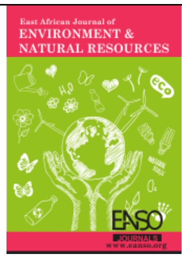

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Original Article

Efficacy of Karie Waste Water Treatment Plant for Domestic Purposes Murang'a County, Kenya

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ABSTRACT

Water is essential not only for life but also as the foundation of a nation's green economy. However, inadequate access to clean and safe drinking water severely jeopardizes public health, especially in developing countries such as Kenya. This study was conducted in Murang'a County, Kenya. The aim was to evaluate the effectiveness of the Karie Wastewater Treatment Plant for residential use by examining key physical parameters (temperature, PH, Dissolved solids, electrical conductivity and Total Dissolved Solids) of wastewater before and after treatment. A total of 45 samples (500 ml each) were collected as grab samples from three sites, that is, the plant inlet, outlet, and a point along River Karie. The study was carried out during the dry season (January–February 2023) and the wet season (May–June 2023). In situ measurements of temperature, PH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) were performed using standard methods and appropriate instruments (mercury thermometer, PH meter, DO meter, and conductivity meter). Results were compared against guidelines from the Kenya Bureau of Standards (KEBS) and the World Health Organization (WHO) to assess suitability for household water use. During the dry season, temperature and PH increased significantly, with mean values of 24.52 ± 1.20°C and 7.5 ± 0.5, respectively ($p < 0.05$). In the wet season, TDS and DO levels were notably higher, with overall mean values of 23.42 ± 0.2°C (temperature), 7.4 ± 0.3 (PH), 234 ± 0.52 (TDS), 5.7 ± 0.3 (DO), and 593 ± 0.13 (EC). While temperature and PH did not significantly differ among the sampling stations ($p > 0.05$), several physical parameters varied significantly between the two seasons. Although most parameters were within allowable limits for domestic water use, the elevated electrical conductivity indicates that additional treatment processes such as advanced filtration, ion exchange, or reverse osmosis are necessary to prevent pollution of River Karie.

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INTRODUCTION

The release of untreated sewage into water bodies is a critical issue contributing to surface and groundwater pollution in Kenya. The gap between wastewater production and treatment remains wide, leading to the discharge of harmful pollutants such as heavy metals, organic compounds, and pathogenic microorganisms. These contaminants degrade water quality, posing risks to human health and aquatic ecosystems (Walakira, 2011). With water being essential for life, its contamination has severe implications (Trivedi *et al.*, 2010). Rapid urbanization, industrial expansion, and climate change have further strained freshwater resources, exacerbating water pollution (Akan et al., 2003).

Kenya has established wastewater treatment plants (WWTPs) in major cities like Nairobi, Mombasa, Eldoret, Nakuru, and Kisumu (Omoto, 2006; Ansari, 2011). Many regions also rely on wastewater ponds or lagoons, which utilize biological processes to reduce pollutants (Alcalde *et al.*, 2003; Kayyali et al., 1999). However, rapid urban growth and industrialization have often exceeded the capacity of these facilities (Syagga, 1992; Khan et al., 1992). As a result, many plants discharge untreated or partially treated sewage, increasing the prevalence of waterborne diseases (Dallas *et al.*, 2008). Heavy metals and chemical residues in sewage further pose long-term health hazards by accumulating in aquatic organisms and entering the human food chain (Li *et al.*, 2018; Nel *et al.*, 2013). Contaminated water is implicated in up to 90 percent of the 1.7 million deaths occurring annually in developing countries (UNESCO, 2020; Apha, 2012), affecting agriculture and industry through reduced crop yields and increased production costs.

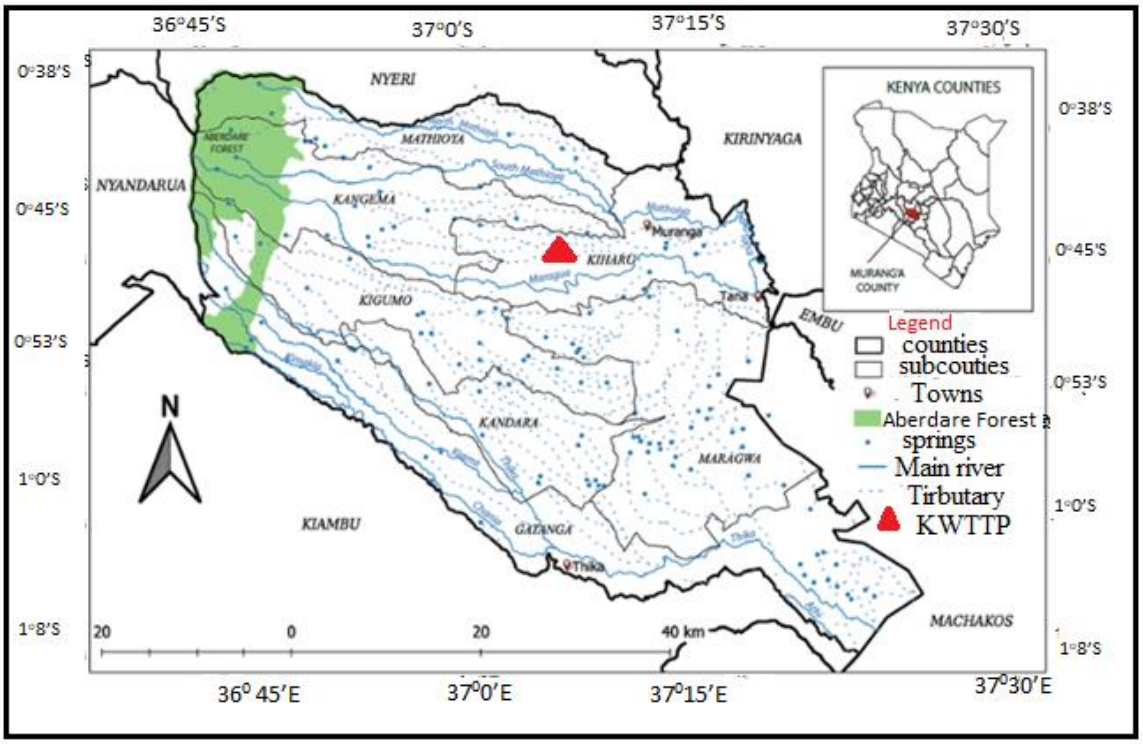
In Murang'a County, wastewater management challenges are worsening due to urban expansion, the growth of Murang'a University, and the elevation of a local hospital to a level-five facility (Maindi *et al.*, 2020). These developments have led to increased wastewater production, but the Karie Wastewater Treatment Plant (KWWTP) has not been adequately upgraded, resulting in substandard effluent discharge (Atharizade *et al.*, 2015). Inadequate sewer infrastructure further exacerbates treatment inefficiencies, raising public health concerns. This study evaluates the performance of KWWTP by analyzing effluent characteristics before and after treatment, comparing them to WHO and KEBS standards. Identifying inefficiencies in the treatment process will help recommend improvements to reduce pollution and health risks. Addressing wastewater treatment shortcomings is crucial for environmental sustainability and public health. Strengthening infrastructure, enforcing monitoring protocols, and enhancing community awareness are vital steps toward ensuring safe water and sustainable development in affected regions. The objective of this study is to evaluate the physical parameters of the wastewater at KWWTP before and after treatment.

STUDY AREA

This research was conducted in Murang'a County (Figure 1), located between latitudes 0°38'S

The study site is within Murang'a County. The county occupies a total area of 2,558.8 km² and houses the Karie Wastewater Treatment Plant (KWWTP).

Figure 1: Map of the Research Area in Murang'a County, Kenya.



Source: [Benson M., 2021]

The plant is situated along the Murang'a–sagana Road and approximately six kilometres from the headquarters of the Murang'a Water and Sanitation Company (MUWASCO), the plant occupies 55 acres of land. The plant receives wastewater from a diverse array of sources, including industrial activities, domestic usage, and surface runoff from the town and its environs (Mwangi, 2021). Effluent entering the plant originates from schools, universities, hospitals, residential areas, and even local garages, ensuring a comprehensive collection of wastewater. The plant treats the wastewater up to a tertiary stage before discharging the treated effluent into the Karie River. Overall, the facility provides essential services to approximately 25,000 residents in Murang'a town and its surrounding areas.

Sampling Sites and Sampling Procedure

The research was conducted at three sampling points: two located at the Karie Wastewater Treatment Plant (KWWTP) and one at the river downstream of where the treated effluent is discharged. The treatment plant uses waste stabilization ponds (WSP) to process the effluent. Specifically, sampling points S1, S2, and S3 were chosen as follows (Figure 2): S1 was positioned upstream of the treatment plant to capture the raw wastewater entering the facility, S2 was located immediately after the treatment plant to assess the

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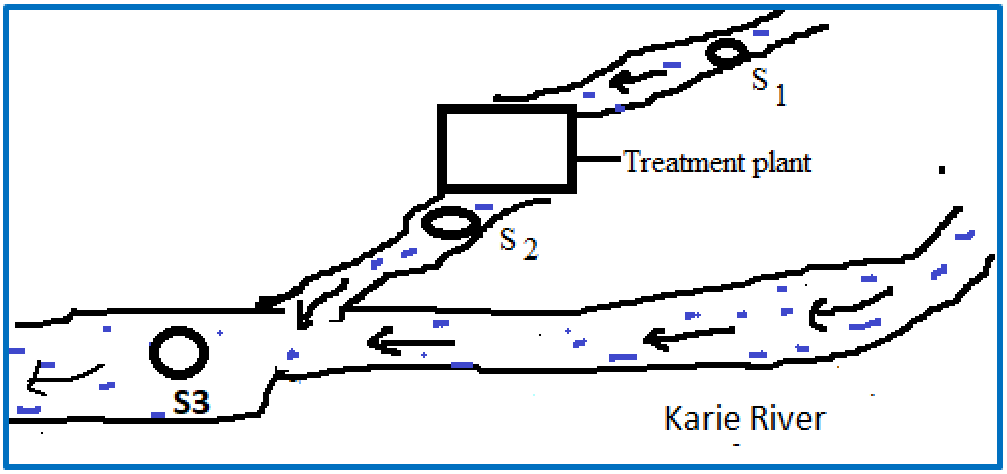
quality of the treated effluent, and S3 was established at the point where the treated discharge enters the river to evaluate the dilution effect. Samples were collected once a month in triplicate during both the wet and dry seasons.

Figure 2: Sampling Locations within KWWTP



Statistical Data Analysis

Statistical data analysis in this study involved a comprehensive evaluation of the physical parameters measured at the three sampling points (S1, S2, and S3) to assess water quality differences before and after treatment, as well as the dilution effect downstream. Samples were collected three times a day during both wet and dry seasons. Normality tests were conducted to determine the suitability of parametric tests, data analysis was conducted using the Statistical Package for Social Sciences (SPSS) for Windows, Version 20, at a significance level of 5%. Descriptive statistics were calculated, including the mean and standard deviation (SD) for the various variables assessed at the sampling points. To identify significant differences among the sampling points, a one-way analysis of variance (ANOVA) was employed.

RESULTS AND DISCUSSIONS

Physical Parameters

Table 1 summarizes the physical parameters measured on water samples from the Karie Wastewater Treatment Plant. These parameters, dissolved oxygen (DO), P^H, temperature (°C), electrical conductivity (EC), and total dissolved solids (TDS) were assessed across all sampling points, with the detailed values presented in the table and further illustrated in Figures 3 through 7.

Table 1: Mean Values ± Standard Deviation of Physical Parameters in Wastewater

Parameter	Inlet	Outlet	Karie river	p-value
Temp (0^C)	24.2±0.8	24.52±0.12	23.56±0.5	0.2107
P^H	7.4±0.2	7.5±0.1	7.32±0.2	0.7602
D.O (mg/l)	5.3±0.2	5.7±0.3	7.9±0.4	0.0075
TDS (mg/l)	948±0.76	234±0.52	453±0.46	0.0001
EC (µS /cm)	880±0.11	593±0.13	123±0.31	0.0004

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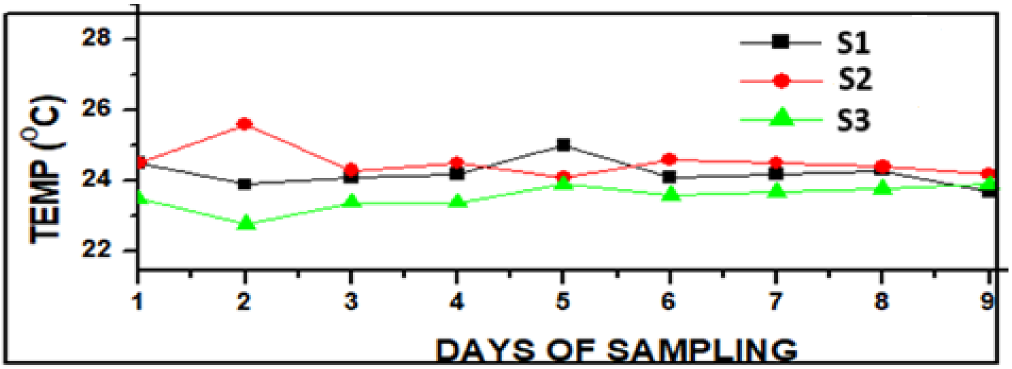
Temperature (0C)

Figure 3 illustrates the temperature profiles measured at three sampling points during the study: S1 (inlet), S2 (outlet), and S3 (Karie River downstream). The temperature at the inlet ranged from 24.1°C to 24.4°C, increasing slightly at the outlet to a range of 24.6°C to 24.9°C, while the Karie River exhibited lower temperatures between 23.4°C and 23.7°C. The mean temperatures recorded were 24.2 ± 0.8°C at the inlet, 24.5 ± 0.12°C at the outlet, and 23.5 ± 0.5°C in the river, with the highest average observed at the outlet and the lowest in the river. These subtle differences suggest that while the wastewater treatment process may induce a slight increase in temperature, the overall thermal conditions remain relatively stable.

Figure 3: Temperature Measured at the Various Sampling Points During the Study Period.



A statistical analysis using a t-test confirmed that the differences in temperature among the sampling points were not statistically significant ($p = 0.2107$), indicating minimal thermal impact from the treatment process. This observation is consistent with similar studies; for instance, Wang *et al.*, (2015) reported marginal increases in temperature at the effluent of treatment plants due to heat exchange processes, while Lee and Kim (2017), found that temperature variations between influent and effluent were insignificant, thus unlikely to disturb downstream aquatic ecosystems. These findings, together with our results, underscore that the wastewater treatment process maintains thermal stability, an important factor for preserving the ecological balance in receiving water bodies.

P^H^

The mean P^H values recorded for the inlet, outlet, and Karie River were 7.4 ± 0.2, 7.5 ± 0.1, and 7.32 ± 0.2 respectively (Table 1). Notably, the highest P^H was observed at the outlet (7.5), while the Karie River exhibited the lowest value (7.32). A t-test revealed no statistically significant differences in P^H levels among the sampling sites ($p = 0.762$), indicating that the wastewater treatment process maintains a relatively stable P^H throughout the system. Similar observations have been reported by Kumar et al., (2018), who found minimal variations in P^H across different points in wastewater treatment systems, reinforcing the notion of process stability.

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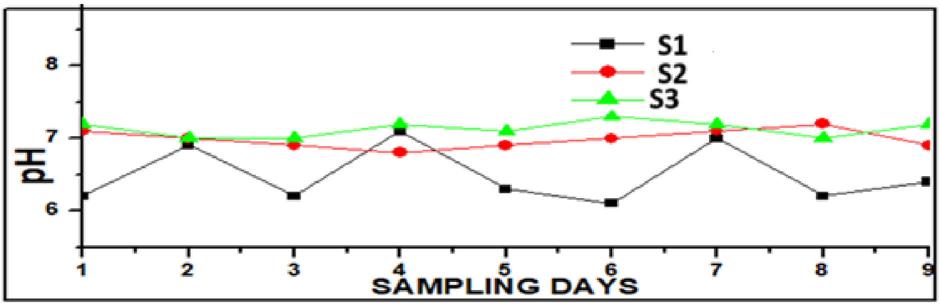
Figure 4: The P^H value Concentration at the Various Sampling Points During the Study Period.



The slightly lower pH observed in the Karie River compared to the outlet may be attributed to natural processes occurring within the maturation ponds of the treatment plant. The removal of carbon dioxide during photosynthesis along the river further lowers the P^H (Williard & Roger, 2013). In addition, the anaerobic degradation of organic matter in the primary reservoir can release organic acids and gases such as carbon dioxide and hydrogen ions, contributing to the overall reduction in P^H. This mechanism is consistent with the findings of Ansari et al. (2011), who documented that microbial and algal activities often result in the production of surplus hydroxyl ions, further driving down P^H levels.

Overall, the P^H concentrations measured across the sampling points remain low and within the acceptable limits set by KEBS, suggesting that the treated effluent does not compromise water quality. These stable P^H levels indicate that agricultural activities along the Karie River can be safely conducted without adverse effects from sewage effluent. The results of this study, in conjunction with those of similar investigations (Kumar *et al.*, 2018; Williard & Roger, 2013; Ansari *et al.*, 2011), confirm that the wastewater treatment process effectively maintains P^H stability, thereby protecting downstream ecosystems and supporting safe land use practices.

Dissolved Oxygen (DO)

The mean dissolved oxygen (DO) values measured at the Karie Wastewater Treatment Plant (KWWTP) were 5.3 ± 0.2 mg/L at the inlet (S1), 5.7 ± 0.31 mg/L at the outlet (S2), and 7.9 ± 0.4 mg/L in the Karie River (S3). A t-test indicated a significant variation among these sampling sites ($p = 0.0075$), suggesting that each point in the treatment process experiences different levels of organic load and oxygenation. The higher DO observed at the outlet relative to the inlet indicates that the biological processes in the treatment ponds such as the presence of algae, macrophytes, and aerobic bacteria help reduce organic pollutants, thereby enhancing oxygen levels. Furthermore, the river exhibited the highest DO (7.9 ± 0.4 mg/L), likely due to natural aeration processes and vegetation along its course, which injects oxygen into the water via photosynthesis (Janjua *et al.*, 2009).

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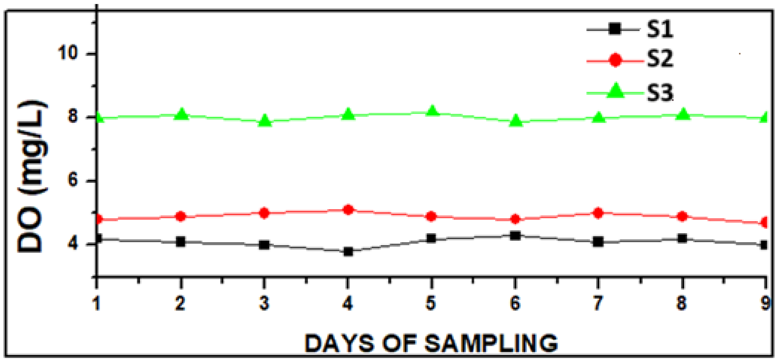
Figure 5: The DO Concentration at the Various Sampling Points During the Study Period.

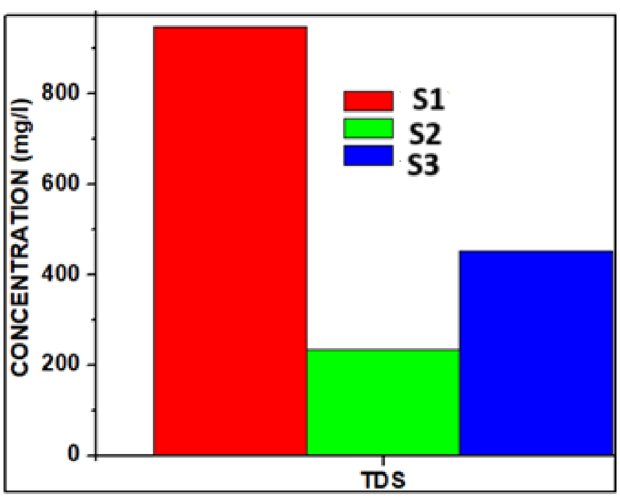


These findings highlight the crucial role of wastewater treatment in maintaining or improving DO concentrations before effluent is discharged into natural water bodies. The relatively low DO at the inlet reflects the high organic load, which demands substantial oxygen for microbial decomposition. As the waste travels through the treatment system, decomposition processes gradually reduce this load, allowing DO levels to increase by the outlet stage. Comparable trends have been observed in other Kenyan wastewater facilities; for instance, Mbugua et al. (2017) reported an increase in DO between influent and effluent streams at the Nakuru Sewage Treatment Plant, while Awuor et al. (2020) noted improved DO in wastewater discharged into Lake Victoria. These studies collectively underscore the importance of efficient treatment processes in mitigating oxygen depletion, safeguarding aquatic life, and ensuring that downstream water users are less impacted by effluent discharges.

Total Dissolved Solids (TDS)

Figure 6 presents the total dissolved solids (TDS) concentrations measured at three sampling points: the inlet, the outlet of the treatment plant, and the Karie River. The highest TDS value was observed at the inlet (948.3 ± 0.76 mg/L), while the outlet recorded the lowest (234.67 ± 0.52 mg/L). In contrast, the Karie River exhibited an intermediate TDS level (453 ± 0.31 mg/L), reflecting both natural contributions and potential residuals from the treated effluent. These results suggest that raw sewage entering the treatment plant carries a substantial load of dissolved solids, which are effectively reduced through the treatment process.

Figure 6: Mean Concentration for TDS at the Various Sampling Points During the Study Period.



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The marked drop in TDS from the inlet to the outlet highlights the efficiency of the treatment plant in removing dissolved impurities. Processes such as sedimentation, biological degradation, and filtration can significantly lower the concentration of ions and organic matter, thereby improving water quality before discharge. Meanwhile, the moderately elevated TDS observed in the Karie River may stem from a combination of treated effluent, natural mineral content, and other diffuse sources such as runoff from surrounding land. Monitoring TDS is critical, as excessively high levels can impair aquatic habitats and limit water usage for domestic or agricultural purposes.

These findings are consistent with similar observations at other Kenyan wastewater treatment facilities. For instance, Mbugua *et al.*, (2017) reported a comparable reduction in TDS at the Nakuru Sewage Treatment Plant, underscoring the role of well-managed treatment processes in enhancing effluent quality. Likewise, Awuor et al. (2020) documented a substantial decrease in dissolved solids between influent and effluent streams at a municipal wastewater plant in Kisumu, attributing this to effective biological and physicochemical treatment stages. Taken together, these studies confirm that robust wastewater management is key to reducing TDS levels, thereby minimizing the environmental impact of effluent discharge into natural water bodies.

Electrical Conductivity (E.C)

The mean electrical conductivity (EC) levels measured at the inlet, outlet, and Karie River were 880 ± 0.11 µS/cm, 593 ± 0.13 µS/cm, and 123 ± 0.31 µS/cm, respectively. The elevated EC at the inlet reflects a higher concentration of dissolved ions, organic matter, and other contaminants in untreated wastewater. In particular, sodium (Na^{+}) and hydroxide (OH^{-}) ions originating from cleaning agents used in households and at Murang'a Level 5 Hospital contribute significantly to this increased conductivity. As the wastewater moves through the stabilization ponds, various biological and chemical processes, such as microbial degradation, precipitation, and adsorption, reduce the concentration of dissolved ions, leading to a marked decrease in EC at the outlet. Sedimentation also plays a key role in lowering EC, as dissolved solids and suspended particles gradually settle at the bottom of the ponds. Additionally, macrophytes and algae in the facultative and maturation ponds consume important salts through root uptake and photosynthesis, further diminishing ion concentrations. This combination of biological and physicochemical mechanisms effectively improves water quality, as evidenced by the substantial drop in EC from the inlet (S1) to the outlet (S2). Similar outcomes have been reported in other Kenyan wastewater treatment plants; for instance, Mbugua et al. (2017) documented significant EC reductions in Nakuru's stabilization ponds, while Awuor et al. (2020) observed comparable patterns in effluent discharged into Lake Victoria.

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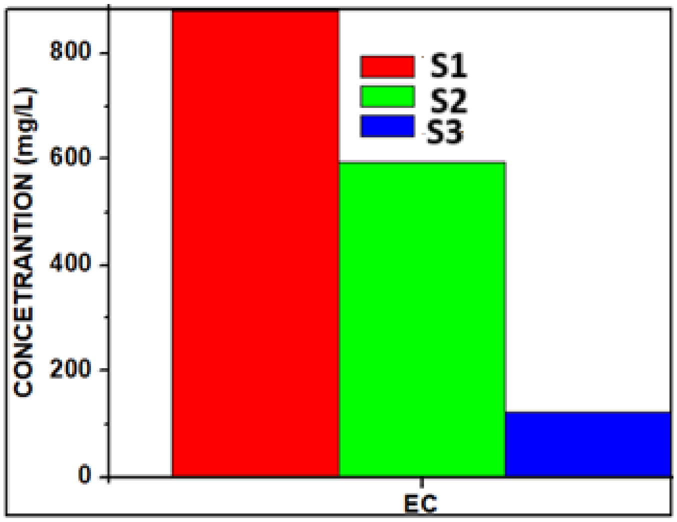
Figure 7: Mean Concentration Electrical Conductivity at the Various Sampling Points During the Study



At the Karie River (S3), EC levels are notably lower (123 ± 0.31 µS/cm) than at both the inlet and outlet, owing in part to the dilution effect once treated effluent mixes with the natural water flow. Biological processes within the river ecosystem such as ongoing microbial decomposition of any remaining organic matter can further reduce the concentration of dissolved ions. Consequently, the overall EC remains low, benefiting downstream aquatic habitats and ensuring safer water use for surrounding communities. This trend underscores the importance of well-managed stabilization pond systems in mitigating the impact of wastewater on local waterways. Several studies conducted in Kenya have reported trends in electrical conductivity (EC) that are consistent with the findings of this research. For instance, Mbugua *et al.*, (2017) observed that influent EC levels at the Nakuru Sewage Treatment Plant were notably higher than those measured in the treated effluent, attributing the decrease to sedimentation, microbial degradation, and nutrient uptake by aquatic vegetation in stabilization ponds. Similarly, Awuor *et al.*, (2020) documented a significant reduction in EC as wastewater flowed through treatment processes in Kisumu, underscoring the efficacy of biological and physicochemical mechanisms in removing dissolved ions. These Kenyan-based studies, alongside the current results, highlight the pivotal role of well-managed stabilization pond systems in mitigating ionic pollutants, ultimately safeguarding downstream water bodies and supporting environmental sustainability.

CONCLUSION

In conclusion, the results indicate that the wastewater treatment process (KWWTP) does not significantly affect temperature, pH and dissolved oxygen while electric conductivity is effectively reduced to acceptable levels for effluent discharge. However, total dissolved solids (TDS) remained above recommended limits, underscoring the need for additional or enhanced treatment stages. Seasonal variations also impacted the plant's performance, with higher temperatures in the dry season promoting more efficient biological degradation in the anaerobic, facultative, and aerobic ponds. Overall, the findings emphasize the importance of ongoing monitoring and process optimization to ensure that the KWWTP consistently meets water quality standards and safeguards the receiving environment.

RECOMMENDATIONS

Based on the findings of this study, it is recommended that regular operational monitoring

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and maintenance should also be intensified, ensuring that parameters like pH, temperature, and dissolved oxygen remain within optimal ranges for biological degradation in the anaerobic, facultative, and aerobic ponds. The Karie Wastewater Treatment Plant (KWWTP) should enhance its existing treatment system to address persistently high total dissolved solids (TDS) levels. Specifically, the plant could integrate additional processes such as advanced filtration, ion exchange, or reverse osmosis to more effectively remove excess dissolved salts. Moreover, establishing clear protocols for seasonal adjustments, particularly during periods of high rainfall or elevated temperatures will help maintain consistent effluent quality. Such improvements will enable the KWWTP to better meet water quality standards, protect downstream ecosystems, and support safe reuse opportunities where applicable.

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