Temperature C	24 C°
Fluoride as F	0.21mg/l

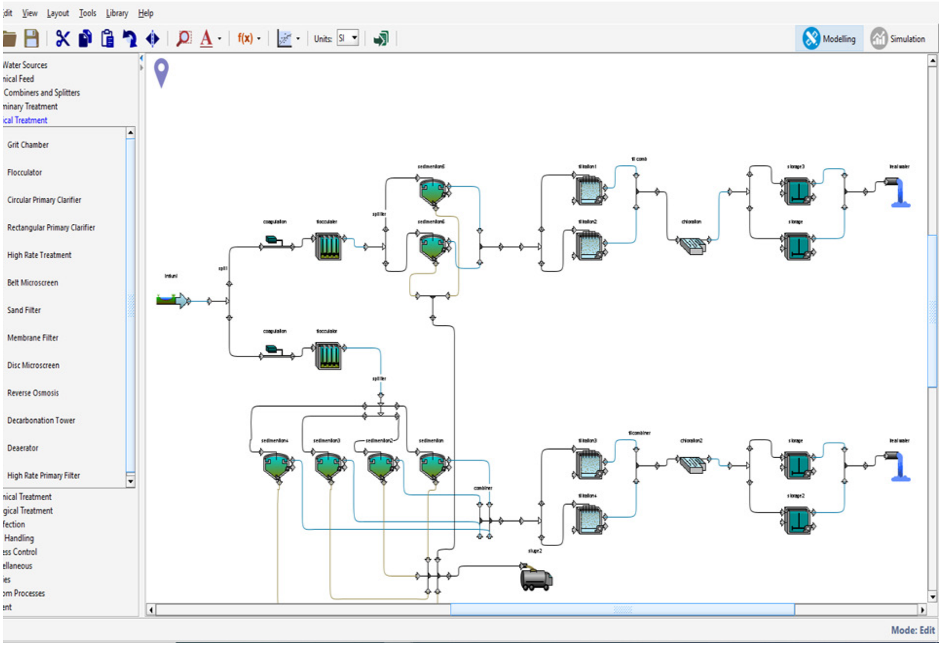

Figure 2. The View of GPS-X

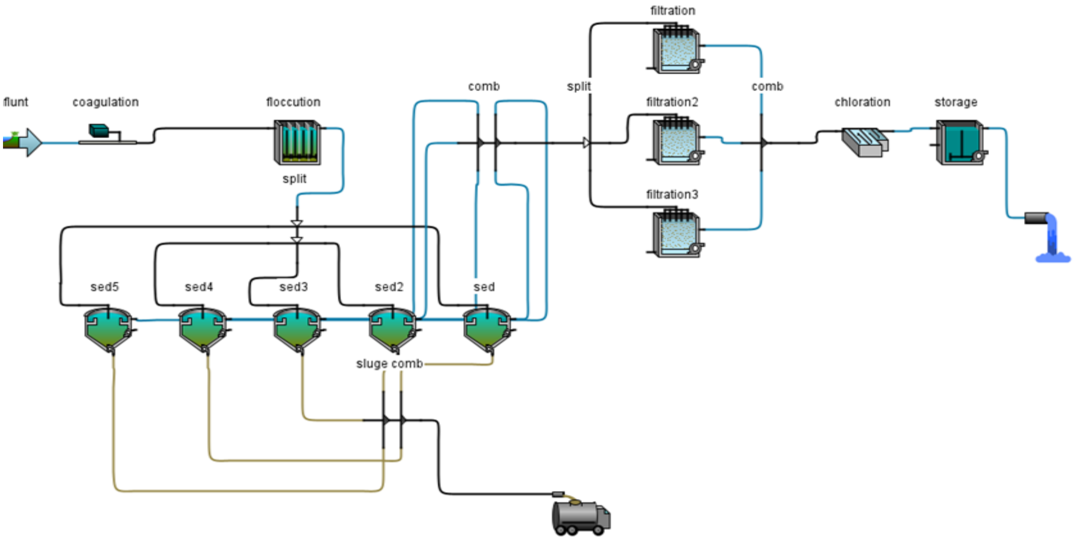

Figure 3. layout of Al-kadhmaya WTP by GPS-X

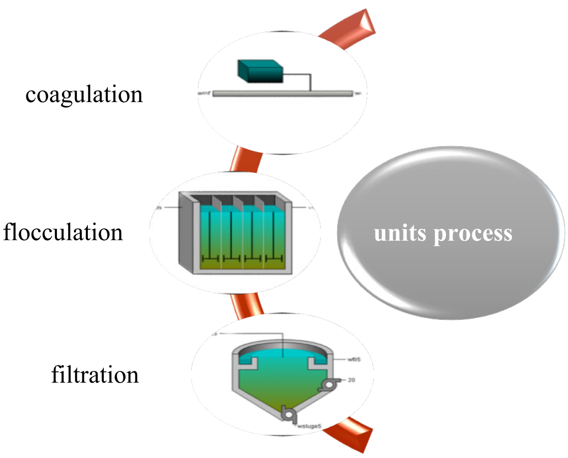

Figure 4. water treatment unit process

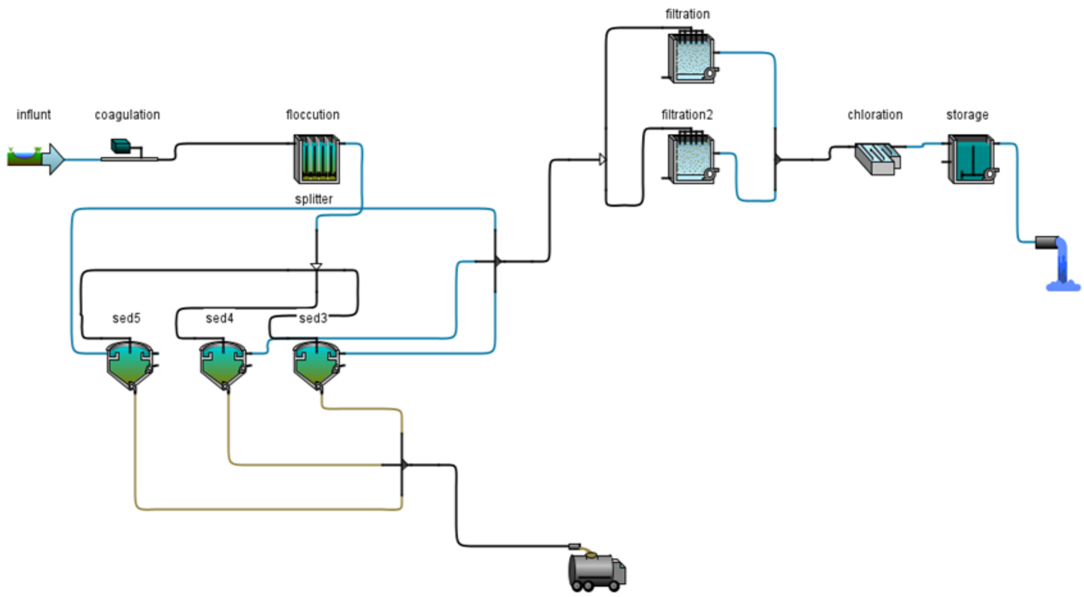

Figure 5. Layout of Al- Kadhmaya WTP in scenario three

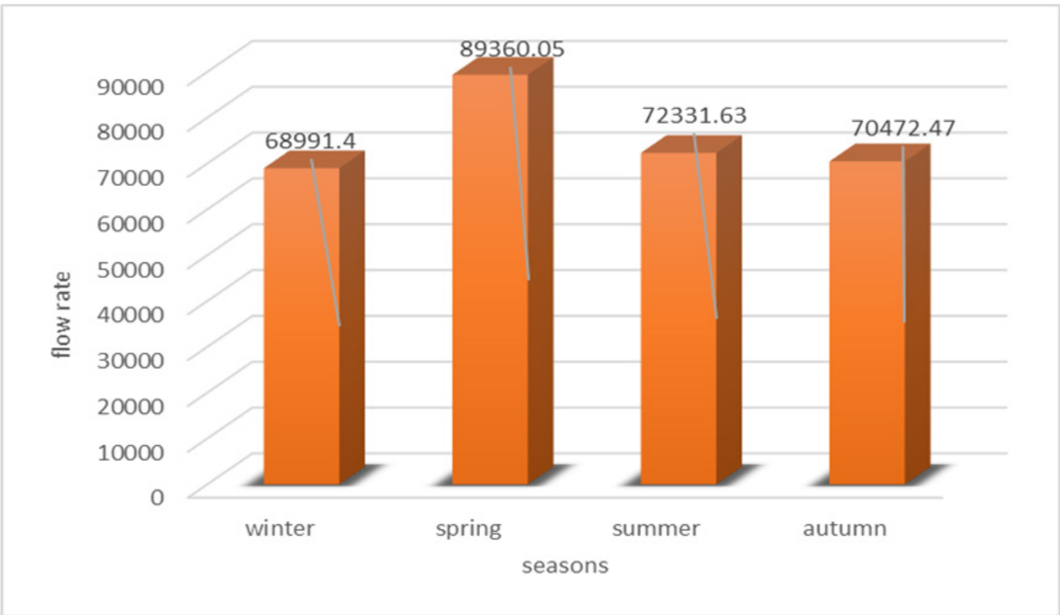

Figure 6. The flow rate of Al Kadhmaya W.T.P. in different seasons

the ability to input the detailed characteristics of the water entering the plant.

Scenario One reflects typical operational conditions observed during the study year 2022. It employs the average flow rate of the plant and includes five sedimentation tanks and eight filtration tanks, mirroring standard working cases. These parameters were recorded when the plant operated efficiently with consistent water parameters and operational conditions throughout the year. Data used in this scenario aligns with calibration data, encompassing the four seasons of the year.

Scenario Two involves utilizing maximum influent concentrations obtained from experimental works and maximum water parameter values. The plant operates at its total capacity, employing the same layout as Scenario One. This scenario tests the plant's response to peak loads and maximum water quality challenges.

In Scenario Three, the Al Kadhmaya plant operates at minimum flow rate and minimum water parameters. Here, only one flocculation tank, three sedimentation tanks, and two filtration tanks are used. The water parameters are adjusted to align the simulation's results with the standard requirements. Figure 5 depicts the layout of the water treatment plant in Scenario Three.

By implementing these scenarios, we determined how the WTP responds to various conditions, from standard operation to peak loads and minimal operation. This analysis helps in understanding the plant's capabilities under different scenarios, aiding in optimizing its performance and ensuring consistent water quality output.

Results and discussion

Water pollution and public health implications are of global concern. Issues around water pollution and health in areas similar to Baghdad where water sources are under inevitable pressure due to several factors include wars, lack of environmental awareness and inadequate infrastructure. In Baghdad, there is disparity in accessibility to safe drinking water from urban to rural areas which causes severe health risks majorly in waterborne diseases.

The simulation of the Al-Kadhmaya water treatment plant consistently demonstrated compliance with Iraqi standards for water quality throughout the year, regardless of seasonal variations. Notably, during spring, the highest recorded flow rate indicated water availability and quality fluctuations, underlining the importance of adaptive management strategies.

The first scenario, known as the adjustment scenario, aimed to evaluate the impact of flow changes on water flow and pollutant levels. Minimal differences were observed between simulated and actual pollutant parameters in the treated water, signifying effective adjustment of the plant layout. Various sensitive parameters, such as Total Suspended Solids (T.S.S.), turbidity, Total Organic Carbon (T.O.C.), Dissolved Organic Carbon (DOC), Total Nitrogen, and Total Biochemical Oxygen Demand (B.O.D.), were carefully considered during simulation to ensure accurate results and assess the plant's effectiveness.

Results indicated that all parameters met Iraqi standards across each season, demonstrating the plant's capability after calibration to deliver optimal results under varying conditions. However, during spring, the highest recorded flow rate was approximately 89360.1 m3/day, likely due to rising water temperatures and increased suspended particles, as illustrated in Figure 6.

The water treatment process helps eliminate toxins and particles that can harm people because it cleans all the infected water into safe water. However, because of poor infrastructure and obsolete treatment technology, many people don’t have access to clean water. The process also uses chemicals such as coagulants and disinfectants to clean water, further complicating the matter as chemicals from these substances can react with the water leading to waterborne disease.

Effective water treatment requires constant monitoring and adjustment of treatment processes to maintain water quality standards. Technologies such as GPS-X software help to model, simulate and optimise water treatment plants, allowing operators to review the performance of the treatment plants and make informed decisions to enhance the quality of the water.

An examination of the Al-Kadhmaya Water Treatment Plant in Baghdad revealed that the ability to apply adaptive management strategies, which address the seasonality of raw water quality and changing environmental conditions, is critical. Despite operational challenges, the plant was found to maintain consistent compliance with Iraqi water treatment standards, illustrating that judicious management and effluence treatment optimization are effective.

The findings highlight the importance of continuous monitoring and adjustment in water treatment plant operations to maintain water quality standards, especially in response to seasonal variations and changing environmental conditions. In Baghdad it takes the collaboration of numerous factors that will improve the quality of water, improve infrastructure, and applied effective managing strategies in water treatment fields. Recognition of the consistent water quality output and diminishing probable health risks due to lesser water quality demands continuous monitoring and optimization. Prioritization of public health and long term comprehensive investment in water management activities can help reduce the trade-off of water pollution and its effects on the health of the citizens in the capital city Baghdad.

Conclusion

In conclusion, the study demonstrated the critical role of water treatment facilities (WTPs) in safeguarding public health by providing safe drinking water. The Al-Kadhmaya Water Treatment Plant assessment using GPS-X software elucidated the effectiveness of different treatment mechanisms. Despite seasonal variations, results demonstrated consistent compliance with Iraqi water quality standards throughout the year. Adaptive management strategies are crucial for addressing water availability and quality fluctuations, as observed during spring. The study emphasizes the importance of continuously monitoring and optimizing WTP operations to ensure consistent water quality output and mitigate potential health risks. These findings contribute to advancing water treatment practices and enhancing public health outcomes.

Author contributions

N.A.K., J.H.A.B. conducted the study design, analyzed the data, and wrote the draft of the manuscript.

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Competing financial interests

The authors have no conflict of interest.

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