**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 in 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 the 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

**Abbreviations**

|  |  |
| --- | --- |
| ANOVA  | Analysis of Variance |
| APHA  | American Public Health Association |
| CBO  | Community Based Organisation |
| CSO | Civil Society organization |
| DAP | Diammonium Phosphate |
| EC | Electrical Conductivity |
| EMCA | Environmental Management Coordination Act |
| GPS | Global positioning System |
| KEBS | Kenya Bureau of Standards  |
| NEMA | National Environment Management Authority |
| NTU | Nephelometric Turbidity Unit |
| pH | Potential Hydrogen |
| SCMP | Sub catchment management Plan |
| SPSS | Statistical Package for the Social Sciences |
| UNSDG  | United Nations Sustainable Development Goals |
| UTaNRMP | Upper Tana Natural Resources Management Project |
| WHO | World Health Organization |
| WRA | Water Resource Authority |
| WRUA | Water Resource User’s Association |

 **INTRODUCTION**

Water is a vital resource, and contamination poses a serious global issue, highlighted by United Nations Sustainable Development Goals (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). Rajapakse et al, (2023), report revealed two billion people 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 as climate change and population growth will worsen the situation (Calvin 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 algae 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). Das et al, (2024), highlight the need for continuous monitoring and have targeted pollution control measures in order to safeguard water resources and public health. Syeed et al, (2023) in their study propose seven systems that would enable safe, timely and comprehensive water quality data collection through a self-operated process with minimum human monitoring and intervention.

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 *and Makokha.,* 2024).

The study area is highly populated and relies heavily on agriculture and livestock. As a result of increased agricultural activity and rising population, the river is facing significant pollution issues. The ongoing use of the river for farming and animal husbandry makes it particularly susceptible to pollution.

This research is essential for assessing the current state of the Kuuru River, understanding the impact of human activities, and evaluating the effectiveness of regulatory measures. The findings will contribute to improved water management practices, enhanced public health, and stronger conservation efforts.

## Limitations of the study

It was anticipated that the study's comprehensive objectives might be hindered due to insufficient funds to conduct research across various seasonal variations, as well as time constraints for data collection The researcher managed this by conducting sampling during a single rainy season and subsequently analyzing identified physicochemical parameters as indicators of pollution.

**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.

### Water Sampling

A stratified sampling method was used to collect 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 to ensure the consistency of the results (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 at Mailu Bridge, Kiorimba Bridge, and finally at Kiburine. A Global Positioning System(GPS) was used to pinpoint these locations, ensuring consistency in sample collection. In total, 18 water samples were obtained. The collected water samples were preserved and transported to the laboratory for analysis according to the methods described in the American Public Health Association (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.

### Water Sampling Procedure

 Water samples were taken from the middle section of the river channel using one-liter plastic bottles. 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. After that, the materials were transported to the laboratory for analysis to determine their physicochemical properties. Before being analyzed, the samples were brought to the lab and kept in a refrigerator at about 4 °C.

### Determination of physicochemical parameters

The turbidity, temperature, pH, conductivity and total dissolved solids measurements were analyzed in the laboratory using different sensors. Turbidity was analysed using a nephelometer that is used to measure the haziness of water caused by suspended solids. This was an optical sensor that measured the intensity of light at 90°by particles in the sample with a wavelength of 860nm and could detect low levels of turbidity as less as 1 NTU.

Electrical Conductivity and total dissolved solids were measured using a conductivity meter that Measures the ability of water to conduct electric current, which correlates with ion concentration. The conductivity meter had an electrochemical sensor with electrodes that measured the current flow through water to determine ion concentration.

pH was measured using pH meterthat Measures the hydrogen ion concentration (acidity or alkalinity) of the water sample. The pH meter had a combination of electrodes (glass electrode for H+ activity and reference electrode) with a measuring range of 0-14 pH. It had a built-in temperature compensation and required calibration with standard buffer solutions (pH4,7 and 10).

Temperaturewas measured by a thermometerthat measures the temperature of the water sample. The sensor had a resistance temperature detector and was paired with multi-parameter probes for simultaneous readings.

All the analysis was done within four hours of collection. The data obtained from the laboratory analysis was systematically organized in the Statistical Package for the Social Sciences (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 the manufacturers specifications. The solution was then diluted with deionized water until evaluated using ultraviolet-visible spectrophotometry at a wavelength of 880nm using a glass cuvette (Teodorof et al, 2021). The same procedure was repeated for all other water samples. The data obtained was 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 the 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. Afterwards, 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. The data obtained was subjected to analysis using one-way ANOVA

## 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 at understanding the local activities and involvement of stakeholders 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 was 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 had 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 was 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 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 at 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 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 The highest being at Kimachia Mkt and the lowest at Meru-Mikinduri highway respectively. Kiburine recorded 20.4°C while other sites recorded temperatures slightly below 20°C as seen in table 1.

### Electrical conductivity

The mean conductivity of water samples ranged between 188.4 μS/cm and 461 μS/cm with the lowest being recorded at Kiorimba and the 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 the sources recorded the lowest value of 1 mg/L. The results are as shown in Table 1.

### Nitrates

The mean concentration of nitrates in the river ranged between 0.002 mg/L and 0.0045 mg/L. The highest level was recorded at Kiburine while the lowest was recorded at both Mailu brigde and Kanthiari at 0.0015 mg/L. 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****(µS/cm)** | **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 | 19.8 | 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 3.50% 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. Those with lower primary education (class 1-3) were 13.83% of the respondents, 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 21.83% 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, 36.15% relied on indigenous knowledge, and 9.38% received formal training.

In livestock keeping, 77.56% of respondents kept livestock, primarily Indigenous breeds (56.93%), with 49.44% practising zero grazing, 37.12% open field grazing, and 13.44% tethering. While 35.64% took animals to the river to drink, 64.36% provided water at home.

When asked about the benefits of riparian conservation, 53.75% of respondents felt motivated by benefits, while 46.25% did not. Among WRUA members, 14.40% 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 | TreesCropsWild shrubsBare | 21.83%61.46%12.24%4.47% |
| Source of information on riparian conservation  | Own KnowledgeIndigenous KnowledgeTraining | 54.47%36.15%9.38% |
| Livestock Keeping  | YesNo | 77.56%22.44% |
| Breed of livestock Kept | IndigenousExoticA mix of the two | 56.93%6.49%36.58% |
| Type of grazing  | Zero grazingTetheringOpen field grazing | 49.44%13.44%37.12% |
| Source of water for animals  | Taking them to the riverGiving them at home | 35.64%64.36% |
| Opinion on whether conservation of the riparian area has derived any benefits that can motivate conservation of the same | YesNo | 53.75%46.25% |
| Benefits as a WRUA member  | Social NetworkTraining on income-generating activitiesIncreased exposure through an exchange programNone | 14.40%16.19%4.48%64.93% |
| Social aspects that lead to the conservation of riparian areas  | YesNo | 22.46%77.54% |

## The 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 fulfil 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, collaborated to manage the Nchura catchment, where Kuuru is located.

Donor funds supported 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 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 were mentioned as 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. Among the respondent, 9.08% were between the age of 18 – 35 year while the majority (56.57%) were in the age bracket of 35-45 years. The remaining percentage of 34.35% were those in age between 45-60 years. Awareness of riparian conservation among WRUA members was perceived to be low with 66.46% of respondents. Only a small percentage of 2.73% had a high level of awareness of riparian conservation. Additionally, 53.91% of the community was unaware of laws allowing participation in riparian conservation and 46.09% being aware of such laws. Awareness sources included CBOs (52.34%), WRA (29.44%), CSOs (9.35%), and other forms such as media and education (8.87%). Most residents (69.81%)were not aware that the management plan for Kuuru River existed. WRUA officials involved a small percentage of 23.14% in their decision-making making leaving most of the majority of the respondents (76.86%). The majority of the respondents were not aware of the involvement of stakeholders like WRA and County government in the conservation of Kuuru river. Only 3.96% were aware of WRA involvement and 96.04% were not aware. None of the respondents was aware of the County government's involvement.

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

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **The response rate in %** |
| The average age of the members in WRUA | 1=18-352=35-453=45-60 | 9.08%56.57%34.35% |
| Level of awareness on riparian among the members | LowAverageHigh | 66.46%29.81%2.73% |
| *Awareness of the law that allows the community to participate in the conservation of riparian areas* | *Yes**No* | *46.09%**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%**8.87%* |
| *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* | *26.14%**73.86%* |
| *WRA involvement in the conservation of Kuuru River* | *Yes**No* | *3.96%**96 .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 (Matos et al, 2024). 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 Diwan, V. (2025), 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, Ombaka and Gichumbi (2012) in Meru South, Kenya and (Ochuka et al, 2019) among others across Africa, which consistently report elevated turbidity in wet seasons due to increased precipitation and sediment discharge.

### 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); Srivastav et al, (2024).

### 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 (Chen et al, 2023), while reduced human activity can lower precipitation ( et al, 2019).

### Conductivity

 Conductivity is influenced by temperature, with warmer water showing higher conductivity (Dewangan et al, 2023). 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 (Akhtar 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 of riparian conservation

The study indicates that awareness creation is essential for effective resource conservation. In the riparian areas, respondents practised 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 (Urbanič et al 2022). 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. Syeed, et al, (2023) suggests that the seven systems from their study, should effectively satisfy the needs of many stakeholders including Government policy makers, domain experts and researchers and the management. This is an indication that multi stakeholder involvement is a prerequisite for riverbank protection and ensuring 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.

The study offers a valuable baseline for understanding the Kuuru River’s ecological stressors and governance gaps. Its interdisciplinary approach bridges scientific analysis and socio-economic contexts, making it a pertinent resource for policymakers, environmental agencies, and local communities. The study is a valuable contribution to environmental science and public health, providing critical insights in other regions with similar scenario.

## Future research

1. The researcher recommends that further research should be done on the potential impact of sediment load resulting from soil erosion within the study area on the aquatic life in Kuuru River.
2. Further research is also recommended to assess the specific relationships between household information and conservation practices in the study area. This can provide insights into potential barriers and opportunities for involving different household members in conservation efforts and promoting sustainable land and water management practices

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