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Physical-Chemical Water Quality Asessment of Rivers within the Athi River Basin Area, Kenya

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Abstract

One of the main issues affecting Kenya's management of its water resources is pollution. In this study, selected physical-chemical characteristics were used to evaluate the river water quality in the Athi Basin area. Standard techniques for examining water and wastewater were used to examine the parameters. The pH (6.4 to 8.5) was generally in compliance with portable water regulations, despite the temperature varying between 20.4℃ and 27.8℃. The electrical conductivity (EC) ranged from 70 µS/cm to 1750 µS/cm while total dissolved solids (TDS) recorded concentration ranging from 43 mg/L to 1085 mg/L. Total suspended solids (TSS, 10 - 233 mg/L), Biochemical oxygen demand (BOD, 1 - 600 mg/L) and chemical oxygen demand (COD, 13-1000 mg/L) wide range of concentrations was observed. Other factors that are assessed are sulphide (<1-6 mg/L), nitrate (ND - 36 mg/L), orthophosphate (7 -18 mg/L) and Ammonia (0.31-52 mg/L). The greatest concentration values were found at sampling locations in informal settlements, indicating direct residential wastewater flow into river systems. The results also suggest that the basin may have been contaminated by industrial and agricultural operations. Some physical-chemical characteristics, such as BOD and COD concentrations, in effluent samples that the wastewater treatment facilities released into the rivers were greater than the KEBS and WHO permissible thresholds, suggesting that they were unfit for domestic consumption, especially drinking. Therefore, more effort should be made by the concerned government departments and organizations to solve the problems with pollution in the basin.

Keywords: Physical-Chemical, Surface Water, Athi Basin, Wastewater, Pollution, Water Quality

INTRODUCTION

Human health, survival, and economic growth all depend on water. However, freshwater makes up less than 1% of the world's water (du Plessis, 2017). The distribution of freshwater throughout time and space is disproportionate. As a result, many areas across the world are considered to be water deficient. Kenya is categorized as a country with a water shortage since it only has 570 m^3 of fresh water available per person annually (Ministry of Water and Irrigation, 2008). In the Arid and Semi-Arid Lands (ASALs), where the shortage is worse, women and children are put under stress as they travel great distances in search of water, particularly for household use (Mulwa et al., 2021).

Pollution, a key obstacle to sustainable water usage globally, greatly exacerbates the global water shortage. It poses a serious threat to the 2030 goal of providing everyone with fair access to clean and cheap drinking water (Sustainable Development Goals, SDG, 6.1). Particularly in underdeveloped nations like Kenya, where inadequate water pollution regulatory agencies, legal frameworks, and enforcements exist, this is particularly severe (WHO/UNICEF, 2021). Rapid urbanization, inadequate sanitation, industrialization, deforestation, and subpar farming methods have all contributed to this.

Physical, chemical, and biological contamination are the three basic types of water pollution that may be characterized. Chemical pollution includes both organic and inorganic chemical contaminants that degrade the chemical quality of water, as opposed to physical water pollution, which predominantly affects the physical features of water (such as turbidity). On the other hand, biological pollution refers to the contamination of water mostly by bacteria and other microbes. Pollution affects the environment, the economy, and the health. For instance, pollution may cause changes to natural cycles (such as the nitrogen cycle), a decline in biodiversity and fish stocks, algal blooms, an increase in the frequency of water borne illnesses like cancer, and food insecurity (Agency, 2020; Data Stream, 2021; Denchak, 2018; Evans et al., 2018; Vallero, 2011, 2019; Venkatesharaju et al., 1970).

Numerous physical-chemical (such as turbidity, pH, electrical conductivity, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), nutrients, heavy metals, and pesticides), as well as bacterial (such as total coliforms and *E. coli*) parameters have been used as water quality indicators globally (Gorde & Jadhav, 2013; Kanase et al., 2016; Renu Nayar, 2020). These factors are crucial in determining the water resources' quality and the hazards of contamination to which they could be subjected (Alam et al., 2007; Bekele et al., 2018; Braga et al., 2022; García-Ávila et al., 2022).

Kenya's government has started a number of initiatives to increase water supply in response to the country's increased water demand. It has started work on a multifunctional dam in Thwake, for instance, to supply water for home use, agricultural, and power production in the lower Eastern area. Due to the alleged contamination of the Athi River, which would supply the majority of the water for the dam, stakeholders are very concerned about the project's viability and sustainability. For instance, BOD levels up to 540 mg/L were observed by Dulo (2008) in Nairobi River, an Athi River tributary, which is an order of magnitude beyond the maximum allowed limit for effluent released into the environment. the identical river. Up to 730 mg/L of COD and 600 µS/cm of electrical conductivity, respectively, were measured by Mbui et al. (2016). However, the research that are now accessible are primarily restricted to a few little tributaries of the Athi River. As a result, the primary goal of this study was to determine the degree of contamination in the Athi River and its major tributaries by examining a few physical-chemical water quality indicators.

MATERIALS AND METHODS

Study Area and Sampling Locations

The Athi River basin served as the study's location (Figure 1). It is the second-longest river in Kenya, flowing from Nairobi to the Indian Ocean via the counties of Machakos, Kibwezi, Taita Taveta, Kilifi, and Mombasa. It is located between Latitudes 1° to 4.5° South and Longitudes 37° to 40° East, with an estimated size of 66,559 km^2.

The middle and lower levels of the basin are typically dry and semi-arid with low population density, compared to the upper regions, which are heavily urbanized and get consistent rainfall.

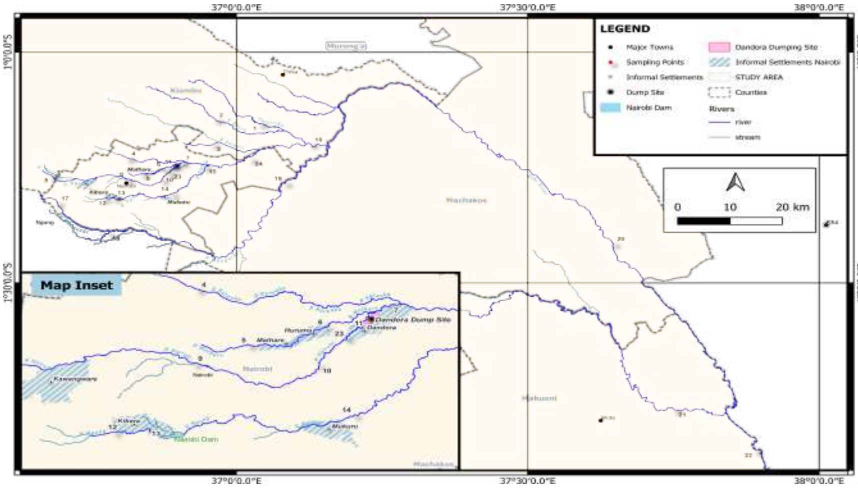

Figure 10: Sampling points in rivers within the Athi basin area.

Upstream of the Athi River, the Ondiri Swamp and Kikuyu springs serve as crucial groundwater recharge locations for the Nairobi suite aquifer. The basin experiences modest groundwater recharge rates of 296 million cubic meters per year and average annual rainfall of 739 mm (Nyingi et al., 2013).

In the Athi River and its tributaries, 22 sample locations were carefully chosen based on their potential for pollution, accessibility, and use. Nairobi River (5), Ngong River (4), Mathare River (3), Mbagathi River (3), Athi River (2), Kamiti River (1), Little Kiboko (1), Ruirwaka (1), Thiririka River (1), and Ruiru River were among the sample locations (1).

The wastewater treatment plants (WWTP) at Ruai and Kariobangi, which drain into the basin, were included in the effluent. Before the Nairobi River and Mathare River converge, the Kariobangi WWTP releases its wastewater into the former using trickling filter technology. Just after the junction of the Ngong and Nairobi rivers, the Ruai WWTP releases its effluent into the Nairobi River using wastewater stabilization pond technology.

Sampling, Sample Treatment and Analysis

At each of the test locations, water was collected in triplicate into 2-liter plastic bottles that had already been sanitized. In order to prevent the introduction of small floating debris and other contaminants while accounting for river mixing, the samples were taken at least 30 cm beneath the water's surface. The open mouth of the bottles used to collect the samples was pointing upstream of the direction the water was flowing. At total 48 samples in all sampling stations were gathered throughout the research period.

The samples were taken in an Ice-cool box on the same day to the Water Resources Authority's Central Water Testing Laboratory. The samples were kept chilled at 4°C in the lab while they underwent analysis. Using a potable multiparameter water quality kit, in-situ measurements of pH, temperature, total dissolved solid (TDS), and electrical conductivity were taken (EUTECH instruments PC 650, Singapore).

Based on the Standard Methods for the Examination of Water and Wastewater developed by the American Public Health Association (APHA), American Water Works, and Water Environment Federation, the following TDS, TSS, BOD, COD, sulphides, Ammonia, Nitrates, and orthophosphates physical-chemical parameters were analyzed. Brandi & Wilson-Wilde (2013); Federation (2012); APHA, 2017; These include total suspended solids (TSS dried at 103°C-105°C, APHA 4500-NH3), ammonia selective electrode method (APHA 4500-NO3), nitrates (ultraviolet-visible spectrometric screening method, APHA 4500-NH3), orthophosphates (Ascorbic acid method, APHA 4500-P), sulfide (iodometric method, APHA 4500-P (Closed reflux-titrimetric method, APHA 5220-C).

Statistical Analysis
The measures' average, mean, standard deviations, minimum and maximum were computed using a Microsoft Excel spreadsheet. Statistical Package for the Social Sciences (SPSS) Software, version 26, from International Business Machine (IBM), on the other hand, was used to construct boxplots and bar graphs for the graphical representation of the data.

RESULTS AND DISCUSSION

Physical Parameters

Temperature

Overall, the temperature ranged between 20.4°C and 27.8°C (Figure 2), with an average of 24.6±2.37°C (Median 25.3°C). The prevailing weather, turbulence, river bank plant cover, thermal discharges, and the time of sampling all have an impact on the temperature of river water. For instance, locations sampled before midday (e.g., Nairobi River at Kikuyu) had the lowest temperatures, while sites sampled in the late afternoon, when the ambient temperature was at its greatest (e.g. Athi River at Wamunyu), had the highest temperatures. The obtained results imply that natural processes, as opposed to thermal effluent discharges, have a greater impact on river water temperature. Additionally, the temperature of the effluent from the WWTPs was within the same range (26.3±0.2°C,). The stability of temperature is crucial because it affects chemical processes, aquatic life, the concentration of dissolved gases, and the toxicity of certain pollutants. For instance, high water temperatures may result in decreased dissolved oxygen availability, the demise of aquatic species, and an increase in algal bloom when nutrients are present (Pitot, 2021).

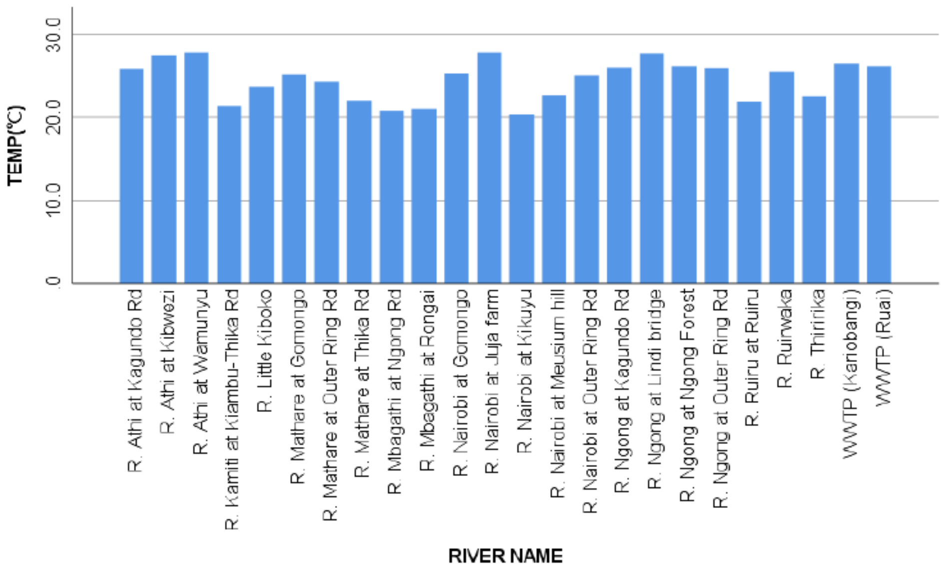

Figure 2: River temperatures in the Athi River Basin and the temperatures at the wastewater treatment facilities (Kariobangi and Ruai).

Electrical Conductivity

The measured conductivity varied from 70 µS/cm to 1750 µS/cm (mean 556±376 µS/cm, median 520 µS/cm) in the rivers and 930 µS/cm - 1110 µS/cm (mean 1020±104 µS/cm) in effluent (Figure 3). Electrical Conductivity recorded in rivers in this study were in compliance the EAS acceptable limits of ≤2500 µS/cm for natural portable water (Table 3). Notably, the Ngong River's Outering Road (1040 µS/cm), Little Kiboko River (1750 µS/cm), and effluent (1110 µS/cm) had the greatest conductivity readings. The industrial effluent discharges from the industrial region through which the Ngong River flows prior to the test location may be the cause of the high conductivity in the river. Little Kiboko River, on the other hand, is primarily spring water (groundwater), which has a greater salt percentage. Athi River had a conductivity of 805 µS/cm, which was within the range found in this study according to Sila (2019).

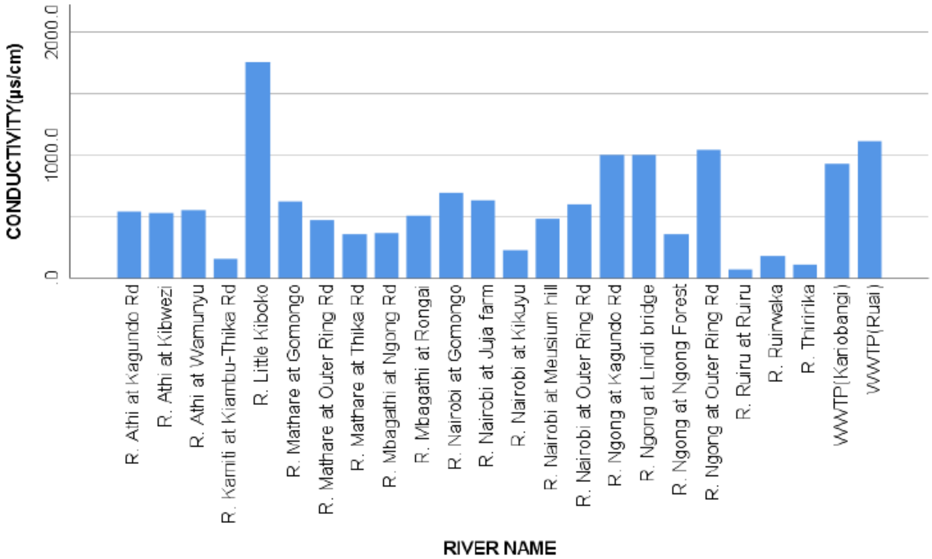

Figure 3: Rivers in the Athi River Basin and wastewater treatment facilities electrical conductivity (Kariobangi and Ruai).

Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

The TDS, which has a direct relationship with conductivity showed similar pattern. It ranged from 43 mg/L – 1085 mg/L (Figure 4) with a mean of 345±233 mg/L and median of 322 mg/L in river samples and 576 mg/L – 588 mg/L in effluent (Table 1). TDS recorded in rivers in this study were in compliance the East African Standards (EAS) acceptable limits of ≤1500 mg/L for natural portable water (Table 3). On the other hand, the TSS varied from 10 to 233 mg/L, (mean of 66 mg/L, median of 45 mg/L, Table 1,) and 20 to 60 mg/L in the river and effluent, respectively (Figure 4). These TSS concentrations recorded in rivers in this study were above the EAS acceptable limits of Nil for natural portable water (Table 3). High TSS concentrations were primarily seen at sites near informal settlements, which is indicative of the effects of solid waste disposal there. Additionally, some of the data might be explained by the river bank erosion that was seen during sampling at several of the sample locations (such as the Nairobi River near Kikuyu). Notably, high TSS concentration was also found at locations where farming is done on riparian land, such as Nairobi R. at Kikuyu and Juja Agricultural, which is an indicator of farm erosion. The Nairobi River has much higher TSS concentrations, according to Mbui et al. (2016). For aquatic life, too much floating silt might be harmful. For instance, the build-up of suspended particles increases the riverbed, making it harder to navigate and raising the danger of flooding. Similar to this, it hinders phytoplankton photosynthesis by light blockage, lowering phytoplankton density, growth rates, and productivity, which has an impact on fish stock.

Table 1: **Analysis of the physical-chemical characteristics of rivers within the Athi river basin area using a Microsoft Excel spreadsheet**

Parameter	Minimum	Maximum	Range	Mean	Median	Standard deviation
pH	6.4	8.5	6.4 – 8.5	7.32	7.35	0.48
Temperature (°C)	20.4	27.8	20.4 - 27.8	24.6	25.3	2.37
E.C (µS/cm)	70	1750	70 - 1750	595	535	384
Ammonia (mg/L)	0.31	52	0.31 - 52	14.8	4.1	17.88
Nitrates (mg/L)	ND	36	ND - 36	8.3	1.95	12.26
Sulphides (mg/L)	<1	6	<1 - 6	5.2	5.4	0.64
Orthophosphates(mg/L)	7	18	7 - 18	11	11	3.13
BOD (mgO_2/L)	1	600	1 - 600	100	20	142
COD (mgO_2/L	13	1000	13 - 1000	230	80	277
TDS (mg/L)	43	1085	43 - 1085	369	332	238
TSS (mg/L)	10	233	10 - 233	66	45	55

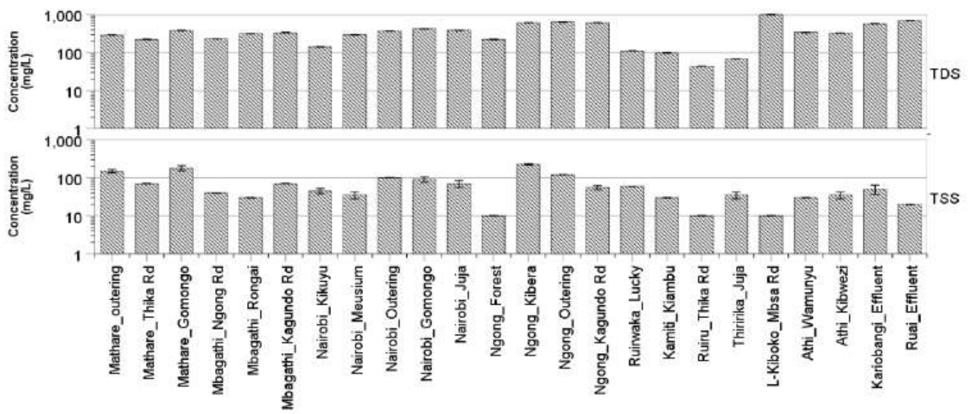

Figure 4: TDS and TSS concentrations in specific rivers in the Athi River basin, as well as wastewater treatment facilities (Kariobangi and Ruai).

Chemical Parameters

pH

The pH values obtained in this study ranged from 6.4 to 8.5, with a mean and median of 7.32±0.48 and 7.35±0.48, respectively (Figure 5). Ruirwaka River recorded the lowest pH of 6.4 with Athi River at Kibwezi recording the highest (pH 8.5). In addition to pollution, the high pH at the Kibwezi station of the Athi River may be caused by the algae's photosynthetic activity, which was seen during sampling. According to Dirisu et al. (2016) pollution by effluents discharged into rivers may interfere with its pH. Comparatively, Dulo (2008) and Sila (2019) reported pH 6.85 - 7.14 in Nairobi River and pH of 7.31±0.14 at Athi River, which are contained in this study's findings. The natural pH of water is 7. In general, any pollutants that interact with a water supply—chemicals, minerals, soil or bedrock composition, etc. will cause an imbalance in the pH. For instance, if the soil or bedrock of the river contains chemicals like carbonate, bicarbonate, or hydroxide, they dissolve and move with the water, changing the pH (Safe Drinking Water Foundation, 2017).

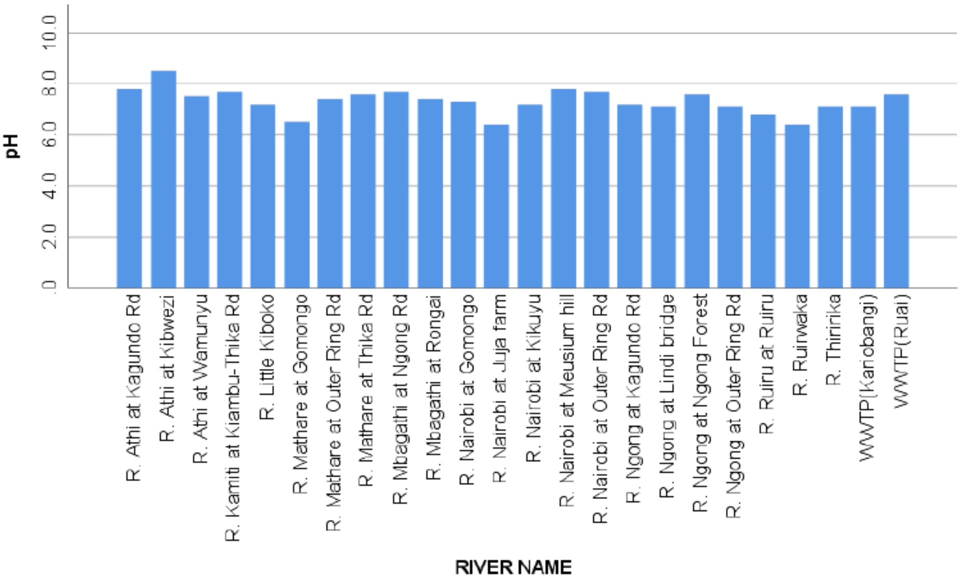

Figure 5: pH levels of selected rivers and wastewater treatment facilities located in the Athi River basin.

BOD, COD and Sulphides

The concentration BOD (1 – 600 mg/L) and COD (13 – 1000 mg/L), varied considerably across the sampling sites (Figure 6). Rivers that pass through informal settlements, such the Ngong River, Mathare River, and Nairobi River, were found to have higher amounts. For instance, the location at the center of the informal community of Kibera, Ngong River, recorded the highest BOD content. Domestic wastewater is dumped straight into the waterways in the informal settlements because of their inadequate sanitary infrastructure. Additionally, pit latrines are built in riparian zones where they mostly discharge into rivers, for example, Ngong River at Lindi bridge in Kibera. Additionally, waterways in such places frequently receive sewage spills from clogged or damaged sewer systems for example, Ngong River at Lindi bridge in Kibera, Nairobi River at Outering road and Mathare River at Thika road. As was predicted, the concentrations were lowest at sites upstream, demonstrating the serious harm that informal settlements do to urban water supplies. Notably, compared to numerous locations upstream, the final two sample sites (Athi River at Wamunyu and Kibwezi) observed reduced BOD and COD content. This is as a result of the stretch's reduced pollution load intake and natural river self-epuration. BOD of up to 150 mgO_2/L and COD of up to 200 mgO_2/L were observed for effluent samples, respectively. The effluent emitted into the environment exceeded the WASREB and NEMA permissible limits of 30 mgO_2/L for BOD and 50 mgO_2/L for COD, respectively (Table 2) as a result of the results. The results are in the same order of magnitude as those found in the Nairobi sub-basin reported by K'oreje et al. (2016) (BOD 10 - 513 mg/L and COD 30 - 1278 mg/L).

Sulphide on the other hand was recorded in the range of <1 mg/L to 6.0 mg/L with an overall mean and median of 5.64 mg/L and 5.4±0.64 mg/L, respectively (Table 1). Most downstream rivers (Athi River at Wamunyu, Athi River at Kibwezi-Kitui road and Little Kiboko River) and all Effluent treatment plant recorded lowest concentration of <1 mg/L which was in compliance with WASREB and NEMA tolerable limits for discharge into public water of 0.1 mg/L (Table 2). Rivers located along outering road (Ngong River, Nairobi River and Mathare

River) recorded concentrations between 4 mg/L and 6 mg/L (Figure 6) due to pollution by organic matter. e.g., rotting plant matter and unprocessed household garbage. When sulfur-reducing bacteria are present, they chemically convert the naturally occurring sulfates in water to hydrogen sulfide, which can be introduced into surface water. Additionally, the content of sulfide in these rivers may be increased by industrial effluent discharges coming from the industrial region through which the rivers pass before to the indicated sample sites.

Table 2: Physical-chemical criteria for discharge into public water: WASREB and NEMA norms

System parameter	Unit	Guideline value
pH		6.5 – 8.5
Electrical conductivity	µS/cm	2500
Ammonia	mg/L	100
Nitrates	mg/L	100
TDS	mg/L	1200
TSS	mg/L	30
BOD (5 days at 20°C) max	mgO_2/L	30
COD, max	mgO_2/L	50
Temperature	°C	±3 of ambient water body temperature
Sulphides	mg/L	0.1

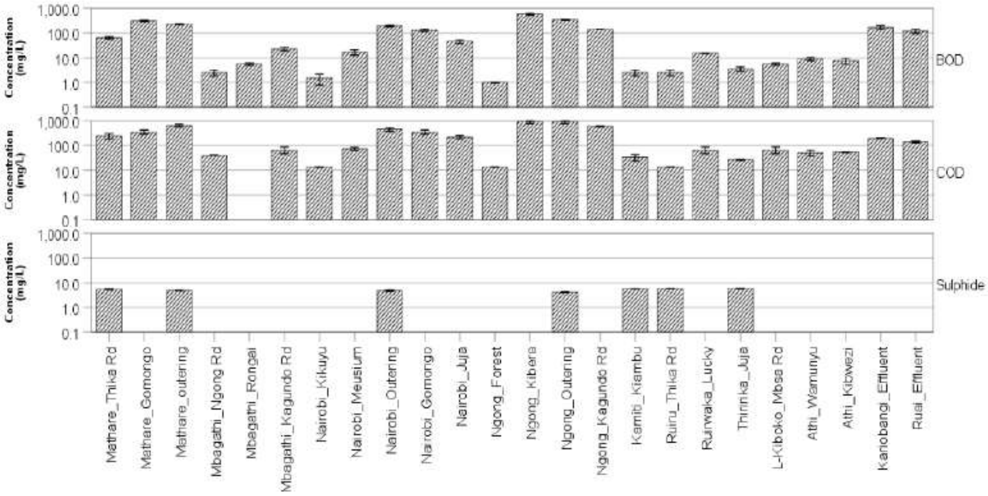

Figure 6: BOD, COD, and sulfide concentrations in rivers and wastewater treatment facilities (Kariobangi and Ruai) in the Athi River basin.

Nutrients

Figure 7 shows the measured concentration of nutrients (orthophosphates, nitrates and ammonia) in the study area. The orthophosphate concentration ranged from 7 mg/L to 18 mg/L with an overall mean of 11±3.13 mg/L (Table 1). Thiririka River recorded lowest concentration of 7 mg/L. On the other hand, Ruai WWTP recorded the highest concentration of 18 mg/L. This shows that domestic wastewater discharges and contamination from agricultural operations (such fertilizers) (Know your H_2O, 2020). Comparatively, Chebet et al. (2020) reported phosphates concentration levels ranging from 0.13 mg/L – 11.06 mg/L in Molo River. Since the Molo River is less polluted by effluent than the Athi basin, these quantities are lower than those found in this research. The excessive use of fertilizers in the farms near these rivers (such as subsistence farming near the Nairobi River at Kikuyu and extensive farming near the Nairobi River at Juja farm) may potentially be a source of phosphates, as may also be manmade sources like the makeup of the bedrock.

Nitrate concentration ranged between ND and 36 mg/L (Figure 7). This concentration range recorded in rivers in this study were in line with the East African Standards (EAS) acceptable limits of 45 mg/L for natural portable water (Table 3). It was not-detected at Nairobi River at Juja Farm, Athi River at Kangundo Road, Mathare River at Ngomongo and Kariobangi WWTP. Because of denitrification processes, nitrate readings obtained in the aforementioned areas of the watershed may not have been detected due to nitrate removal activities (Nyilitya et al., 2020). The greatest quantity was found in the Mbagathi River at Ngong Road, which was 36 mg/L. This might be because ammonia is produced naturally by processes like the breakdown of organic waste, gas exchange with the atmosphere, and nitrogen fixation.

Ammonia was measured at concentration ranging from 0.31 mg/L (Thiririka River) to 52 mg/L (Mathare River at Gomongo), (Figure 7). With this highest ammonia concentration at Mathare River at Gomongo was high above East African Standards (EAS) acceptable limits of 0.5 mg/L for natural portable water (Table 3). However, Irungu (2018) reported lower range of nitrate (0.4 mg/L -10 mg/L) and ammonia (0.1 mg/L – 2 mg/L) in River Sondu, This, despite extensive agricultural activity along the Sondu River, can be ascribed to limited pollution input. This may be owing to the fact that only a tiny fraction of fertilizers applied may leak into groundwater and surface waters, but a big portion of them end up in the soil's organic nitrogen pool, where nitrogen is metabolized, taken up by plants, and/or lost by leaching over a long period of time (Bijay-Singh & Craswell, 2021).

Ammonia is frequently produced by bacteria when organic debris that collects in water is broken down. Microbiota either mineralize organic nitrogen or, less frequently, use dissimilatory nitrate reduction to create ammonia. Because nitrification prevents the oxidation of ammonia to nitrite [NO_2^-] and nitrate [NO_3^-]), ammonia is particularly common in surface water. Benthic or surface water biota may be poisoned by ammonia produced in surface water (Lapota et al., 2000; United States Environmental Protection Agency, 2022).

Table 3: EAS (East African Standards) physical-chemical parameter specifications for portable, natural water

System parameter	Unit	Guideline value
pH		5.5 – 8.5
Electrical conductivity	µS/cm	2500
Ammonia	mg/L	0.5
Nitrates	mg/L	45
TDS	mg/L	1500
TSS	mg/L	Nil

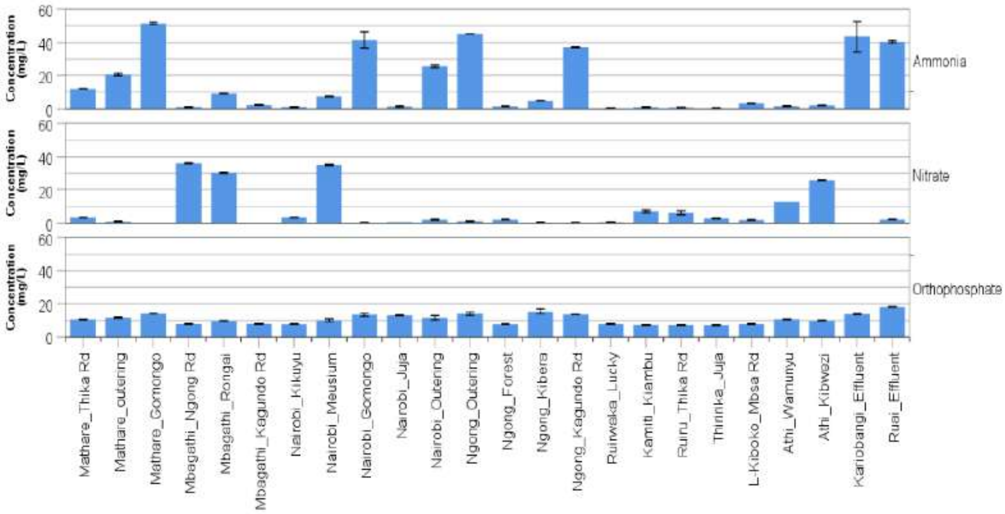

Figure 7: Nutrient concentration in selected rivers and the two wastewater treatment facilities (Kariobangi and Ruai) within the Athi river basin.

CONCLUSION

The goal of this study was accomplished, and data analysis findings revealed that several of the water sources under investigation have significant degrees of contamination based on their physical-chemical characteristics. This is mostly caused by the injection of raw sewage, which has high concentrations of BOD and COD, into the water systems, poor sanitation in informal settlements (like the Kibera slums), and subpar farming practices near these surface water sources. As a result, without any kind of treatment, the majority of rivers within the Athi River basin area's water is unsafe for drinking. To prevent water contamination, local governments, the federal government, and other water stakeholders must develop effective pollution control measures. This will make it possible for the population that depends on this surface water supply to have access to at least clean, healthy water that is sufficient for their daily household activities. However, there is also need for both home and industrial wastewater effluents to be properly treated before being released into surface water bodies.

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