**WATER QUALITY, POLLUTION AND MANAGEMENT OF KUURU RIVER, MERU COUNTY, KENYA**

**ABSTRACT**

Water pollution is a significant concern as it impacts the quality and availability of essential water resources. The Kuuru River, a tributary of the Tana River in Meru County, is vital for drinking water and irrigation. This study evaluated water quality, land use, and environmental conservation in the Kuuru River's riparian zone, from its source to the Kathita River. It also assessed institutional contributions to river conservation under the legislative framework. Turbidity, total dissolved solids (TDS), pH, temperature, electrical conductivity (EC), nitrates, and phosphates from 18 water samples. A descriptive survey using semi-structured questionnaires was administered to 384 household heads to obtain data on land use and environmental conservation practices. Semi-structured questionnaires were also administered to 6 key informants from relevant institutions to gather information on their interventions of the river protection activities. Physicochemical parameters were analysed using one-way ANOVA, and a One Sample t-test was employed to determine whether the values exceeded the permissible standards. The questionnaires were entered into SPSS software for data management, where comparative analysis was used for data analysis. Among the parameters measured TDS (94.4-230mg/L), pH (7.06-8.29), temperature (19.4-20.90C) and Nitrates (0.0045-0.0125mg/L) met the set standards by World Health Organization (WHO), the National Environmental Management Authority (NEMA), and the Kenya Bureau of Standards (KEBS) for drinking water. However, levels of EC (461S/m), turbidity (640NTU) and phosphates(3mg/L) were elevated, indicating presence of pollutants. Anthropogenic activities in Maskani, Kanthiari, Kimachia markets and Meru-Mikinduri highway were identified as the main drivers of pollution. The study highlighted a lack of awareness regarding riparian conservation, linked to inadequate stakeholder involvement and support. It recommends periodic water quality assessments and increased stakeholder engagement for better conservation awareness.

**Keywords:** Water pollution, Water quality, Land use, Environmental conservation, Anthropogenic activities, Stakeholder involvement and Riparian conservation

**INTRODUCTION**

Water is a vital resource, and contamination poses a serious global issue, highlighted by UNSDG Goal 6 on clean water access. (Matta *et al.,* 2022). Poor water quality results from physical changes, human contaminants, and invasive species, negatively impacting the quality of life for users. (Ortigara *et al.,* 2018). According to (Rajapakse *et al.,* 2023), the 2022 report revealed two billion lack safe drinking water, while half the global population faces severe water scarcity annually. Since it's a scarce resource, water needs to be protected to the highest degree as climate change and population growth will worsen water scarcity issues (Lee *et al.,* 2023).

Point sources of pollution are thought to be the cause of 450 billion m3 of effluent entering global water basins annually Haarstrick, A., and Sharma, L. (2024). Over time, researchers and planners have faced challenges due to nonpoint source pollution, which refers to pollutants of various types from numerous sources (Meng *et al.,* 2024). Agricultural practices on freshwater quality in rivers contribute to elevated nutrient levels and sedimentation in river systems. Excessive nutrient runoff, particularly from fertilizers, leads to eutrophication, causing algal blooms and oxygen depletion, detrimental to aquatic ecosystems (Karani E 2024).

There is a significant threat to the decline of ecosystem services due to human impact on aquatic ecosystems. Pollutant monitoring is required to assess its impacts and effects on the quality of river water and to create mitigation plans (Altenburger *et al.,* 2019).

Poor water quality has a direct impact on water quantity in several ways. The amount of usable water in a given area is effectively reduced by polluted water since it cannot be used for drinking, bathing, industry, or agricultural activities (Singh *et al.,* 2020).

Water pollution is an international problem that has worsened in both rich and developing nations, endangering billions of people's physical and environmental health as well as economic progress (Ajibade *et al.,* 2021). The World Health Organization 2016 defines "water quality" as its suitability for specific uses, establishing global standards to ensure safety, especially for drinking water.

Developed countries continue to experience a range of problems related to water quality, including eutrophication, fermentation, natural mixes and residue from sources of agricultural, industrial, and urban waste (Ukhurebor *et al.,* 2024).

In Kenya, the Water Quality Regulations of 2006 gave guidelines for water used for drinking, industrial, agricultural, recreational, fisheries, wildlife, and water used for any other purposes (Kipsang *et al.,* 2024). This is in a bid to protect the increasing population from using contaminated water for any purpose. This came about as a result of water resources in Kenya increasingly becoming contaminated by both point and nonpoint sources (Obiero *et al.,* 2024).

**MATERIALS AND METHODS**

## Study Design

This research study used a combination of quantitative and qualitative data. The first data set used quantitative data from laboratory experiments to measure the amount of physicochemical parameters in water. The second and third data sets used qualitative data from the administration of the questionnaires.

## Quantification of the physicochemical properties of the water of Kuuru River from its source to the Kathita River.

The data set was drawn from taking eighteen water samples from designated sampling locations for laboratory analysis. The analysis of water samples for pollution indicators was sampled from three sampling points at different locations in the three zones.

### Sample collection

Stratified sampling method was used to collected water samples in sets of three from each of the nine designated sampling locations along the Kuuru River. The collection of water samples occurred between 10:00 am and 12:00 pm (Chebet *et al.,* 2020). Within the forest, two samples were taken: one at the source and another downstream after crossing the Meru-Maua road. In the middle zone, samples were obtained behind the Kithangari dispensary, the Kimachia shopping center, along the Meru-Mikinduri highway, and at the Kathangali-Mbeu bridge. Moving to the lower zone, samples were collected on the Mailu Bridge, Kiorimba Bridge, and finally at Kiburine. GPS was used to pinpoint these locations, ensuring consistency in sample collection. In total, 18 water samples were obtained during this phase of sampling. The collected water samples were preserved and transported to the laboratory for analysis according to the methods described in the APHA guidelines for the examination of water and wastewater. The physicochemical parameters subjected to the analysis included turbidity, total dissolved solids (TDS), pH, temperature, electrical conductivity (EC), nitrates, and phosphates.

### Sampling Procedure

Water samples were taken from the middle section of the river channel using one-liter plastic bottles that had been previously cleaned. After that, the materials were examined in a lab to determine their physicochemical properties. During the field sampling process, the collection bottles were carefully rinsed three times with water from the sample site. Subsequently, the bottles were opened and submerged to a depth of 5 cm below the water surface, ensuring no air bubbles were trapped within. The containers were labelled with appropriate codes on site and to keep the water samples cold, they were briefly stored in coolers filled with ice. Before being analyzed, the samples were brought to the lab and kept in a refrigerator at about 4 °C. Sample collection activities were carried out between 10:00 am and 12:00 noon to ensure consistency in the results obtained.

### Determination of physicochemical parameters

The turbidity, temperature, pH, and conductivity measurements were analyzed in the laboratory using a nephelometer and a conductivity meter within four hours of collection. The data obtained from the laboratory analysis were systematically organized in the SPSS software for statistical purposes. The software was used to calculate the mean for each variable (turbidity, temperature, pH, total dissolved solids (TDS), and conductivity). The analysis involved the use of one-way analysis of variance (ANOVA) to assess the data, and for the variable of phosphates, a one-sample t-test was employed to determine whether its values exceeded the established standards

### Determination of Phosphates

A volume of 50 cm³ of the water sample was transferred into a volumetric flask with a capacity of 500 cm³. Subsequently, 5 cm³ of ammonium molybdate solution and 2.0 cm³ of ascorbic acid were added to the flask while gently swirling the mixture according to manufacturers ’specification. The solution was then diluted with deionized water until evaluated using ultraviolet-visible spectrophotometry at a wavelength of 880nm using glass cuvette (Teodorof et al., 2021). The same procedure was repeated for all other water samples. The data obtained were subjected to analysis using one-way ANOVA, and a One Sample t-test was employed to determine whether the phosphate values exceeded the permissible standards.

### Determination of Nitrates

Concentration of nitrates (NO3-) was determined by spectrophotometric screening method according to Edori and Iyama, (2020) the water sample of 10 cm³ was transferred into a volumetric flask with a capacity of 50 cm³. Subsequently, 10 cm³ of 13 N sulfuric acid was added and mixed by gently swirling the flask. The flask was then allowed to reach a thermal equilibrium in a cold-water bath within the temperature range of 0 to 10°C. Thereafter, 0.5 cm³ of brocine-sulfanilic acid was added to the solution, which was then diluted with deionized water up to the mark on the flask. The resulting solution was placed in a hot water bath at a temperature of 100°C for approximately 25 minutes to achieve optimal color development. Afterward, the flask was allowed to cool down to room temperature. The color developed in the solution was assessed using ultraviolet-visible spectrophotometry at a wavelength of 230nm (Silva et al., 2024). This process was repeated for all other water samples.

## Land use and environmental conservation activities

### Sampling design

This study used a descriptive survey design, distributing semi-structured questionnaires to 384 household heads to assess land use changes and conservation practices. The determination of the sample size was based on the application of the formulas by Kalton, G. (2020).

The sample size was derived at from the following equation:

N= (t)2x (s)2/ (d)2

Where t = value for selected alpha level in each tail (the alpha level of .05 which is 1.96)

Where s = estimate of standard deviation in the population which is 0.5

Where d = acceptable margin of error for mean being estimate (.05% acceptable margin of error).

The survey aimed to understand local activities and involvement in managing the Kuuru River. Questions covered household land characteristics, including land size and tenure type (inherited, purchased, rented). At the household level, respondents were identified by gender, family head, age, education level, and household size. Conservation-related questions included knowledge and activities regarding riparian zones, types of planted vegetation, and information sources. The survey also asked about livestock types, grazing methods, water sources, and tree species planted. Finally, it explored motivations for riparian conservation, such as benefits from WRUA membership, training on income-generating activities, and social network opportunities.

## Data analysis

The questionnaires were entered into an Excel sheet, and SPSS software was used to create tables and charts. Content analysis was used to analyse the data. The interpreted data were presented in the form of tables and graphs.

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## Contribution of the institutional framework to the conservation of Kuuru River

### Sampling design

The third data set was drawn from a semi-structured questionnaire administered to six key actors mandated toprotect rivers and on interventions and activities undertaken to protect the river. The institutions that questionnaires were administered include the Water Resources Authority (WRA), the Meru County Government Department of Environment and the Department of Agriculture Livestock Development & Fisheries, the National Environmental & Management Authority (NEMA), Kuuru and Ngakinya Water Resource Users Association (WRUA), and the Upper Tana Natural Resources Management Project (UTaNRMP).

The questionnaire provided broad information on the parameters of the Water Resource User Association by checking the duration that community members have been members of the WRUA, the age of the WRUA members, the level of awareness on conservation of the riparian zones among the members of the WRUA and theinvolvement ofthe WRUA in decision making. The questionnaire was also designed to check the community’s awareness of the laws that govern the conservation of the environment and the source of information on these laws.

Questionnaires were also administered to institutions to check on their role in conserving the Kuuru River riparian area, the stakeholders with whom they work, and the allocation established by the institution forthe conservation of the Kuuru River. The activities the institution has carried out in the conservation of the Kuuru River, the frequency of participation,the participation of the community in decision-making, internal challenges, and the effect of devolution on river conservation.

## Data analysis

Data were entered into the SPSS software for data management, where comparative analysis was used for data analysis. This involved comparing the responses to the questionnaires from various institutions. It was achieved by cross-tabulation of bar and pie charts.

**RESULTS**

## Physicochemical properties of the water of Kuuru River

**Turbidity (NTU)**

Turbidity of the well water samples varied from 20.8 NTU to 640 NTU. Maskani recorded the lowest turbidity of 20.8 NTU while the highest was recorded at Meru mikinduri high of 640 NTU. The river source recorded 24.7 NTU while kiorimba recorded 227 NTU. Results are shown in table 1.

## Total Dissolved Solids (TDS)

Mean total dissolved solids concentrations ranged from 94.4 to 230 mg/L, with the highest values recorded at Maskani and the lowest at Kiorimba (Table 1). At the Kuuru river source it was recorded a TDS of 221 mg/l.

### pH

The mean pH for the entire study area ranged from 7.06 to 8.29 with the highest of 8.29 being recorded at Mailu bridge and the lowest value of 7.06 at the source (Table 1). all the sampling sites recorded a pH of above seven which slightly basic.

### Temperature

The mean temperature for the water samples in the study area ranged from 20.9º C to 19.4º C with Behind Kimachia Mkt recording the highest temperature of 20.9º C and the lowest temperature of 20.4º C recorded at Meru-Mikinduri highway as seen in table 1. another sites recorded temperatures slightly above 200C which is Kiburine recording 20.4°C. while the area behind Kimachia market recorded 20.9°C.

### Electrical conductivity

Mean conductivity of water samples ranged between 188.4 μS/cm and 461 μS/cm with the lowest being recorded at Kiorimba and highest recorded at both the source and Maskani (Table 1).

### Phosphate

The mean Phosphate levels ranged from 1 to 2.8 mg/l. The highest value of 2.8 mg/l was recorded at Kathangali bridge while at the sources recorded the lowest value of 1 mg/l. The results are recorded in table 1.

### Nitrates

The mean concentration of nitrates in the shallow well waters ranged between 0.002 mg/l and 0.0045 mg/ml. They highest level was recorded at Kiburine while the lowest was recorded at both Mailu brigde and Kanthiari of 0.0015 mg/ml. The results are recorded in table 1.

**Table 1: *Physicochemical properties of Kuuru River at different sampling sites and their set standards***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Turbidity (NTU)** | **TDS (mg/L)** | **pH** | **Temperature**  **(℃)** | **Conductivity**  **(µscm-1)** | **Phosphates**  **(mg/L)** | **Nitrates**  **(mg/L)** |
| At Source | 24.7 | 221 | 7.06 | 20 | 461 | 1 | 0.002 |
| Maskani | 20.8 | 230 | 7.83 | 19.6 | 461 | 1.18 | 0.002 |
| Kanthiari | 21.1 | 163 | 7.73 | 19.6 | 326 | 3 | 0.0015 |
| Kimachia Mkt | 635 | 140.6 | 8.03 | 20.9 | 282.3 | 2.5 | 0.0125 |
| Meru/Mikinduri Road | 640 | 136.2 | 8.15 | 19.4 | 272.3 | 2.7 | 0.004 |
| Kathangali bridge | 346 | 117.5 | 7.95 | 19.6 | 234.9 | 2.8 | 0.0035 |
| Mailu bridge | 253 | 130.2 | 8.29 | 19.6 | 260.4 | 3 | 0.0015 |
| Kiorimba | 227 | 94.4 | 8.19 | 19.5 | 188.4 | 0.5 | 0.0025 |
| Kiburine | 204 | 105 | 8.15 | 20.4 | 210 | 1.7 | 0.0045 |
| Mean | 263.51 | 148.66 | 7.93 |  | 299.59 | 1.9422 | 10.886 |
| WHO | 5 | 600-1000 | 6.5-8.5 | 12-25 | 400 | 0.1 | 50 |
| NEMA | 5 | 1200 | 6.5-8.5 | 12-25 | 400 | 0.1 | 10 |
| KEBS | 5 | 1500 | 6.5-8.5 | 12-25 | 400 | 0.1 | 10 |

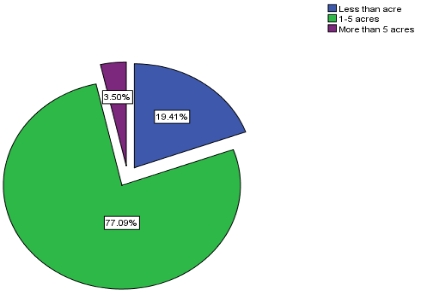
## Land Use and Environmental Conservation Activities

To quantify changes in land use and environmental conservation in the Kuuru River, several parameters were considered to support the study discussions.

### Ownership of land size in acres

The results varied, with 19.41% of the respondents owningless than an acre of land for farming, 77.09% indicated that they had land sizes between 1-5 acres’, while 3.05% indicated that they had more than 5 acres of land for smallholder farming as indicated in figure 1.

**Figure 1**: **Pie chart showing size of land in the study area**

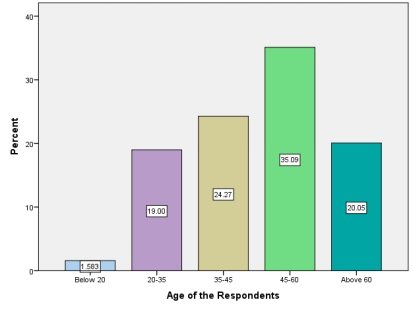


**Information on the household**

**Age of the respondents**

The graph in figure 2 shows that 35.09% of the respondents were between the ages of 45-60 years, 24.27% were between 35-45 years, 20.05% were above 60 years, 19% were between 20-35 years, while 1.583% were below 20 years.

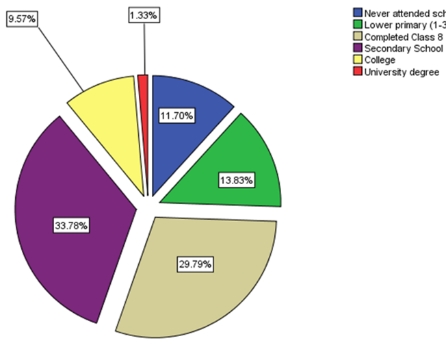
**Figure 2: Bar graph showing the age of the respondents**



### Level of education of respondents

The study established that 11.70% of the respondents had no formal schooling or, rather, never attended school, 13.83% of the respondents received lower primary education, for example, from classes 1-3, 29.79% went up to class 8, 33.78% attained secondary education level, while 9.57% constituted respondents who received tertiary education. Only 1.33% had a university degree. This is indicated in figure 3.

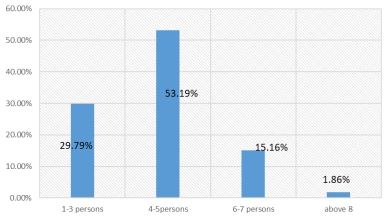
**Figure 3: A pie chart showing the level of education of the respondents**



### Household size of respondents

Figure 4 shows that 29.79% of the respondents had a household size of between 1-3 persons, 53.19% were between 4-6 persons, and 15.16% indicated a household size of approximately 6-7 while 1.86% indicated a household size of above 8.

**Figure 4: Bar graph showing the household sizes in the area of study**

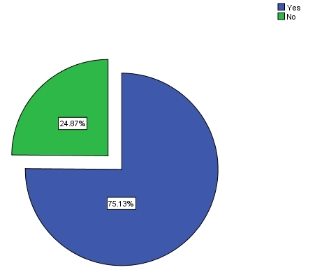


## Conservation of the River's Riparian Zone

### Idea on the Conservation of the River's Riparian Zone

Based on the replies issued by participants in the research field, 75.13% of the respondents indicated that they had an idea of river conservation, while 24.87% of respondents didn’t. This is as indicated in figure 5.

**Figure 5: Pie chart showing the idea of riparian conservation**



### Riparian vegetation and socioeconomic impact on the Riparian Zone

According to the study, table 2 shows that 40.10% of respondents planted trees along riparian areas, 61.46% planted crops, 12.24% let wild shrubs grow, and 4.47% left the area bare. Regarding riparian conservation, 54.47% gained knowledge independently, 49.74% relied on indigenous knowledge, and 9.38% received formal training.

In livestock keeping, 76.56% of respondents kept livestock, primarily indigenous breeds (56.93%), with 49.44% practicing zero grazing, 36.11% open field grazing, and 13.44% tethering. While 33.64% took animals to the river to drink, 64.36% provided water at home.

When asked about benefits from riparian conservation, 52.75% of respondents felt motivated by benefits, while 46.25% did not. Among WRUA members, 14.4% benefited from social networking, 16.19% from training on income-generating activities, and 4.48% from exposure programs. However, 77.54% of respondents saw no social aspects encouraging riparian conservation, with only 22.46% affirming social motivation for conservation.

**Table 2: Riparian Vegetation and Socioeconomic Impact on the Riparian Zone**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **The response rate in %** |
| Type of vegetation along the riparian area | Trees  Crops  Wild shrubs  Bare | 40.10%  61.46%  12.24%  4.47% |
| Source of information on riparian conservation | Own Knowledge  Indigenous Knowledge  Training | 54.47%  49.74%  9.38% |
| Livestock Keeping | Yes  No | 76.56%  22.44% |
| Breed of livestock Kept | Indigenous  Exotic  A mix of the two | 56.93%  6.49%  36.58% |
| Type of grazing | Zero grazing  Tethering  Open field grazing | 49.44%  13.44%  36.11% |
| Source of water for animals | Taking them to the river  Giving them at home | 33.64%  64.36% |
| Opinion on whether conservation of the riparian area has derived any benefits that can motivate conservation of the same | Yes  No | 52.75%  46.25% |
| Benefits as a WRUA member | Social Network  Training on income-generating activities  Increased exposure through an exchange program | 14.40%  16.19%  4.48% |
| Social aspects that lead to the conservation of riparian areas | Yes  No | 22.46%  77.54% |

## Contribution of the institution provided by the legislative framework in the conservation of Kuuru River

### Existing Legislative Framework and Institution Regulators in the Conservation of Kuuru River

The focus group discussion revealed that the Kuuru River management involves various stakeholders, but many fail to fulfill their roles. The Upper Tana is the main donor to Kuuru WRUA, providing approximately 2 million KES for managing the newly formed Sub-Catchment Management Plan (SCMP). Stakeholders, including the County Department of Agriculture, Livestock, and WRA, collaborate to manage the Nchura catchment, where Kuuru is located.

Donor funds will support activities such as developing a water allocation plan, conducting a baseline water survey, protecting the riverbank, marking riparian areas, and training farmers in water-friendly practices. However, challenges include inadequate community awareness, insufficient support from WRA to enforce the Water Act 2016, lack of offices and funding for WRUAs, and unsustainable land use practices. The Upper Tana project coordinator emphasized that WRUAs need smaller operational areas to manage water resources effectively, as their current expansive coverage hampers resource management. Improved farmer training, pollution control, and integrated pest management are essential for better conservation outcomes.

### Kuuru Water Resource Users Association (WRUA)

The Kuuru sub-catchment, managed by Kuuru WRUA within the Kathita/Mutonga sub-region of the Tana region, is divided into four management zones: forest, upper, middle, and lower.

Table 3 indicated that the mean age of WRUA members ranged mostly between 35 and 60 years. Awareness of riparian conservation among WRUA members was perceived as low by 66.46% of respondents. Additionally, 53.91% of the community was unaware of laws allowing participation in riparian conservation. Awareness sources included CBOs (52.34%), WRA (29.44%), CSOs (9.35%), and other forms such as media and education (8.88%). Most residents were ignorant of the laws and cultivated on riverbanks, posing a threat to the riparian area.

**Table 3: Response for different parameters on Kuuru Conservation**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **The response rate in %** |
| The average age of the members in WRUA | 1=18-35  2=35-45  3=45-60 | 8.08%  56.57%  34.35% |
| Level of awareness on riparian among the members | Low  Average  High | 66.46%  29.81%  2.73% |
| *Awareness of the law that allows the community to participate in the conservation of riparian areas* | *Yes*  *No* | *44.09%*  *53.91%* |
| *Source of information on the awareness of the law of conservation* | *Through WRUA*  *Through CBO*  *Through civil society organization*  *Others* | *29.44%*  *52.34%*  *9.35%*  *8.88%* |
| *Opinion on the community awareness of the law allowing the community to participate in the conservation of riparian areas* | *Yes*  *No* | *37.25%*  *62.75%* |
| *Management plan of Kuuru River* | *Yes*  *No* | *30.19%*  *69.81%* |
| *Involvement in decision-making by WRUA* | *Yes*  *No* | *23.14%*  *73.86%* |
| *WRA involvement in the conservation of Kuuru River* | *Yes*  *No* | *3.96%*  *94.04%* |
| *County involvement in the conservation of Kuuru River* | *Yes*  *No* | *0%*  *100%* |

**DISCUSSION**

## Changes in water quality

### Turbidity

Statistical test results showed that the river's turbidity far exceeded the WHO standard, ranging from 20.8 to 640 NTU against the recommended 5 NTU, indicating possible pollution or sedimentation issues (Nafi'Shehab *et al.,* 2021). High turbidity can harm aquatic ecosystems, suggesting a need to mitigate sediment runoff and pollution. Turbidity levels varied by site, with areas behind Kimachia market, Meru-Mikinduri highway, and Kathangali showing high levels due to sloping, agriculture-heavy landscapes. High TDS levels, as noted by (Müller *et al.,* 2020), can reduce water clarity, hinder photosynthesis, and elevate water temperature through heavy metal reactions.

These findings align with studies like (Ouma *et al.,* 2016), who recorded high turbidity in Kenya's Lake Victoria catchment, and Ombaka and Gichumbi (2012) in Meru South, Kenya, among others across Africa, which consistently report elevated turbidity in wet seasons due to increased precipitation and sediment discharge (Ochuka *et al.*, 2019).

### Total Dissolved Solids

The study found that river TDS levels were below WHO standards (94-240 mg/L, compared to 600-1000 mg/L) and within NEMA and KEBS limits, indicating good water quality regarding dissolved solids, suitable for uses like irrigation. High turbidity, attributed to rainfall and soil erosion, exceeded WHO limits, highlighting potential pollution and ecological impacts, suggesting a need to curb sediment runoff. Statistical tests showed a negative correlation between TDS and turbidity and a strong positive correlation between TDS and conductivity, linking dissolved solids to water conductivity levels. High turbidity, associated with suspended microorganisms and sediments, impacts water aesthetics and complicates disinfection Pandit & Kumar (2022). Although areas like Maskani and Kimachia show more human activity, TDS levels remain acceptable across all points, supporting overall water quality Lawal *et al*., (2023); Mushtaq *et al*., (2022).

### pH

pH variations are influenced by factors like seasonal surface runoff, which brings in organic matter that decomposes, increasing carbon dioxide and lowering pH. Anthropogenic activities and nutrient enrichment also play roles, with aquatic plant growth and decomposition contributing to acidification. Increased precipitation further lowers pH by introducing organic matter that depletes oxygen. Additionally, synthetic fertilizers releasing acids such as ammonium and sulfates contribute to pH reduction Ashitha *et al.,* (2021); Sobral *et al.,* (2020).

### Temperature

Temperature fluctuations in the Kuuru River are influenced by solar intensity, cloud cover, and humidity. The removal of riparian vegetation exposed the river to more heat, while increased turbidity also contributed to temperature changes by absorbing heat. Natural factors like runoff, weather, and water levels further impact temperature Aladejana & Ebijuoworih, (2024). Vegetation cover plays a key role in stabilizing water temperature (Jane *et al*., 2021), while reduced human activity can lower precipitation (Yang *et al*., 2019).

### Conductivity

Conductivity is influenced by temperature, with warmer water showing higher conductivity (He *et al*., 2020). The cooler climate of Imenti Forest, where Kuuru River originates, contributes to variations in conductivity across sampling sites, potentially indicating pollutant introduction Khan & Patel, (2021). High conductivity suggests elevated levels of dissolved substances, minerals, or chemicals, indicating potential pollution (Ngatia *et al*., 2023).

### Phosphates

Research by Wekesa, A. M., & Otieno, C. (2022) found that intensive agricultural runoff and excessive fertilizer use raise phosphate levels in rivers. In the study area, high phosphates in the Kuuru River are attributed to runoff from farms using DAP fertilizer and a lack of riparian conservation. Additionally, livestock drinking directly from the river and waste sediments contribute to elevated phosphates, aligning with findings from Solihu and Bilewu (2022) on the Asa River in Nigeria.

### Nitrates

Nitrogen-rich organic matter in polluted water may result in low nitrate levels (Muñoz-Palazon *et al.,* 2021). In the study area, heavy DAP fertilizer use and organic sediment input contribute nitrogen, lowering nitrate levels in the Kuuru River. Decomposition reduces dissolved oxygen, slowing ammonia conversion to nitrite and nitrate, which may require nitrite and ammonia monitoring due to their toxicity Ciji & Akhtar, (2020). Nitrate sources include fertilizer, animal waste, and runoff from human activities (Ho et al., 2019; Nyilitya *et al.*, 2020).

## Land use and environmental conservation activities

**Land Size Ownership**

Insights from focus groups and the Ministry of Agriculture reveal that smallholder farmers in the study area, due to limited land, often intensify farming using fertilizers, pesticides, and herbicides, leading to runoff pollution during rains Kaur and Sinha, (2019). This intensification, combined with cultivation on slopes and near water bodies, increases erosion risks (Kogo *et al*., 2020). Insufficient buffer zones further allow pollutants to reach water bodies, impacting water quality, aligning with (Autio *et al*., 2021) findings on small land sizes and conservation challenges.

### Tenure System

Land ownership affects conservation practices, with land purchasers often neglecting environmental risks like water proximity this aligns with studies by O'Donnell, (2019). Inherited land is typically subdivided, resulting in smaller plots that complicate sustainable use Atieno and Alumasa, (2022). Kasimbazi (2020) noted that rented land suffers more degradation, as short-term tenants may avoid conservation efforts. Leonhardt *et al*., (2019) further highlighted that rental insecurity hinders soil protection. Thus, land tenure significantly impacts environmental commitment and conservation efforts.

### Socio-economic impact

Household characteristics studied for influence on riparian zone included the household size and its effect to land use. Household sizes ranged from 1-3 to over 8 members, with larger households demanding more resources, impacting sustainable management of the Kuuru River. This study echoed findings by Rubhara and Oduniyi (2021), noting that larger households can benefit from additional labor resources but face challenges due to smaller farming plots. Larger households may extract more resources, while land allocation affects land use and conservation (Zermeño‐Hernández *et al*., 2020). Perceptions of wetlands vary; households not utilizing them often deem them unproductive Gamble, (2021). Wetlands provide essential green spaces for livestock and crop resilience, but intensified agriculture threatens their sustainability Maltby, (2022); Jacob *et al.*, (2022).

### Demographic characteristics

The study found that household characteristics—gender, age, education level, and size—significantly impact the conservation of the Kuuru River riparian zone. Among respondents, 53.95% were male and 44.05% female. While gender roles influence environmental decision-making, the study indicated that gender representation did not significantly affect riparian conservation, aligning with Mamboleo and Adem (2023). The age distribution showed that 34.09% were aged 45-60 years, providing valuable knowledge about conservation practices, while younger individuals offered innovative ideas. The majority of smallholder farmers were between 35-60 years, reflecting the economic activity of the population.

Education levels varied, with 11.70% having no formal schooling and 10.9% attaining tertiary education. Ardoin *et al*., (2020) emphasized that education influences environmental awareness and the adoption of sustainable practices. However, low parental literacy hampers children’s education, affecting conservation efforts.

### Knowledge on riparian conservation

The study indicates that awareness creation is essential for effective resource conservation. In the riparian areas, respondents practiced conservation measures, including planting indigenous, water-friendly trees, despite the illegal cultivation of riparian land under the Environmental Coordination and Management Act 1999. Many also planted commercial exotic species like eucalyptus and grevillea, which negatively impact the riparian zone (Musa *et al.*, 2016). NEMA's restoration order and local executive actions highlight the need to remove eucalyptus from riparian areas.

There is a significant lack of recognition regarding the importance of riparian conservation, necessitating collaboration among stakeholders to enhance sustainable resource use Miruka (2021). The Kenya Institute for Public Policy Research and Analysis (2017) reported a decline in wetland areas, from 111,376 hectares in 2010 to 50,930 hectares in 2014, highlighting urgent policy shifts for wetland protection. Increased financial backing and technical support for the Water Resources User Association (WRUA) could boost membership and encourage greater community involvement in preserving the river ecosystem.

## Contribution of the institution provided by the legislative framework to the quality of water and conservation of Kuuru River

Stakeholder participation in preserving and enhancing water quality within the Kuuru River ecosystem has faced significant challenges. This study reveals critical issues concerning stakeholder engagement and its impact on the river's health. The well-being of this vital natural resource is at risk due to ineffective actions by many stakeholders responsible for its conservation, leading to ongoing water quality degradation that threatens both ecological integrity and local communities.

The 2015 EMCA (Amendment) Act defines riparian zones as extending 30 meters from the highest flood level and 6 meters from property boundaries. Adhering to these legal parameters is crucial for effective riparian protection.

Additionally, the County Government of Meru and Kenya Forest Services play vital roles in preserving riverbanks to achieve the national goal of maintaining 10% forest cover. However, their conservation efforts are often not communicated to the local community, which limits effectiveness. Actively engaging the community is essential for fostering shared responsibility in conserving the Kuuru River's riparian zones.

Illegal water extraction and irrigation practices also pose significant challenges. To address these issues, the Meru Water Service Board and Water Resources Authority must regulate water intakes from the river to ensure equitable access for downstream users and preserve water quality.

A troubling finding of the study is the lack of community awareness regarding stakeholder participation in the conservation of the Kuuru River. This awareness gap underscores the need for proactive initiatives from NEMA and other authorities to educate the public about the importance of conservation efforts.

Water Resources Users Associations (WRUAs) are crucial for enforcing the Water Act, but they require adequate support and resources to fulfil their responsibilities. This includes comprehensive training and resource allocation to enhance their effectiveness in managing water resources.

In summary, the limited participation of stakeholders in conserving the Kuuru River negatively impacts water quality. To address this, all stakeholders—NEMA, county governments, Kenya Forest Services, water authorities, and local communities—must commit to collective action and proactive engagement. Improved awareness, strict enforcement of regulations, and community involvement are vital for conserving the Kuuru River and enhancing its water quality.

The study emphasizes the urgency for stakeholders to take concrete actions to fulfill their roles, particularly regarding the enforcement of the EMCA against polluting activities. Proactive measures by local authorities and forest services can significantly contribute to preserving riverbanks and overall water quality.

Community awareness regarding stakeholder involvement is crucial, highlighting the need for education and sensitization efforts Canfield, K. N. (2022). The Meru County Department of Environment should also actively engage in river conservation to address climate change.

Overall, achieving effective conservation of the Kuuru River requires increased awareness campaigns, stringent regulatory enforcement, and active community participation. This aligns with findings that stress the importance of collaboration and integrated approaches among stakeholders in managing water resources effectively Schoon *et al.*, (2021), Şenol, C., and Taş, M. A. (2023), Elekwachi, W. (2020) and Alcamo, J. (2019).

**Conclusions**

The statistical analysis conducted within this study has yielded valuable insights into the physicochemical parameters of the Kuuru River, shedding light on their implications for both land use and environmental conservation. These findings offer valuable guidance for making informed decisions in water management, land use planning, and conservation endeavours. The aim is to ensure that land use practices remain sustainable and responsible while safeguarding the environment.

The research demonstrates that agricultural activities, characterized by intensive farming methods, the application of agrochemicals, and soil erosion, exert a substantial influence on the water quality of the Kuuru River. These practices contribute significantly to elevated levels of phosphates, nitrates, total dissolved solids (TDS), and turbidity. Concurrently, they impact the pH and temperature variations of the water. To counteract these negative effects and safeguard local water resources, the implementation of conservation measures and sustainable agricultural practices is essential.

Both the size of the land and the prevailing tenure system have the potential to shape the intensity of agricultural practices, the proximity of these practices to water bodies, and the adoption of sustainable land management techniques. Therefore, it is imperative for farmers, landowners, and policymakers to take these factors into consideration. By doing so, they can mitigate the potential detrimental impacts on water quality and establish a harmonious balance between agricultural activities and environmental preservation.

The study highlights a significant proportion of respondents who showed awareness of riparian conservation and actively participated in conservation activities. Effective management of riparian zones, including careful vegetation practices, responsible livestock management, and promoting awareness of associated benefits, can greatly contribute to improved water quality. These measures help reduce pollution, prevent erosion, and promote sustainable practices related to land and water management.

The Kuuru River, being a vital natural resource, faces significant challenges due to the limited involvement of stakeholders in its conservation. To rectify this situation and improve water quality, it is imperative for all stakeholders, including NEMA, the county government, Kenya Forest Services, water authorities, and the local community, to actively engage and fulfill their responsibilities. By fostering increased awareness, stringent regulation enforcement, and robust community participation, the goal of conserving the Kuuru River and enhancing its water quality can be realized. This endeavour requires collective commitment and cooperation among all stakeholders to ensure the long-term sustainability of this invaluable ecosystem.

## Cover Letter for the researcher

Due to the nature of the research, an introductory letter from the School/ Faculty was sufficient to proceed with the research. The research did not involve direct involvement with human or animal samples.

## Consent to Participate in Research

Prior permission was obtained from the research participants. The participants were given a consent form which after reading and understanding, they would then sign as a form of their agreement to participate in the research.

Consent to collect water samples from the Kuuru River was issued by the Kuuru WRUA chairperson.

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