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# Levels Of Selected Heavy Metals And Microbial Bacteria In Karie Wastewater Treatment In Murang'a, Kenya

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***Abstract***
*Ensuring that wastewater treatment facilities operate effectively is crucial for maintaining the quality of effluents discharged into natural water bodies and the surrounding environment, in accordance with regulatory standards. This research focuses on assessing the average levels of selected heavy metals (lead, copper, and zinc) and microbial organisms (total and fecal coliforms) before and after treatment at the Karie wastewater treatment plant in Murang'a County. Thirty 500 ml grab samples were collected from three designated points: the inlet (S1), the outlet (S2), and a downstream location on River Karie (S3). Sampling took place during both the dry season (January–February 2023) and the wet season (May–June 2023). To preserve sample integrity, sanple collected were stored on ice (below 10 °C) until laboratory analysis. Heavy metal concentrations were determined via Atomic Absorption Spectrometry (AAS), while coliform counts were expressed as colony-forming units (CFU) per 100 ml of wastewater. In the treated effluent (S2), mean concentrations levels of lead, copper, and zinc were 0.082 ± 0.01 mg/L, 0.168 ± 0.01 mg/L, and 0.311 ± 0.001 mg/L, respectively. Mean total and fecal coliform levels were $6.3 \times 10^4$ and $3.5 \times 10^4$ CFU/100 ml, respectively. These findings were compared against standards set by the Kenya Bureau of Standards (KEBS) and the World Health Organization (WHO). Statistical analysis (t-test, $p < 0.05$) was applied to the laboratory data, with results illustrated in tables and graphs. Lead concentrations and coliform counts (total and fecal) exceeded both WHO and KEBS limits for domestic water. The plant proved inadequate in removing total and fecal coliforms as well as lead, indicating microbial and heavy-metal contamination of the treated water— rendering it unfit for household use. Based on these outcomes, the study recommends a redesign of the treatment facility, alongside enhanced monitoring of wastewater inflows, to achieve more effective purification processes.*
***Keywords:*** *Heavy metal, effluents treatment, karie, colony forming units*

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## I. Introduction

Water is the cornerstone of human health, ecosystem integrity, and socioeconomic development, yet global freshwater resources face increasing pressure from competing demands (du Plessis, A. (2023). In Murang'a County, Kenya, this challenge is exacerbated by rapid urban expansion in Murang'a town following the upgrade of Murang'a University of Technology, which has attracted students and staff and driven up local population density (Murang'a University of Technology, 2023). Three years ago, the county referral hospital was elevated from Level 4 to Level 5, expanding its capacity and services but also introducing greater volumes of pharmaceuticals, disinfectants, and medical wastes into the municipal sewer system (Mathenge *et al.*, (2023)). Alongside these institutional developments, Murang'a's burgeoning industrial sector discharges heavy metals and chemical by-products into the sewer network, while university laboratories contribute a range of chemical reagents and biological effluents (Mugo *et al.*, (2022); Murang'a University of Technology, 2023). Climate variability compounds these pressures, more frequent and intense rainfall events produce stormwater surges that disrupt hydraulic loading and reduce retention times in treatment processes, Kenya Meteorological Department, Kandie *et al.*,(2024). Together, these factors risk overwhelming the Karie Wastewater Treatment Plant (KWWTP), the critical facility charged with protecting downstream water quality in River Karie.

Ineffective removal of priority contaminants such as lead, copper, zinc, microbial pathogens, and emerging pharmaceutical residues poses serious threats to public health, Akpor *et al.*,(2014) .Recent surveillance data report a rise in waterborne diseases across Murang'a County, including outbreaks of diarrheal illnesses linked to microbial contamination of household water supplies (Ministry of Health, Kenya, 2023). Moreover, many residents and smallholder farmers downstream depend on treated effluent from KWWTP for washing, domestic cleaning, and irrigation, creating additional exposure pathways Ehalt *et al.*, 2022. To evaluate whether KWWTP can meet these evolving challenges, this study assesses the plant's efficiency in removing three heavy metals (lead, copper, and zinc) and two biological indicators (total and fecal coliforms). Following methods outlined by Kariuki, *et al.*. (2023), thirty grab samples (500 ml each) were collected at the inlet (S1), the outlet (S2), and a downstream point on River Karie (S3) during both the dry season (January–February 2023) and the wet season (May–June 2023). Samples were preserved on ice (below 10 °C) and analyzed in the laboratory, heavy metals via Atomic Absorption Spectrometry (AAS) and coliform counts expressed as colony- forming units per 100 ml. Statistical comparisons of influent and effluent concentrations using t-tests at the 5% significance level provide a robust measure of treatment efficacy across seasons and pollutant classes.

By benchmarking measured concentrations against standards set by the Kenya Bureau of Standards and the World Health Organization Chen *et al.*, (2023) , this research will identify specific operational shortcomings particularly in the removal of lead, coliform bacteria, and potential pharmaceutical residues and quantify the influence of seasonal flow variability. The findings will underpin targeted recommendations for technological upgrades, process optimizations, and enhanced monitoring protocols. In doing so, this research aims to ensure that KWWTP can reliably accommodate increased loads from the Level 5 hospital, the university campus, urban stormwater surges, and industrial discharges, ultimately safeguarding public health, securing agricultural productivity, and preserving the ecological integrity of River Karie.

## II. Materials And Methods

**Study Area**

In this paper, the focus is on the Karie Wastewater Treatment Plant (KWWTP), which covers an area of approximately 55 hectares. It is located in Murang'a County, with its geographical coordinates being latitudes 0°38'S and 1°7'S and longitudes 36°E and 37°27'E Mwangi *et al.*, (2021), as shown in Figure 1. The rationale for selecting this study stems from the considerable number of schools, hospitals, restaurants, and food vending establishments located in areas where the discharge of food wastewater and its quality are of paramount concern.

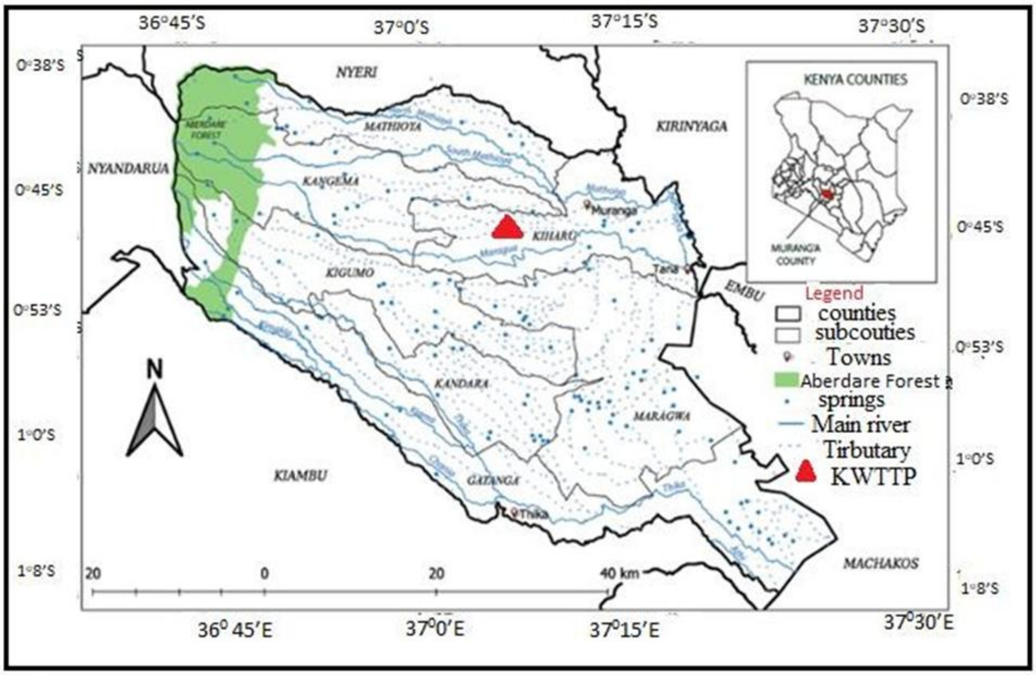


**Figure 1: Map of the research area in Murang'a County, Kenya. [Benson M., 2021] as the source**

The KWWTP is the main treatment plant that collects town sewage and its surroundings by piping lines and the effluents after treatment are channeled into adjacent Karie River. Topographically, KWWTP is located in elevation height of 1310 m above sea level Geographically, in Murang'a the dominant soil type is humic, Nitisols, recognized for their dusky red to reddish-brown coloration Omuto *et al.*, (2013). These soils are characterized by their considerable depth, effective drainage, and a humid topsoil that consists of friable clay. The temperature variations in Murang'a County are primarily determined by altitude. The highest annual temperatures in the eastern lower parts range between 26° C and 30° C, while the minimum annual temperatures range between 14°C and 18°C. Hansen, J., (2006 )In contrast, the western highland areas can experience minimum temperatures as low as 6°C, while maximum temperatures do not exceed 30°C throughout the year.

**Sampling Method**

Wastewater grab samples were obtained monthly, from early January to early December 2023, using polyethylene bottles at both the influent and effluent sites of the ponds. To obtain a representative sample of the treatment plant sampling was conducted at three designated locations: the (S1),inlet, the (S2) outlet, and the (S3) Karie River itself. The inlet, identified as point S1, is situated immediately prior to the anaerobic ponds, while the outlet, marked as S2, is located at the discharge point. The third sampling site, labeled S3, is positioned within the Karie River. Wastewater samples were collected from sampling points S1, S2, and S3 during the wet season in October and the dry season in January. Sampling sites were marked and mapping was done with the aid of a Geographic Information System (GIS) machine. A 2-liter plastic container was employed to draw wastewater to a depth of approximately 10-15 cm. Each site provided triplicate samples, which were mixed thoroughly prior to obtaining a 100 ml sub-sample for laboratory analysis. Samples intended for laboratory analysis were preserved in sterilized polyethylene bottles at a temperature of 4°C using a cool box with ice and subsequently transported to the laboratory for the assessment heavy metal (copper, lead and zinc), total and fecal coliforms. The wastewater was stored in 500 ml plastic containers, and a 200 ml sub-sample was taken from the homogenized sample for further examination.

**Data Analysis And Presentation**

Data analysis was done in accordance with WHO guideline for drinking water quality (APHA 1998, WHO 2017). Data analysis was carried out through One-Way ANOVA at a 95% confidence level, using SPSS 22 for Windows. This approach was based on the premise that significant differences existed among the heavy metals, specifically copper, lead, and zinc, as evidenced by a p-value below 0.05. Additionally, the ANOVA method was applied to evaluate the mean concentrations of heavy metals and microbial bacteria (Total and fecal coliforms) as well as to compare the levels against the WHO and KEBS standards. Tables and graphs were used to present the data obtained.

**Determination of Heavy Metals**

Wastewater samples were subjected to digestion in triplicate, following the procedure outlined by APHA (2005). A volume of 10 ml of filtered water was combined with 5 ml of concentrated nitric acid and heated to 100°C, with the addition of three drops of hydrogen peroxide until the evolution of brown fumes ceased. The resulting mixture was then filtered through Whatman 0.45 µm filter paper into a 100 ml volumetric flask, which was subsequently filled with distilled water for analysis using a flame atomic absorption spectrophotometer. The absorbance values obtained from the sample solutions were utilized to determine the concentration.

## III. Results And Discussions

**Heavy Metals**

The table below present the average concentrations of copper, zinc and lead across all sampling sites throughout the study period.

| | | Sampling sites | | |
|---|---|---|---|---|
| Parameters | S1 | S2 | S3 | p value |
| Lead (Pb) | 0.115 ±0.01 | 0.082±0.01 | 0.054±0.01 | 0.0001 |
| Zinc(Zn) | 0.278 ±0.01 | 0.168 ±0.01 | 0.079 ±0.01 | 0.0001 |
| Copper ( Cu) | 0.456±0.002 | 0.311±0.001 | 0.288±0.001 | 0.1785 |

**Table 1:** The mean values ± standard deviation of selected heavy metal in all the sampling sites during the period of study.

Recommended limit for the heavy metal (mg l)

P value

| Organization | Variable | Lead (Pb) | Zinc (Zn) | Copper ( Cu | 0.0001 |
|---|---|---|---|---|---|
| WHO | Drinking water | 0.01 | 3 | 2 | 0.0001 |
| KEBS | Drinking water | 0.05 | 5 | 1 | 0.1785 |

**Table 2:** The limits of selected heavy metals in drinking water as recommended by WHO and KEBS

**Lead (Pb)**

Table 1 displays the average lead concentrations at the three sampling sites, with values of 0.115 ± 0.01 mg/L at S1, 0.082 ± 0.01 mg/L at S2, and 0.054 ± 0.01 mg/L at S3. Variations among these points were evident, particularly the elevated levels at S1, which likely resulted from runoff carrying lead washed off galvanized roofs and steel structures into the soil (Aroka *et al.*, (2010).), as well as contributions from corroding pipelines and nearby industrial discharges. A pronounced uptick in January coincided with reduced influent flow, which diminished treatment efficiency and allowed higher lead retention. By S2, mean concentrations declined due to the plant's use of filtration technologies such as activated carbon and membrane systems and the adsorption of lead onto sludge that is subsequently removed (Katsou *et al.*, 2011).

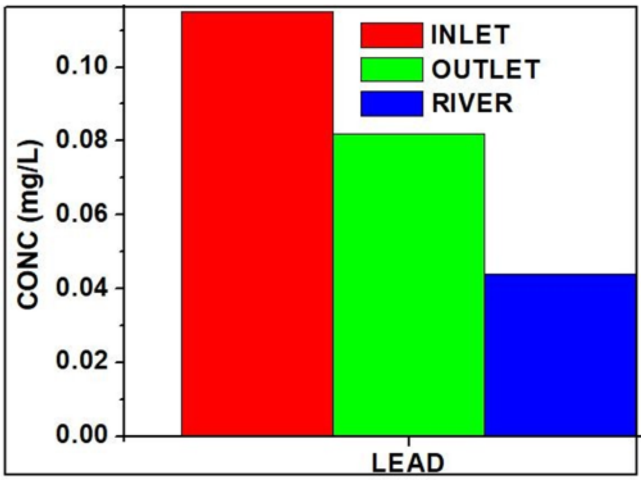


**Figure 3:** Mean value for lead during the study period (2023)

Combined chemical, physical, and biological processes, including coagulation and sedimentation, further stripped dissolved and particulate-bound lead from the wastewater. These findings corroborate *Chen et al.*, (2023), who observed 60–75% reductions in lead through similar multi-stage treatment, and mirror Otieno *et al.* (2022), who reported drops from 2.0 mg/L in influent to 0.3 mg/L in effluent. Despite these decreases, S3 concentrations still exceeded WHO (0.01 mg/L) and KEBS (0.05 mg/L) limits (Table 2), indicating that Karie River water remains unsuitable for domestic use. Extending retention times in both sedimentation and biological reactors can enhance heavy-metal removal by increasing precipitation and microbial adsorption (Zhang *et al.* 2011), and, as demonstrated by Feng *et al.* (2013), coupling primary settling, activated-sludge treatment, and tertiary coagulation can achieve over 90% lead removal.

**Zinc (Zn)**

Table 1 reports mean zinc values of 0.278 ± 0.01 mg/L at S1, 0.168 ± 0.01 mg/L at S2 and 0.079 ± 0.01 mg/L at S3, with a p value of 0.0001 indicating highly significant differences across sites. The peak measurement at S1 can be traced to direct input of effluent from metal processing industries and seasonal runoff washing zinc off roads, roofs and other surfaces. At S2 the amount declines when lime or sodium hydroxide is added to raise the $P^H$. Under these conditions zinc ions convert into insoluble zinc hydroxide, which settles out in the clarifier. In addition, bacteria and algae assimilate residual zinc into their cells; when the biomass is removed as sludge, the bound metal leaves the system. Downstream at S3, the treated flow merges with water from the Karie River, diluting the remaining zinc to 0.079 mg/L. Table 2 confirms that all results fall well below the 3 mg/L limit set by WHO and the 5 mg/L limit set by KEBS for safe drinking water. Overall, the plant removes roughly 71.6 percent of the zinc load between inlet and final discharge. This performance demonstrates that the succession of chemical precipitation, biological uptake and natural dilution achieves compliance with both national and global water quality standards.

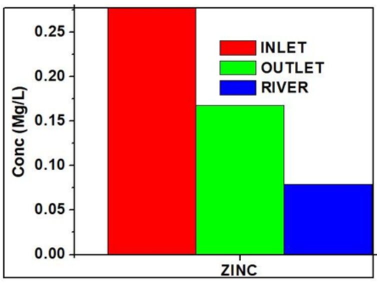


**Figure 4:** Mean value for zinc during the study period (2023)

These findings are aligned with the research conducted by Wang *et al.*, (2014), which indicated a notable decrease in copper concentrations in effluent relative to influent, achieving an average removal efficiency of 75-80%. Their study examined the effectiveness of removing different metals, including zinc, in municipal wastewater treatment facilities.

**Copper (Cu)**

Table 1 indicates that copper concentrations are greatest at S1 and fall at S2, a pattern driven largely by precipitation in the treatment ponds as shown n figure 5. When agents such as lime or other coagulants are added, dissolved copper converts into an insoluble form that settles out during clarification. At the same time, activated sludge plays a key role in removing copper: microbial flocs bind and take up copper ions, which are then discarded with the settled biomass. Within the ponds, copper also reacts with other wastewater constituents to form complexes that exit the system through sedimentation or filtration. These observations mirror those of Ali *et al.*, (2018), who reported that the Bandar Abbas plant reduced influent copper levels by 40.5–71.1 percent through a combination of physical settling and biological uptake.

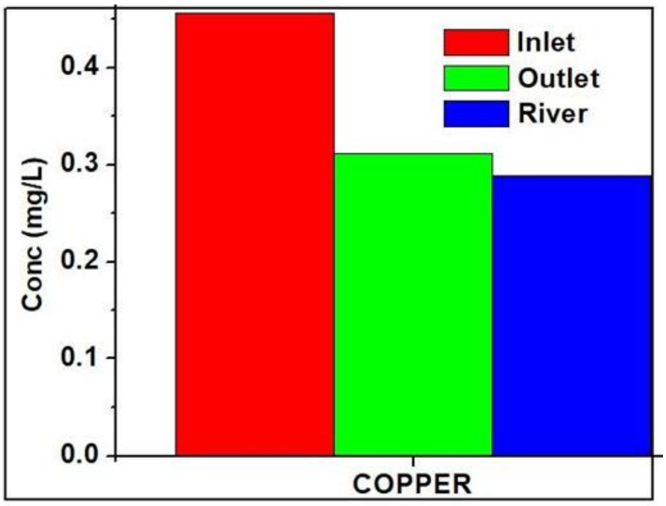


**Figure 5:** Mean value for lead during the study period (2023)

At S2, mean copper still measures 0.311 mg/L, exceeding the Kenyan standard of 0.1 mg/L, likely due to high influent loads, gaps in process performance, or episodic inputs from urban and agricultural sources particularly runoff carrying copper-based pesticides. Further downstream at S3, inflow from the Karie River dilutes the treated effluent, lowering copper concentrations. Table 2 shows that all sites comply with the WHO limit of 2 mg/L and the KEBS threshold of 1 mg/L, confirming that, despite some exceedances midstream, the overall system meets both national and international drinking-water guidelines.

**Bacteriological Analysis**

The bacteriological analysis parameters in the study period were analyzed for (Total and fecal coliform) before and after treatment at Karie wastewater treatment plants as shown in Table 2.

| Parameter | S1 | S2 | S3 | p value |
|---|---|---|---|---|
| Total coliforms | $2.36\times 10^7$ cfu/100 ml | $1.53\times 10^6$ cfu/100 ml | $6.3\times 10^4$ cfu/100 ml | 0.0001 |
| Fecal coliform | $0.81\times 10^7$ cfu/100 ml | $5.35\times 10^5$ cfu/100 ml | $3.5\times 10^4$ cfu/100 ml | 0.0001 |

**Table 3.** The mean values coliforms in all the sampling sites during the period of study.

| Variable | WHO | KEBS | P value |
|---|---|---|---|
| Total coliform | 0/100 ml | 0/100 ml | 0.0001 |
| Fecal coliform | 10/100 ml | 10/100 ml | 0.0001 |

**Table 4** The statistical analysis of Karie Treatment Plant as compared to WHO/KEBS

**Total Coliform**

At S1 the highest counts of total coliforms were recorded, reflecting the immediate influx of untreated domestic sewage, industrial discharges and surface runoff contaminated with human and animal waste. Table 3 illustrates a substantial reduction in bacterial loads as the wastewater passes through the treatment stages; this decline is largely due to the plant's extended hydraulic retention time, which allows physical settling, biological consumption and natural die-off of microorganisms. A landmark study of twelve European plants in 1999–2000 found that systems incorporating longer contact periods such as activated-sludge units with nitrification and denitrification steps, and lagooning basins achieved the greatest drop in faecal coliforms, underscoring the value of prolonged treatment sequences.

By S2 the concentration has fallen significantly, yet remains above both WHO and KEBS limits (Table 4), leaving the effluent unsafe for direct consumption. This lingering exceedance can be blamed on episodic surges in organic load, reduced retention during heavy rains that overwhelm the system, and potential shortfalls in aeration or sludge-handling that hinder complete inactivation. Downstream at S3, further attenuation occurs through additional settling, solar inactivation and dilution with Karie River inflows, bringing counts closer to but not always within regulatory thresholds. Comparable lagoon-based schemes in Tanzania (Morogoro, Mwanza and Iringa) recorded influent faecal loads between $7.95 \times 10^7$ and $3.12 \times 10^8$ cfu/100 mL and achieved 1.99 to 3.81 log-unit removals, demonstrating how design parameters and operational conditions directly shape microbial removal efficiencies. Continuous optimization—such as adding a disinfection step or improving sludge management would be needed to guarantee compliance under all seasonal and loading scenario

**Fecal Coliforms**

Table 3 shows a marked drop in average fecal coliform counts, largely due to the settling of solids during sedimentation. In these tanks, heavier particles sink to the bottom, carrying attached bacteria with them and thus lowering the total microbial burden. Very light pathogens, such as certain bacteria and viruses, may remain suspended unless they clump together with larger matter. To improve removal, coagulants like ferric chloride or alum are added in the primary stage. These chemicals neutralize particle charges and cause fine solids to form larger aggregates that settle more readily. As a result, flocs laden with coliforms and other pathogens are removed in the clarifier. A study by Akrong *et al.*, (2024) in Ghana reported a 98.4 percent log reduction in microbes in waste stabilization ponds. Aziz *et al.*, (2013) reached similar conclusions in landfill leachate treatment, where coagulation and flocculation effectively stripped out suspended solids, color and organic load, implying strong pathogen removal.

Despite these gains, fecal coliform levels at S2 remain above the Kenya Bureau of Standards zero-coliform limit for drinking water. This persistence suggests weaknesses in the disinfection step. If chlorine dosing is too low or contact time too short, some bacteria survive and exit with the effluent. Mechanical faults such as clogged filters, malfunctioning clarifiers or poor sludge management can further compromise removal. Heavy rainfall or sudden industrial inflows can overwhelm the biological reactors, reducing their capacity to break down organic matter and inactivate pathogens. Seasonal swings in temperature also influence microbial die-off and can strain system performance.

## IV. Conclusion And Recommendation

The treatment train at Karie WWTP demonstrated strong efficacy in removing most targeted heavy metals. Lead concentrations fell from 0.115 mg/L at the inlet (S1) to 0.054 mg/L after biological treatment (S3), a reduction of roughly 53%, though final levels still exceed both WHO (0.01 mg/L) and KEBS (0.05 mg/L) drinking-water limits. Zinc removal was more pronounced—dropping from 0.278 mg/L at S1 to 0.079 mg/L at S3—a 71.6% decrease, with all stages remaining well below WHO's 3 mg/L and KEBS's 5 mg/L thresholds. Copper showed moderate decline through precipitation and activated-sludge uptake, with influent levels (0.456 mg/L) reduced to 0.288 mg/L by S3; although the mid-stage value at S2 (0.311 mg/L) exceeded KEBS's 0.1 mg/L limit, the final effluent complied with both KEBS (1 mg/L) and WHO (2 mg/L) guidelines. Chemical precipitation, biological adsorption, and river dilution collectively delivered substantial metal removal, confirming the plant's capacity to meet most national and international water-quality standards for zinc and copper. Microbial indicator removal was substantial but incomplete. Total and fecal coliforms dropped markedly from S1 through S2 under extended retention, sedimentation, coagulation, and activated-sludge processes; however, counts at S2 remained above WHO and KEBS zero-coliform requirements, indicating that chlorination and filtration stages did not achieve full inactivation under current operational conditions. Further downstream at S3, additional natural attenuation and dilution with Karie River inflows brought levels closer to but not consistently within regulatory limits. While the system effectively reduces microbial loads by over 98% in log terms, the persistence of detectable coliforms in the final effluent highlights a need for optimized disinfection contact times and enhanced hydraulic control to fully align with potable-water criteria.

To fully align the Karie WWTP's effluent quality with WHO and KEBS standards, enhancements to both disinfection and post-treatment polishing are warranted. Boosting the chlorine dosage and extending contact time or supplementing with ultraviolet disinfection would more reliably inactivate residual coliforms, while fine-tuning flow distribution and hydraulic retention, especially during wet-season surges, would prevent short-circuiting and ensure each treatment stage operates at design capacity. Introducing a tertiary polishing unit, such as sand filtration or activated-carbon adsorption, would capture trace metals and any remaining microbial particles before discharge. Finally, improving sludge withdrawal frequency and handling protocols would minimize the risk of re-entraining adsorbed heavy metals and biomass back into the treated water, thereby reinforcing the plant's overall capacity to deliver safe, compliant effluent.

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