

Water Urbanism and Land Use Change: A Conservation Strategy for Nanyuki Riverine Ecosystem, Laikipia County

*Nelson Michael Akwata Mudeny, Mugwima Njuguna and Shadrack Mutungi Simon

<https://orcid.org/0009-0002-9465-9422>

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Abstract

Urban riverine ecosystems are increasingly threatened by rapid land use transformations driven by urbanization, agricultural expansion, and infrastructure development in the Global South. This study develops a conservation strategy for the Nanyuki River by examining the effects of land use change on hydrology, water quality, and biodiversity within a water urbanism framework. A mixed-methods approach integrating spatial analysis, field measurements, water quality assessment, biodiversity surveys, and stakeholder perspectives was employed. Findings reveal significant spatial variation along the river corridor. Upstream sections remained relatively stable, while urbanized midstream areas experienced reduced flows, biodiversity decline, and severe microbial contamination. Downstream sections exhibited cumulative pollution impacts associated with increased impervious surfaces, riparian encroachment, and wastewater discharge. The study demonstrates that land use intensity is a major driver of ecological degradation and reduced river health. It proposes a water urbanism conservation framework integrating land use planning, riparian protection, decentralized wastewater management, and community-based governance to support sustainable river restoration and adaptive urban water management.

Keywords: Ecosystem services, GIS, land use change, mixed-methods, NDVI, Nanyuki River, riparian buffer, social-ecological systems, water urbanism

INTRODUCTION

Riverine ecosystems are among the most vital and dynamic natural systems, supporting ecological balance and human livelihoods globally. They provide essential ecosystem services, including water supply, biodiversity habitat, nutrient cycling, and climate regulation. These ecosystems are increasingly threatened by accelerated land use transformations linked to urbanization, agricultural expansion, and infrastructure development, particularly in rapidly growing towns of the Global South. In many developing regions, including Kenya, weak enforcement of environmental regulations and rising population pressures have intensified human encroachment into riparian zones, resulting in significant ecological degradation (Mbonaga et al., 2024; Mugambi et al., 2022). This underscores the need for context-specific studies that examine how land use dynamics interact with river systems under

urban pressures.

Land use change is widely recognized as a primary driver of environmental transformation in riverine ecosystems. Activities such as deforestation, agricultural expansion, and settlement development disrupt natural hydrological processes. For example, the removal of riparian vegetation reduces infiltration capacity, increasing surface runoff, soil erosion, and sedimentation. These processes degrade water quality, alter flow regimes, and reduce habitat suitability for aquatic species (Oliveira et al., 2018; Mbonaga et al., 2024). Additionally, agricultural inputs introduce nutrients such as nitrogen and phosphorus into river systems, contributing to eutrophication and reduced dissolved oxygen levels (Beaty, 2021; Abdinisir, 2022).

*Corresponding author:

Nelson Michael Akwata Mudeny Jomo Kenyatta University of Agriculture and Technology Nairobi Kenya

Email: mudemike94@gmail.com

Urbanization further intensifies these impacts by transforming permeable landscapes into impervious surfaces. Roads, buildings, and pavements increase runoff volumes and pollutant loads entering rivers. In many cases, urban growth outpaces wastewater infrastructure development, resulting in untreated effluent discharge and solid waste pollution. This pattern is evident in several urban rivers, including the Nairobi River, where informal settlements and industrial activities have significantly compromised ecological integrity (Gituara, 2021; Abdinasir, 2022). Such cases illustrate broader systemic challenges in urban environmental governance.

In response to these challenges, the concept of water urbanism has emerged as an integrated approach to urban planning and environmental management. Water urbanism emphasizes the incorporation of water systems into urban design, recognizing rivers as ecological and social assets rather than exploitable resources. Unlike conventional planning approaches, water urbanism explicitly links spatial planning with hydrological and ecological processes, thereby enhancing urban resilience and sustainability (Kamil et al., 2019; Mugambi et al., 2022). However, its application in small and rapidly urbanizing towns remains underexplored, particularly within African contexts.

THEORY

Despite growing global awareness of river ecosystem degradation, empirical research on smaller urban rivers remains limited, especially in developing countries. In Kenya, studies have largely focused on major river basins such as the Tana and Athi rivers, leaving smaller systems underrepresented. This gap constrains the development of localized planning interventions and evidence-based conservation strategies (Abdinasir, 2022; Mulwa, 2019).

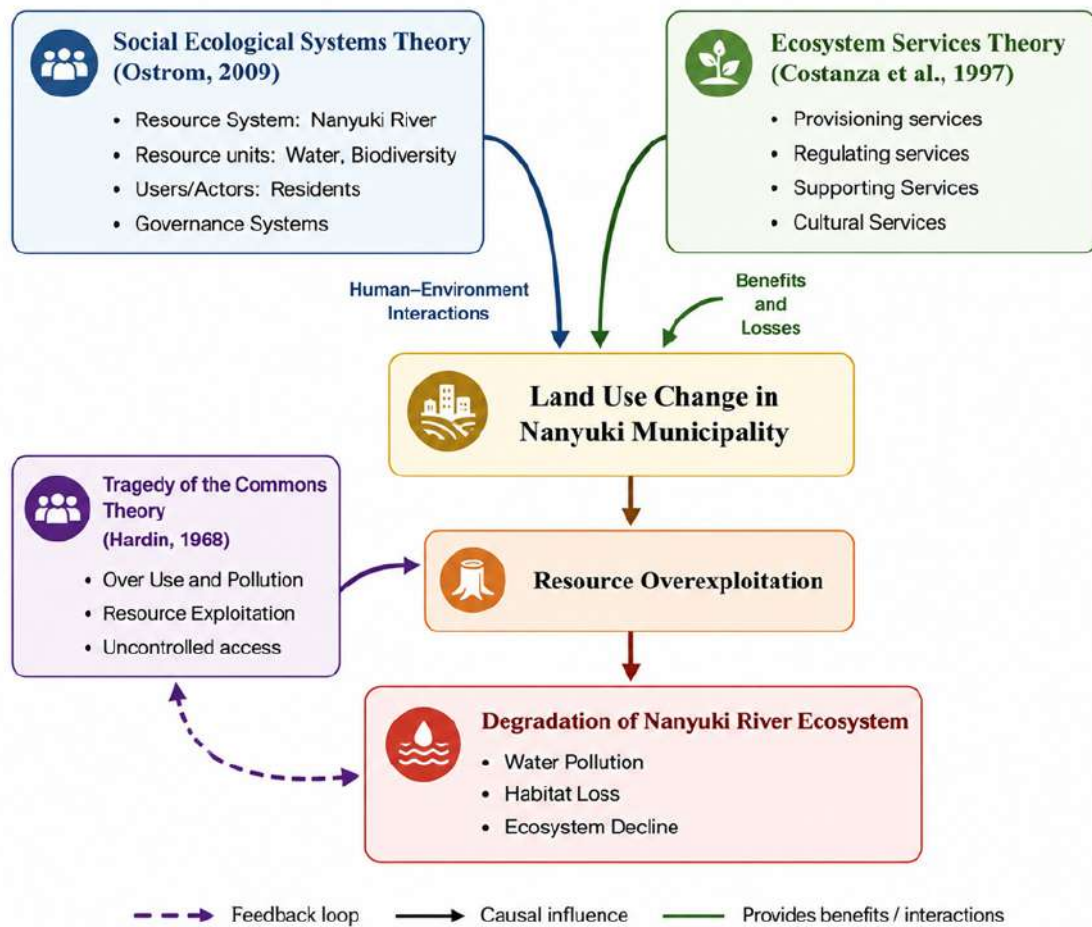
The Nanyuki River presents a critical case for examining these dynamics. Flowing through Nanyuki Municipality, it supports domestic use, irrigation, and light industry. Increasing urbanization and agricultural activities have resulted in riparian vegetation loss and declining water quality. These pressures highlight the vulnerability of small urban rivers to cumulative land use impacts and weak regulatory enforcement

(Abdinasir, 2022; Mbonaga et al., 2024).

This study is grounded in three complementary theoretical frameworks as shown in **Figure 1**: Social-Ecological Systems (SES) theory, Ecosystem Services theory, and the Tragedy of the Commons. Rather than treating these frameworks descriptively, they are operationalized to guide variable selection, analysis, and interpretation. SES theory informs the analysis of interactions between human activities (e.g., land use change) and ecological outcomes (e.g., biodiversity loss). Ecosystem services theory provides a basis for evaluating the functional benefits of river systems, including provisioning, regulating, and supporting services. The Tragedy of the Commons explains how unregulated access and competing land uses contribute to resource overexploitation (Ostrom, 2009; Hardin, 1968).

Figure 1 illustrates the integrated theoretical framework underpinning the study. The framework demonstrates how land use change in Nanyuki Municipality emerges from the interaction between social, ecological, and governance systems. The Social Ecological Systems Theory explains the relationship between resource users, governance structures, and ecological resources such as water and biodiversity. Ecosystem Services Theory highlights the benefits derived from river ecosystems, including provisioning, regulating, supporting, and cultural services, which are affected by changes in land use. The Tragedy of the Commons Theory explains how uncontrolled access, overuse, and weak regulation contribute to resource exploitation and environmental degradation. The interaction of these theoretical perspectives shows that increasing land use pressures lead to resource overexploitation, which subsequently results in river ecosystem degradation manifested through water pollution, habitat loss, and ecosystem decline. The framework therefore provides a holistic explanation of how human activities, institutional arrangements, and ecological processes interact to influence the condition of the Nanyuki River ecosystem and informs the development of sustainable conservation and management strategies.

Previous studies have largely examined these frameworks in isolation; however, this study integrates them to provide a more comprehensive understanding of urban river degradation. This



Note: The framework illustrates how theories and human actions drive land use change, leading to resource overexploitation and river ecosystem degradation.

FIGURE 1

Integrated theoretical framework for understanding land use change and river ecosystem degradation in Nanyuki Municipality

Source: Author (2026), adapted from Elinor Ostrom (2009), Robert Costanza et al. (1997), and Garrett Hardin (1968).

integration represents a key contribution by linking socio-economic drivers, ecological processes, and governance challenges within a unified analytical framework.

Guided by these perspectives, this study investigates the effects of land use activities on the Nanyuki Riverine ecosystem, focusing on water quality, hydrology, and biodiversity (Figure 2). The study adopts a mixed-methods approach to capture both biophysical changes and community perceptions, thereby improving analytical depth and contextual relevance.

The study is guided by the following objectives:

- i. To assess the spatial and temporal patterns

of land use change along the Nanyuki River corridor (2000-2006).

- ii. To evaluate the impacts of land use change on water quality, hydrology, and biodiversity.
- iii. To evaluate community perceptions of river degradation
- iv. To develop a water urbanism-based conservation framework for sustainable riverine ecosystem management.

By addressing these objectives, the study contributes to closing the gap in localized urban river research and advances the application of water urbanism within small-town contexts. It further highlights the importance of integrating land use planning, environmental governance, and

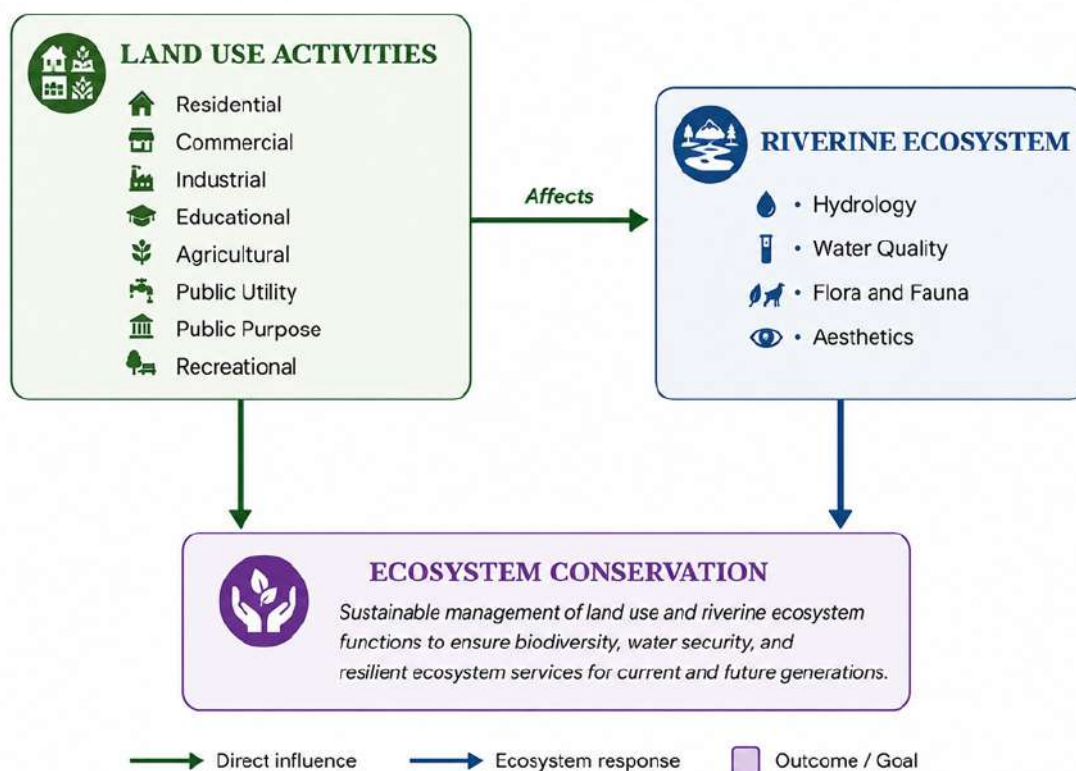


FIGURE 2 Conceptual framework showing the relationship between land use activities, riverine ecosystem components, and ecosystem conservation

Source: Author, 2026

community participation in river conservation.

Figure 2 presents the conceptual framework guiding the study. The framework illustrates how various land use activities, including residential, commercial, industrial, educational, agricultural, public utility, public purpose, and recreational developments, influence the condition of the riverine ecosystem. These land use activities affect key ecosystem components such as hydrology, water quality, flora and fauna, and aesthetic value. Changes in these ecological components subsequently determine the effectiveness of ecosystem conservation outcomes. The framework assumes that increasing intensity and expansion of land use activities can either enhance or degrade river ecosystem health depending on the nature and management of those activities. Consequently, sustainable ecosystem conservation requires balancing human land use demands with the protection and restoration of riverine ecosystem functions. The framework therefore provides the analytical basis for examining how land use change affects the Nanyuki River ecosystem and informs

the development of appropriate conservation strategies.

Land use patterns within the study area are illustrated in Figure 3. The results show that land use is highly heterogeneous, reflecting competing demands of urban expansion, commercial agriculture, and settlements. Urban areas, including informal settlements, are concentrated near the town center, while smallholder farming dominates the periphery. Riparian encroachment has led to vegetation clearance, establishment of farms, and discharge of wastewater into the river (Abdinasir, 2022; Mbonaga et al., 2024).

Ecologically, the Nanyuki River supports a variety of flora and fauna. Riparian vegetation includes native trees, shrubs, and grasses, while aquatic habitats support fish, amphibians, and macroinvertebrates. However, biodiversity is declining due to habitat fragmentation, pollution, and altered flow regimes (Koskey et al., 2021; Mbonaga et al., 2024). The river is also vital for community livelihoods, supporting irrigation,

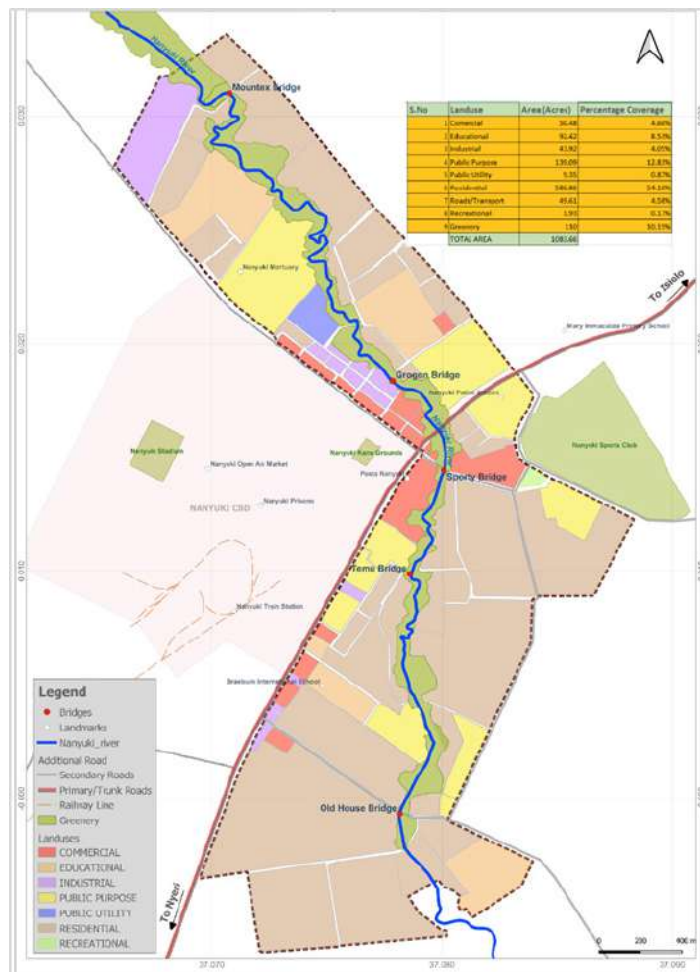


FIGURE 3
 Existing land use map
 Source: Google Maps, 2026

domestic water use, and recreational activities.

The choice of this study area was strategic because it reflects the interplay between urbanization, agriculture, and riverine ecosystem health. By focusing on this stretch, the study captured critical spatial and temporal gradients of land use pressures, providing a representative case for understanding urban river dynamics in similar developing-town contexts (Abdinasir, 2022; Mulwa, 2019).

RESEARCH METHODS

The study employed a quasi-experimental research design integrating quantitative and qualitative data to assess the effects of land use activities on the Nanyuki River ecosystem. The design was appropriate because it allowed comparison

of naturally occurring river conditions across spatial gradients (upstream, midstream, and downstream) without manipulation of variables. The methods combined field measurements, laboratory analyses, biodiversity assessments, community surveys, key informant interviews, and spatial analysis using GIS and remote sensing. This allowed for a comprehensive understanding of land use impacts on water quality, hydrology, and biodiversity.

Research Design

A quasi-experimental research design was adopted to capture the status of the Nanyuki River and its riparian zone at a specific period, while a longitudinal design was applied to assess land use change trends over time (2000-2026). The design combined observational and comparative analytical approaches to strengthen causal inference between land use change and ecological

conditions. The study combined observational, experimental, and survey methods to triangulate findings from multiple sources, enhancing reliability and validity.

Materials

The materials used in this study comprised a range of field sampling equipment to facilitate the collection of accurate environmental data. These included water sampling bottles, a turbidity meter, pH meter, dissolved oxygen (DO) meter, Secchi disk, and GPS units for geo-referencing sampling points, as applied in similar studies by Abdinasir (2022). In addition, quadrats and transect lines were utilized for vegetation surveys and biodiversity assessment. Laboratory materials included a spectrophotometer for nutrient analysis, incubators for microbial counts, and chemical reagents for water quality assessment. GIS software (ArcGIS 10.8) and remote sensing datasets (Landsat 5, 7, and 8) were used for spatial

analysis, land use classification, and NDVI/ NDBI computation. Structured questionnaires, interview guides, and observational checklists were used for socio-economic data collection. These tools enabled integration of ecological, spatial, and social datasets within a unified analytical framework.

Study Area

The study was conducted along the Nanyuki River, which flows through Nanyuki Municipality in Laikipia County, Kenya. Nanyuki is a rapidly urbanizing town at the foothills of Mount Kenya, characterized by a semi-arid to temperate climate, diverse topography, and mixed land uses including residential, commercial, agricultural, and light industrial activities (Abdinasir, 2022; Mbonaga et al., 2024).

As shown in **Figure 4**, the selected study area stretched approximately 5 kilometers, from the Old

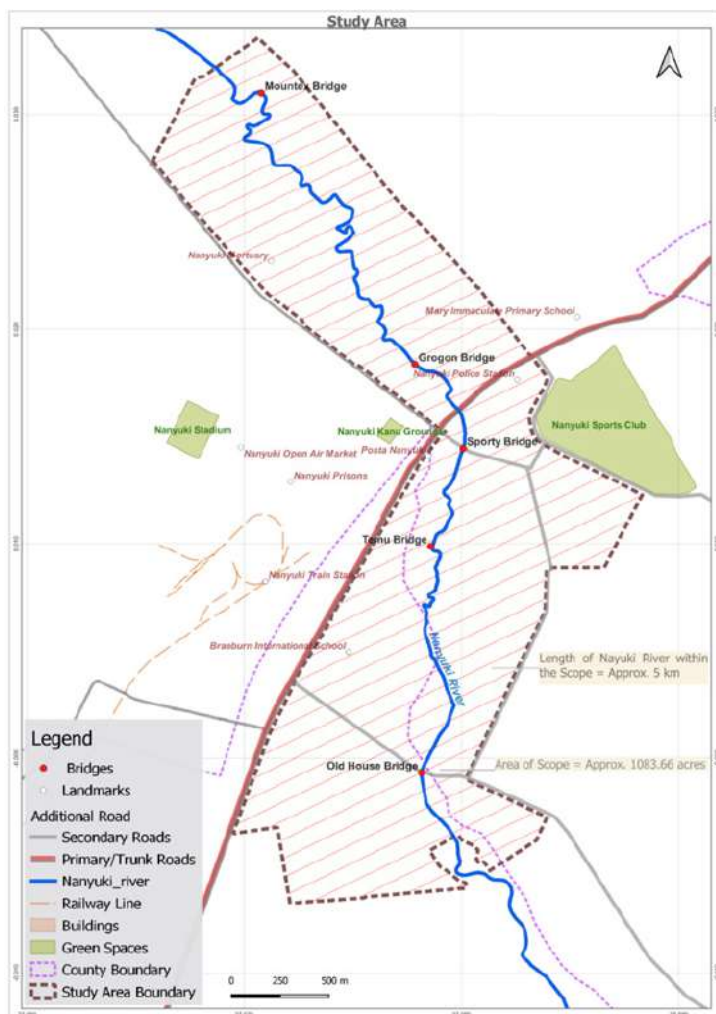


FIGURE 4

Study area

Source: Author (2026).

House Bridge (river entry point) to the Mountex Bridge (exit point). A 300-meter riparian buffer zone on either side of the river was delineated to capture areas most impacted by human activities. This threshold was informed by established hydrological studies which demonstrate that buffer widths in the range of 100–300 meters are effective in capturing key ecological processes such as flood attenuation, sediment retention, and nutrient filtration, particularly in semi-arid and rapidly urbanizing catchments. The upper limit was selected as a precautionary measure to account for floodplain variability and intensified human pressures along the river.

Sampling Procedures and Sample Size

A stratified sampling design was used for ecological assessment based on river zonation (upstream, midstream, downstream) and land use intensity was adopted. Eight sampling sites were selected purposively along the 5-kilometre stretch. The sample size of eight sites was justified based on ecological representativeness and feasibility for intensive multi-parameter field and laboratory analysis. Upstream sites represented baseline conditions, midstream sites represented high anthropogenic influence, and downstream sites captured cumulative impacts.

For community perception analysis, a stratified random sampling approach was applied using GIS-based spatial grids (315 strata of 1 hectare each) as shown in **Figure 5**. A total of 150 questionnaires were distributed proportionally based on structure density. This ensured statistical representativeness across heterogeneous land use zones. Within each stratum, simple random sampling without replacement was applied. The proportional allocation method ensured unbiased representation of both high-density and low-density settlement areas, improving statistical validity.

Methods of Data Collection

Water quality assessment was conducted at the National Public Health Laboratory using the Water Quality Index (WQI), integrating pH, turbidity, temperature, nitrates, phosphates, BOD, and faecal coliforms. WQI values were statistically compared across river zones using one-way ANOVA to determine significant spatial differences ($p < 0.05$). Hydrological characteristics were evaluated using the discharge equation

$Q = A \times V$. Data were statistically analyzed to assess spatial variation in flow regimes across river segments using descriptive statistics and comparative analysis. Biodiversity surveys were analyzed using the Shannon-Wiener Diversity Index. Species richness and diversity indices were compared across sampling sites using ANOVA to test for significant ecological differences between land use zones.

Data Analysis and Integration

The data were analyzed using descriptive statistics (mean, standard deviation) and inferential statistics. One-way ANOVA was used to test differences across spatial zones, while Spearman's rank correlation (using R software) was used to examine relationships between land use variables and ecological indicators. GIS techniques were used to map ecological degradation hotspots. Qualitative and quantitative data were integrated through triangulation during interpretation, where field observations and interview findings were used to explain statistical and spatial results.

Ethical Considerations

Ethical approval was obtained from NACOSTI and relevant Laikipia County authorities prior to data collection. Informed consent was obtained from all respondents, who participated voluntarily and were informed of their right to withdraw at any time. Confidentiality was maintained through anonymization of respondent data, and all information was used strictly for academic purposes. The study also adhered to environmental data collection ethics, ensuring minimal disturbance to ecological systems during fieldwork.

RESULTS

Land Use and Land Cover Changes

Table 1 presents an analysis of land use and land cover (LULC) changes along the Nanyuki River corridor, revealing substantial transformation between 2000 and 2013, with 2026 representing the current land use status. The findings indicate a sustained shift primarily driven by urban expansion, population growth, and agricultural intensification. Satellite imagery, GIS-based classification, and change detection analysis consistently showed a transition from a predominantly natural landscape to a highly modified urban–agricultural system by 2013,

TABLE 1
 Land use land cover trends (2000-2026)

Land Use Class	2000 (%)	2013 (%)	2026 (%)	Interpretation
Bare / Cleared Land	19.23	7.56	3.81	Continuous decline due to vegetation recovery and urban infill
Riverine Vegetation	10.07	16.26	21.47	Gradual increase driven by riparian regeneration; however, part of the observed gain reflects classification shifts arising from higher-resolution imagery and refined vegetation classification thresholds in later years, which improved detection of narrow riparian buffers
Grassland	54.02	23.38	30.64	Sharp decline (2000–2013) followed by partial recovery, indicating land use transition and regeneration dynamics
Shrubland	2.13	7.82	6.66	Moderate increase reflecting secondary vegetation succession and disturbed land recovery
Built-up Area	14.56	46.14	38.19	Major expansion between 2000–2013, slight stabilization/redistribution by 2026

Source: Author (2026)

by 2026 (30.64%). Riverine vegetation increased from 10.07% to 21.47%, although this increase is partly attributed to classification refinement and improved NDVI sensitivity in later imagery rather than full ecological restoration. Shrubland showed moderate increase, reflecting secondary succession.

Spatial LULC maps in **Figure 6** visually confirm

progressive encroachment of built-up areas into riparian zones, particularly within and downstream of Nanyuki Town, with clear spatial clustering of high-intensity land use.

Change detection analysis (**Table 2**) further confirmed a transition in land dynamics. Urban expansion was highest between 2000 and 2013 (35.14%) ($p < 0.05$), but reduced significantly to

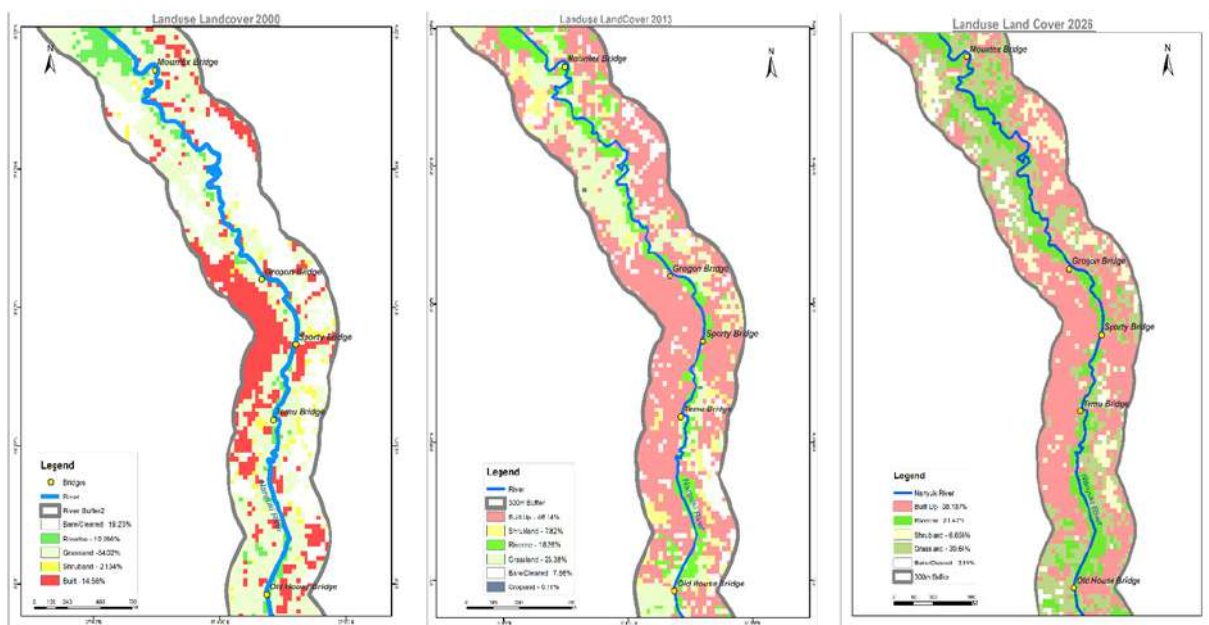


FIGURE 6
 Land use land cover classification maps
 Source: Author, 2026

TABLE 2
Change detection 2000-2026

Change Category	2000–2013 (%)	2013–2026 (%)	Interpretation
Vegetation Loss	1.77%	2.59%	Increasing vegetation conversion in the later period, linked to urban pressure and encroachment
Vegetation Gain	8.02%	20.88%	Significant regeneration/reclassification of vegetated areas, particularly riverine and shrub recovery
Urban Expansion	35.14%	10.53%	Rapid urban growth in the early period followed by a slowed expansion and densification phase
No Change	55.14%	66.24%	Increasing spatial stability, indicating consolidation of established land uses

Source: Author (2026)

10.53% between 2013 and 2026, indicating a shift from rapid expansion to consolidation. Vegetation gain increased from 8.02% to 20.88%, while vegetation loss slightly increased from 1.77% to 2.59%, indicating ongoing but localized land conversion pressure.

The proportion of “no change” areas rose to 66.24%, indicating landscape stabilization but also persistence of established land use patterns.

NDVI and NDBI analyses presented in **Table 3** further reinforced these trends. NDVI values showed an increase between 2000 and 2013 (0.395 to 0.612), followed by a decline in 2026 (0.515), indicating vegetation stress linked to urban densification. NDBI values declined from 0.450

to 0.124, confirming reduced expansion intensity and a shift toward compact urban form.

NDVI maps shown in **Figures 7–10** collectively indicate that while urban expansion has slowed, ecological pressure remains concentrated in riparian and urban zones.

Water Quality Trends

Water quality along the Nanyuki River showed clear spatial variation across upstream, midstream, and downstream sections. Results indicated that microbial pollution was the dominant form of contamination, while chemical parameters largely remained within acceptable limits (KS EAS 12:2018; KEBS standards).

TABLE 3
NDVI and NDBI findings

Index	Category	2000	2013	2026	Interpretation
NDVI	Maximum (Vegetation Density)	0.395	0.612	0.515	Significant increase (2000–2013) followed by slight decline, indicating initial vegetation recovery then pressure from urban consolidation
	Minimum (Degraded/ Non-vegetated)	-0.350	0.035	0.008	Reduction in extreme negative values suggests decline in bare surfaces and partial surface stabilization
NDBI	High (Built-up Intensity)	0.450	0.163	0.124	Sharp decline, indicating reduced horizontal expansion and transition to densification
	Low (Non-built/ Vegetated Areas)	-0.262	-0.403	-0.311	Increasing negativity (2000–2013) reflects vegetation loss; slight reversal by 2026 suggests localized recovery

Source: Author (2026)

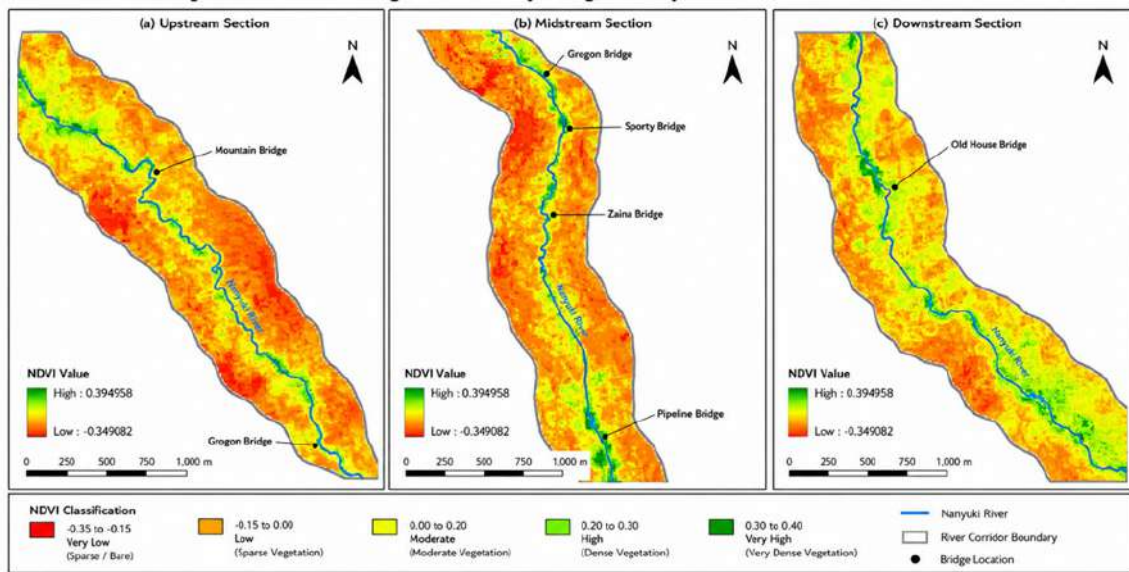


FIGURE 7

NDVI-based vegetation density along the Nanyuki River corridor in 2000

Source: Author (2026), derived from landsat satellite imagery and GIS-based Normalized Difference Vegetation Index (NDVI) analysis

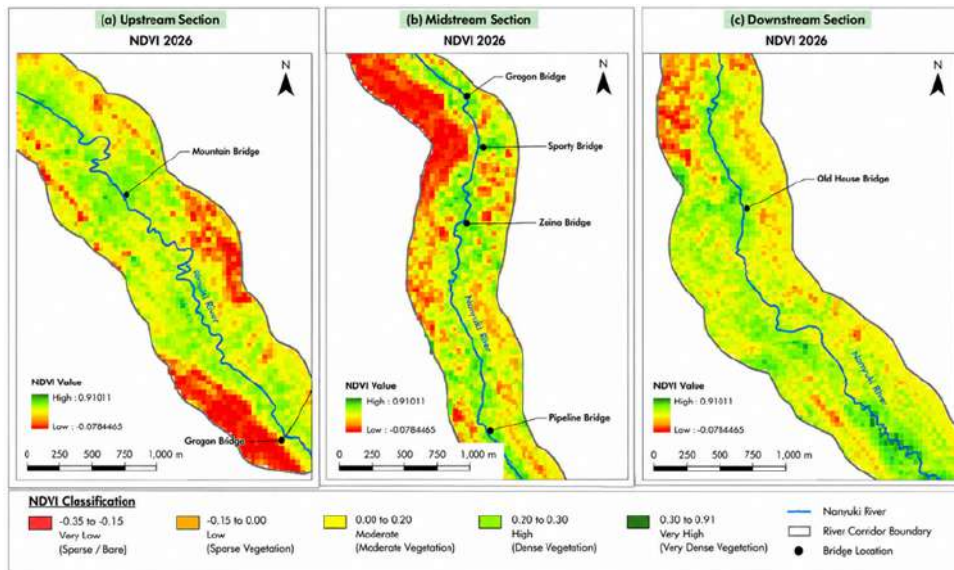


FIGURE 8

NDVI distribution along the Nanyuki River corridor, 2026

Source: Author (2026), derived from Landsat imagery analysis

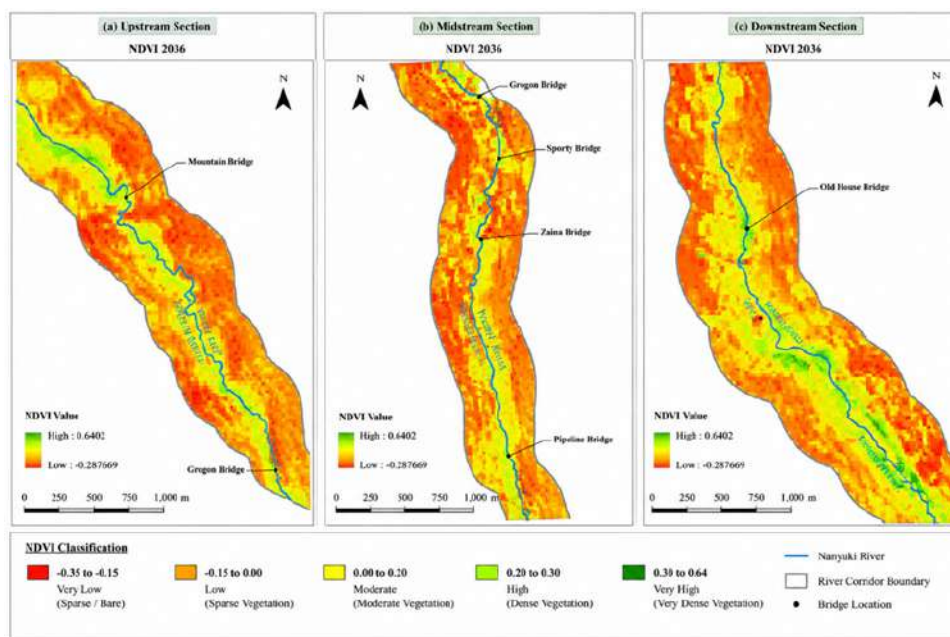


FIGURE 9
 NDVI distribution along the Nanyuki River corridor, 2000
 Source: Author (2026), derived from Landsat imagery analysis.

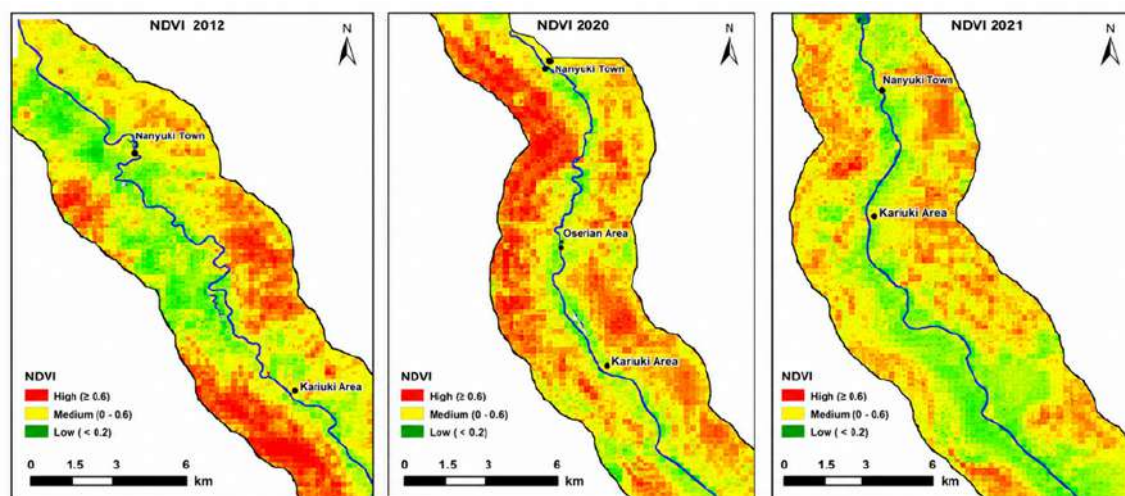


FIGURE 10
 Spatial distribution of Normalized Difference Built-up Index (NDBI) values along the Nanyuki River corridor in 2013
 Source: Author (2026)

Bacteriological results showed progressive deterioration downstream. Total coliform and *E. coli* counts exceeded WHO/KEBS standards (0 CFU/100 ml) at all sites, confirming widespread contamination ($p < 0.05$ across river zones for microbial indicators). Downstream values peaked at 630 CFU/100 ml (total coliforms) and 320 CFU/100 ml (*E. coli*), indicating severe pollution loading.

Upstream sections already showed baseline contamination (e.g., 95 CFU/100 ml), confirming that pollution originates beyond the urban core. **Figures 11 and 12** illustrate spatial variation in coliform and *E. coli* levels.

Chemical parameters remained relatively stable. pH ranged between 8.0–8.5, while nitrates, iron, manganese, and heavy metals remained within permissible thresholds. Turbidity slightly exceeded

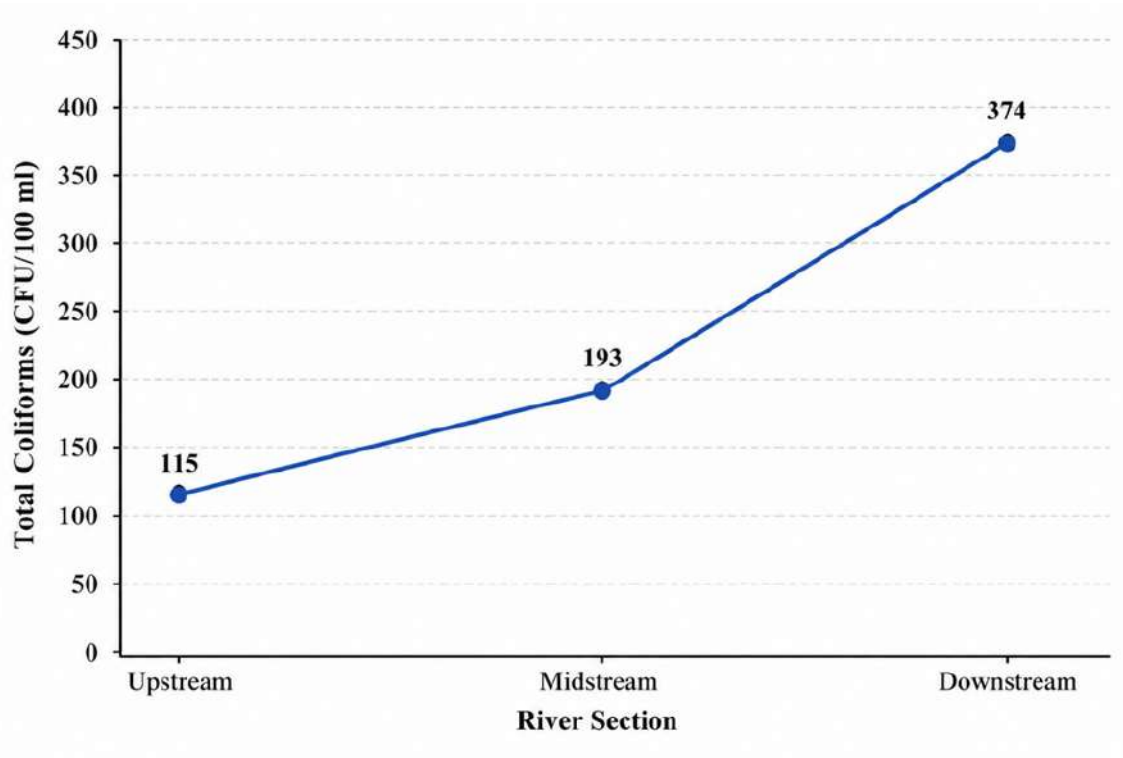


FIGURE 11
 Total Coliform Levels along the Nanyuki River Course
 Source: Author (2026)

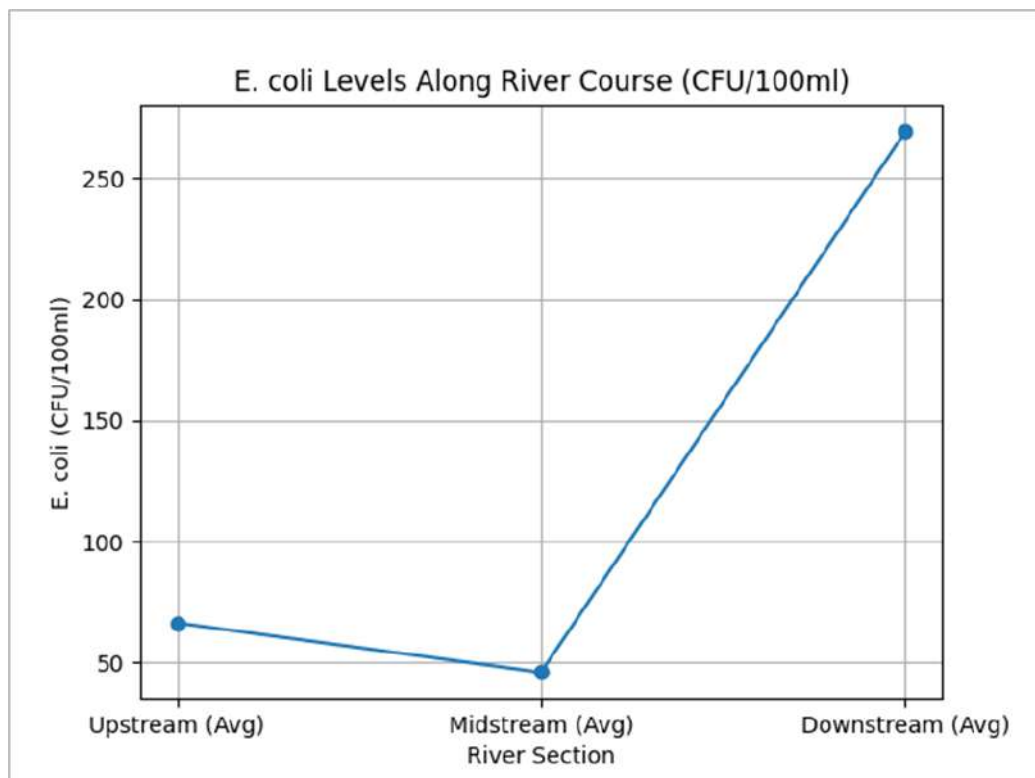


FIGURE 12
 E. coli Levels along the Nanyuki River Course
 Source: Author (2026), derived from Landsat imagery analysis

standards upstream but reduced downstream.

The results as shown in **Figure 13** confirm that water quality degradation is primarily microbiological rather than chemical, driven by sanitation and wastewater discharge rather than industrial pollution (Gituara, 2021; Mugambi et al., 2022).

Biodiversity Assessment

The biodiversity assessment revealed a clear decline in species richness and diversity along the river corridor. Spatial variation was evident between upstream, midstream, and downstream zones, closely linked to land use intensity.

Shannon-Wiener Index results as shown in **Table 4** indicated low to moderate diversity across taxa, with trees ($H' = 2.45$), herbaceous plants ($H' = 2.28$), and fauna ($H' = 2.48$), confirming disturbed ecological conditions.

Upstream sections showed relatively higher diversity as shown in **Table 5**, with Ukumbusho (Sporty Bridge) recording the highest tree diversity ($H' = 2.37$). In contrast, Old House ($H' = 1.45$) and Grogan Bridge ($H' = 1.49$) recorded the lowest values, reflecting high disturbance levels.

A total of 157 trees from 14 families were recorded, with 67% being indigenous species. However,

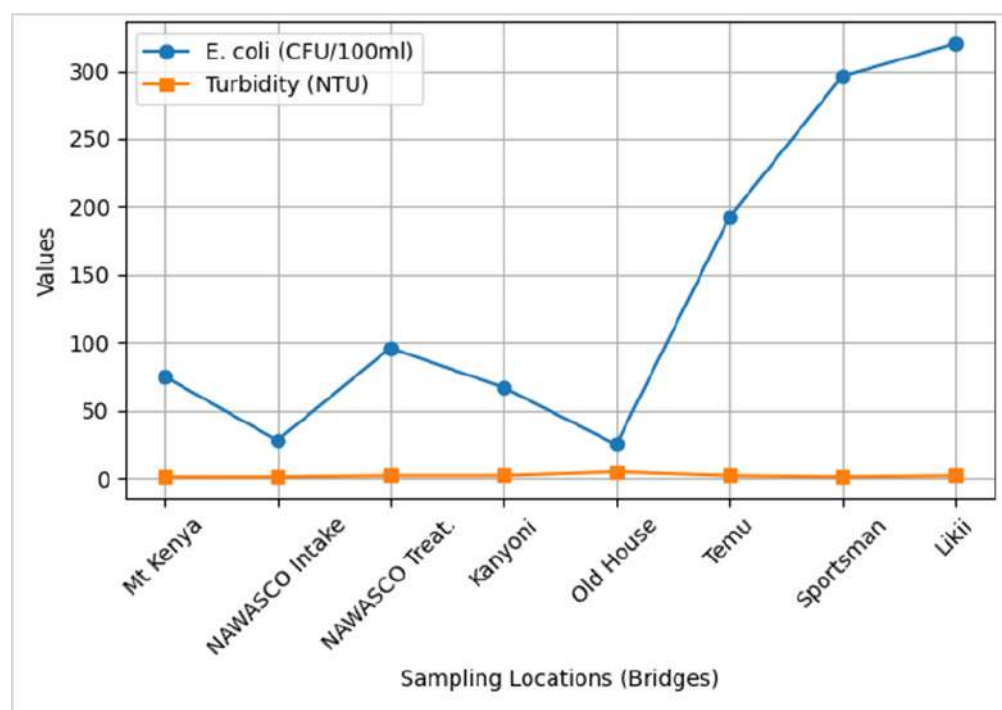


FIGURE 13
Combined bacteriological and chemical analysis of water quality along Nanyuki River
Source: Author (2026)

TABLE 4

Shannon-Wiener Relative Values

Value	Species Diversity (H')	Findings	
Very High	>3.50	Trees	2.45
High	3.00 – 3.49	Herbaceous Plants	2.28
Moderate	2.50 – 2.99	Fauna	2.48
Low	2.00 – 2.99		
Very Low	1.99 and below		

Source: Baliton et al. (2020)

TABLE 5
 Shannon-wiener species diversity index

	Sampling point	Tree Species (H')	Herbaceous Plants (H')	Fauna Species (H')
1	Mountex Bridge	2.08	1.73	1.62
2	Grogan Bridge	1.49	2.13	1.27
3	Ukumbusho (Sporty Bridge)	2.37	0.11	1.57
4	Temu	2.05	2.16	1.12
5	Old House	1.45	2.14	1.72

Source: Author (2026)

disturbed zones were dominated by exotic and invasive species such as *Grevillea robusta*, *Eucalyptus grandis*, and *Lantana trifolia*. Faunal diversity followed a similar pattern, with reduced richness in urbanized sections due to habitat fragmentation. Statistical results (H' values) showed significant spatial differences across sites ($p < 0.05$), confirming land use influence on biodiversity distribution.

Hydrological Observations

Hydrological analysis showed significant spatial variation in river characteristics influenced by land use change as shown in **Table 6**. River width increased downstream (6.3–9.5 m), while depth and velocity fluctuated across zones. Midstream sections exhibited reduced discharge (3.16–3.44 m³/s), indicating hydrological stress linked to abstraction and impervious surfaces. Upstream conditions remained relatively stable, while downstream discharge increased due to cumulative runoff rather than ecological recovery.

The midstream urban section recorded the greatest hydrological disruption, with reduced flow efficiency and increased variability. Key informants confirmed that abstraction and urban development significantly altered natural flow regimes.

The results from the study showed a statistically meaningful spatial difference in discharge patterns across river zones ($p < 0.05$). The findings underscored that land use transformation, abstraction pressure, and urbanization were key drivers of altered hydrological behavior, with significant implications for water availability, ecosystem integrity, and sustainable river basin management (Oliveira, 2018; Lei et al., 2022).

Impact of Land Use on the Nanyuki Riverine Ecosystem

The study found that the Nanyuki Riverine ecosystem is strongly shaped by intensive land use change, particularly urban expansion, where

TABLE 6
 Hydrological survey data

Sampling Site	River Width (m)	Average Depth (m)	Flow Velocity (m/s)	Discharge (m ³ /s)
NAWASCO Intake Point	6.5	0.80	0.90	4.68
Mt Kenya Bridge	6.3	0.75	0.88	4.16
NAWASCO Treatment Intake	6.7	0.82	0.92	5.06
Kanyoni Bridge	8.2	0.60	0.70	3.44
Old House Bridge	8.0	0.58	0.68	3.16
Temu Bridge	9.0	0.70	0.80	5.04
Sportsman Arms Bridge	9.2	0.72	0.82	5.43
Likii Bridge (Kirieri)	9.5	0.75	0.85	6.06

Source: Author (2026)

residential and built-up areas dominate the river corridor (54.16%) as illustrated in **Table 7**. This transformation has led to widespread ecological degradation, reflected in declining vegetation health, reduced riparian buffers, and increased impervious surfaces.

Perception data shows high levels of concern among respondents regarding river pollution (91.03%) and ecosystem deterioration (83.97%), with urbanization (62.18%) and wastewater discharge (69.23%) identified as the main drivers of degradation. Spatially, impacts vary along the river: upstream areas show emerging agricultural pressures, midstream urban zones experience the highest pollution loads from wastewater and runoff, and downstream sections accumulate the greatest pollutant concentrations and ecological stress.

Correlation and regression analyses confirm these patterns statistically, showing strong positive relationships between built-up land and pollution indicators (notably *E. coli* and coliforms), and strong negative relationships with biodiversity and channel condition. Regression models further demonstrate that land use intensity is a significant predictor of river health decline, particularly for bacteriological contamination ($R^2 = 0.83$) as shown in **Table 8** ecological integrity ($R^2 = 0.52$) as shown in **Table 9**. The results indicate a clear shift toward an urban-impacted river system characterized by higher runoff, increased pollution loading, reduced biodiversity, and altered channel morphology.

Figure 14 demonstrates a positive correlation between the extent of built-up areas and *E. coli* concentrations, indicating that increased

TABLE 7

Existing land use in the study area

Land Use	Acreage	Percentage Coverage (%)
Commercial	50.48	4.66
Educational	92.42	8.53
Industrial	43.92	4.05
Public Purpose	139.09	12.84
Public Utility	9.35	0.86
Residential	586.86	54.16
Transport	49.61	4.58
Recreational	111.93	10.33
Total	1,083.66	100.00

Source: Author (2026)

TABLE 8Regression Model (Analysis of Built-up areas % vs *E. coli* concentrations)

Model	R	R Square	Adjusted R Square	Std. Error
1	0.91	0.83	0.80	28.5

Source: Author (2026)

TABLE 9

Regression Model (Analysis of Built-up areas % vs Fauna Diversity)

Model	R	R Square	Adjusted R Square	Std. Error
1	0.72	0.52	0.45	0.21

Source: Author (2026)

urbanization is associated with higher levels of microbial contamination. In contrast, **Figure 15** shows a negative relationship between built-

up areas and fauna diversity, suggesting that increasing urban development is linked to a decline in ecological diversity.

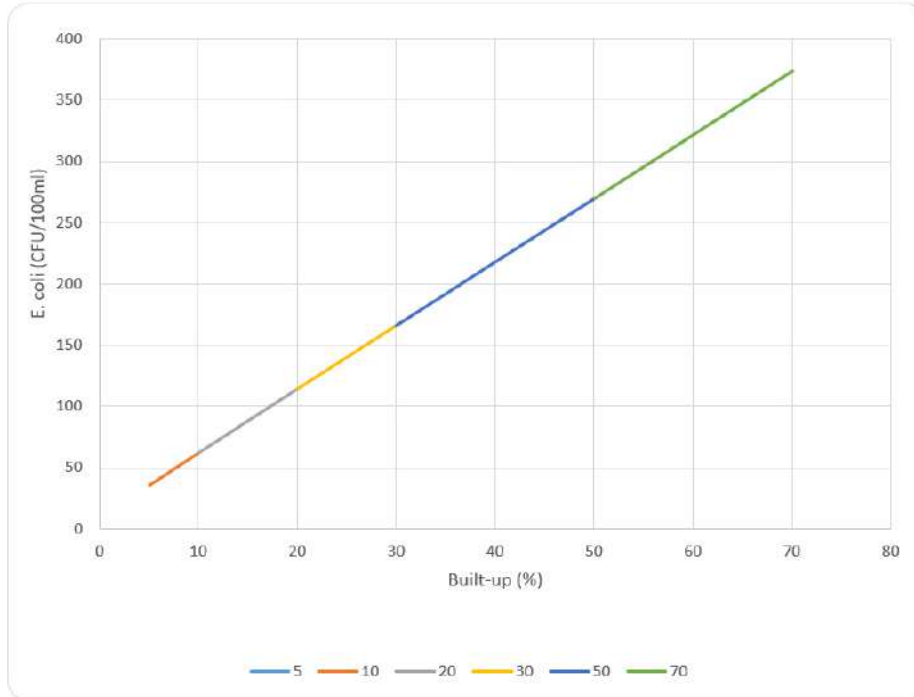


FIGURE 14
 Built-up areas % vs E. coli concentrations
 Source: Author (2026)

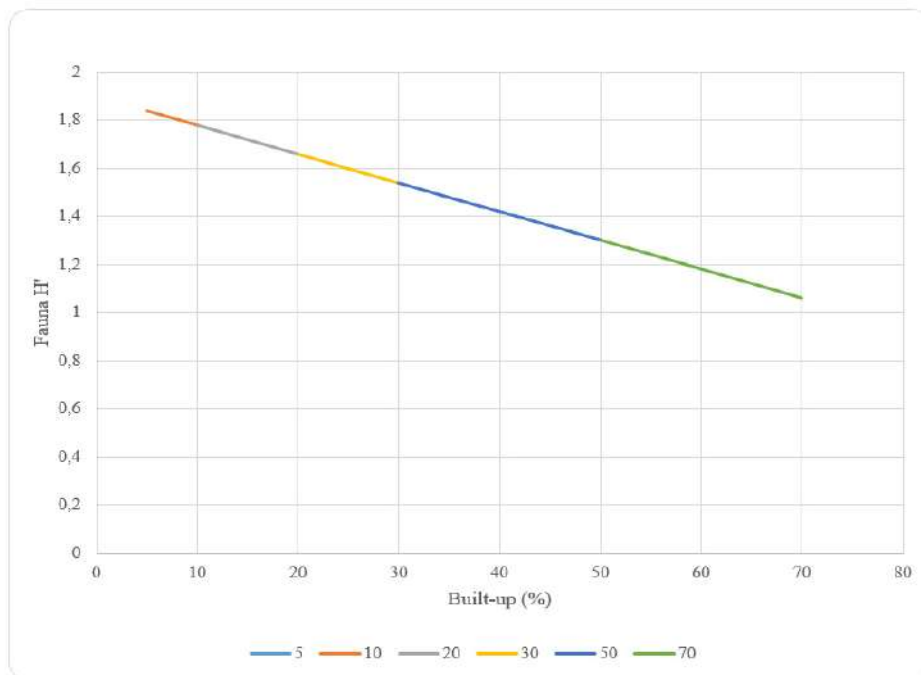


FIGURE 15
 Built-up area (%) vs Fauna Diversity
 Source: Author (2026)

Community Perceptions

The study revealed that community respondents demonstrated high awareness of the river's ecological importance ($M = 6.34$) and pollution concerns ($M = 6.37$). Climate change ($M = 6.45$) and wastewater discharge ($M = 5.66$) were identified as major threats. Support for conservation was high ($M = 6.55$), but participation levels remained low ($M = 3.93$), indicating a gap between awareness and action. **Table 10** shows the results from the study on awareness and perception.

Risk perception results presented in **Table 11** showed that the river is widely viewed as polluted and unsafe, with visible contamination and flooding identified as key risks. However, CFA results indicate that while most constructs (awareness, threats, and conservation attitudes) are well measured, some indicators particularly within risk and safety show weak or inconsistent validity.

Regression analysis presented in **Table 12** showed

that conservation attitude and willingness to act were the only significant predictors of pro-environmental behavior ($R^2 = 0.087$, $p = 0.003$). However, trust in institutions remained moderate, and government effectiveness was rated low ($M = 2.82$), indicating institutional dissatisfaction.

DISCUSSION

The findings of this study demonstrate a strong and consistent relationship between land use activities and the degradation of the Nanyuki River ecosystem, directly addressing the study objectives. Detailed field measurements and spatial analysis across the river continuum confirm that increasing land use intensity from upstream low density zones to highly urbanized midstream areas has significantly altered hydrological conditions, water quality, and ecological integrity. The observed land use and land cover changes, particularly rapid urban expansion and agricultural encroachment into riparian zones within Nanyuki Municipality, have reduced vegetation cover

TABLE 10

Awareness and perception

Awareness and Perception	Mean	Std. Deviation	Coefficient of variation
Nanyuki River provides recreational opportunities to my community	4.949	2.031	0.410
I am aware of the importance of the Nanyuki River as a natural resource to the community.	6.340	1.257	0.198
The river is important for the economic livelihood of my family and Nanyuki residents.	5.750	1.702	0.296
I understand the negative effects of pollution on river ecosystems.	6.365	1.035	0.163
Land use changes have affected the quality of the river over time.	5.160	1.872	0.363
Our future generation will not require the riparian reserve and its ecosystem	3.218	2.186	0.679
I am concerned about pollution and its effects on Nanyuki River	6.353	0.935	0.147
Nanyuki River and its ecosystem adds value to our community	6.115	1.320	0.216
Nanyuki riverine ecosystem has deteriorated in recent years	6.083	1.325	0.218
I avoid using Nanyuki River due to safety and cleanliness concerns	5.391	1.848	0.343
I am concerned about the future of Nanyuki River	6.365	1.066	0.167

Source: Author (2026)

TABLE 11
 Risk and safety

Factor	Indicator	Estimate	Std. Error	z-value	p	95% Confidence Interval	
						Lower	Upper
Risk and Safety	Flooding from Nanyuki River is a big concern in my area	1.000	0.000			1.000	1.000
	Pollution and contamination is evident along Nanyuki River.	-7.246	6.466	-1.121	0.262	-19.919	5.427
	I believe that Nanyuki River is currently clean and pollution free	7.880	7.037	1.120	0.263	-5.912	21.671
	I feel safe letting my children play near Nanyuki River	8.092	7.164	1.130	0.259	-5.948	22.133

Source: Author (2026)

TABLE 12
 Regression model

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.295a	.087	.069	.80523

a. Predictors: (Constant), Conservation_Attitude_and_Willingness_to_Act, Awareness_and_Perception, Perceived Threats

Source: Author (2026)

and weakened the buffering capacity of the river corridor. These findings are consistent with NDVI trends showing declining ecological resilience and reduced capacity for filtration, erosion control, and microclimate regulation (Lei et al., 2022; Mbonaga et al., 2024), thereby confirming that land use change is a primary driver of environmental transformation. However, unlike studies in more strictly regulated urban catchments where riparian recovery has been observed following enforcement interventions, such as sections of the Nairobi River rehabilitation programme, the Nanyuki River system exhibits limited recovery signals, suggesting weaker governance effectiveness, continued encroachment, and persistent land use pressure.

Empirical results further reveal pronounced spatial deterioration in water quality. While upstream sites such as NAWASCO Intake and Mt. Kenya Bridge exhibited relatively stable hydrological conditions (discharge: 4.16–4.68 m³/s) and moderate ecological integrity, they

already showed bacteriological contamination (95–100 total coliforms; 28–75 E. coli), indicating the presence of diffuse pollution sources. As the river enters the urban core, conditions deteriorate markedly, with reduced discharge (as low as 3.16 m³/s at Old House), elevated microbial loads, and declining dilution capacity. Midstream urban sites such as Temu and Sportsman’s Arms recorded extreme contamination levels (up to 300 total coliforms and 296 E. coli), coupled with severe ecological degradation, including collapse of herbaceous diversity ($H' = 0.11$). Downstream accumulation effects were evident at Mountex Bridge, where pollutant concentrations peaked (630 total coliforms; 320 E. coli) despite increased discharge (6.06 m³/s). These findings correspond with patterns observed in other urban rivers in Kenya, including the Nairobi River, where urbanization and inadequate waste management systems contribute significantly to river pollution (Gituara, 2021; Mugambi et al., 2022). Similar trends have also been reported globally, linking intensified land use to declining

water quality and ecosystem health (Beaty, 2023; Oliveira et al., 2018). Importantly, the persistence of contamination in upstream areas indicates that pollution is not solely urban generated but also influenced by diffuse catchment-wide sources, particularly agricultural runoff, livestock activities, and inadequate sanitation infrastructure.

Biodiversity assessment results further highlight the ecological consequences of riparian degradation. Declines in Shannon-Wiener Diversity Index values downstream reflect habitat fragmentation, vegetation loss, and reduced ecological connectivity. The replacement of native riparian vegetation with agricultural and invasive species has diminished ecosystem stability, consistent with findings from comparable river systems in Kenya and elsewhere (Koskey et al., 2021; Mukanoheri et al., 2023). Hydrological observations reinforce these patterns, showing altered flow regimes characterized by reduced base flows and increased peak discharges associated with impervious surfaces and vegetation loss, which are typical characteristics of urbanized catchments (Lei et al., 2022; Oliveira et al., 2018). These interacting stressors suggest that biodiversity decline is not an isolated ecological outcome but rather part of a broader socio ecological breakdown driven by simultaneous disruption of hydrological processes, habitat quality, and land cover integrity.

Statistical analysis strengthens these conclusions. The regression model examining the relationship between built-up land and bacteriological contamination showed that built-up area explained 83% of the variation in *E. coli* concentrations ($R^2 = 0.83$), indicating a strong association between urban development and microbial pollution. In contrast, the broader river condition model showed that land use intensity explained 31% of the variability in overall river condition ($R^2 = 0.31$), suggesting that additional factors, including governance effectiveness, institutional enforcement, hydrological processes, and behavioural practices, also influence ecosystem health. These results demonstrate a measurable and systematic linkage between urbanization and ecological decline. Community perceptions further corroborate the empirical findings, with residents reporting declining water quality, reduced water availability, and loss of ecosystem services, reflecting the socio ecological dimensions of river degradation (Abdinasir, 2022; Mulwa, 2019). The moderate

explanatory power of the model further suggests that additional factors, including institutional enforcement capacity, governance effectiveness, behavioural sanitation practices, and catchment management approaches, may significantly influence river conditions and therefore warrant further investigation.

These findings can be effectively interpreted through the Social Ecological Systems (SES) framework, which emphasizes the interdependence between human activities and ecological systems (Mbonaga et al., 2024; Ostrom, 2009). The degradation of the Nanyuki River demonstrates how unsustainable land use practices disrupt the balance between resource users, governance structures, and ecological resources. Ecosystem Services Theory further highlights the loss of critical functions such as water purification, biodiversity support, flood regulation, and cultural benefits arising from ecological degradation (Costanza, 2016; Mulwa, 2019). Similarly, the Tragedy of the Commons framework explains how weak governance, inadequate enforcement, and competing land use interests contribute to resource overexploitation and environmental decline (Abdinasir, 2022; Hardin, 1968). Collectively, these theoretical perspectives demonstrate that river degradation is not merely an environmental phenomenon but also an institutional and behavioural challenge in which failures of collective action amplify ecological stress and undermine sustainability.

From a policy and planning perspective, these findings underscore the urgent need for an integrated basin-wide conservation approach. Such an approach should include stricter enforcement of riparian buffer regulations, improved wastewater management systems, restoration of degraded riparian habitats, and wider adoption of nature based solutions. The study particularly supports the establishment of a Nanyuki River Commission as a central coordinating institution capable of harmonizing stakeholder actions, strengthening enforcement, facilitating data sharing, and overseeing long-term conservation efforts. Unlike fragmented sectoral interventions currently in place, such a coordinated institutional framework would be better positioned to address the multi-causal nature of river degradation. The strong alignment between scientific evidence and community

perceptions further emphasizes the importance of participatory and community-based approaches in achieving sustainable river management (Mugambi et al., 2022; Mulwa, 2019). Beyond Nanyuki, these findings have broader relevance for rapidly urbanizing secondary towns across Kenya and East Africa, where similar governance challenges, unplanned urban expansion, agricultural encroachment, and inadequate environmental management continue to threaten riverine ecosystems. Consequently, the Nanyuki River provides a useful model for understanding and addressing urban river degradation within emerging urban centres throughout the region.

CONCLUSION

This study established that land use transformations within Nanyuki Municipality have significantly degraded the ecological health of the Nanyuki River. Evidence from spatial analysis, field measurements, and stakeholder insights consistently demonstrates declining water quality, reduced biodiversity, and altered hydrological regimes along the river continuum. Rapid urban expansion, agricultural encroachment into riparian reserves, and inadequate waste management systems emerged as the dominant drivers of this degradation. The midstream urban section functions as the primary pollution hotspot, where the river's natural self-purification capacity is exceeded, while downstream sections reflect cumulative pollutant loading despite partial dilution effects. These trends undermine ecosystem integrity and pose significant risks to water security, public health, and local livelihoods. The study demonstrates that river degradation is spatially uneven but systemically linked to land use intensity across the entire catchment.

The findings further indicate that land use change has been largely unplanned and weakly regulated, resulting in loss of riparian vegetation, expansion of impervious surfaces, and increased surface runoff. Consequently, sedimentation has intensified, groundwater recharge has declined, and flood risks have increased. Despite high levels of community awareness, limited institutional capacity and weak enforcement continue to constrain effective action, highlighting a persistent gap between environmental knowledge and governance that contributes to ongoing ecological decline.

RECOMMENDATIONS

i) Establishment of the Nanyuki River Commission

Addressing these challenges requires a shift toward an integrated, basin-wide governance and conservation approach. Central to this framework is the establishment of a Nanyuki River Commission, designed not as an additional bureaucratic layer but as a legally empowered and performance-oriented coordination mechanism to address existing institutional weaknesses, including fragmentation and weak enforcement. Anchored within the Physical and Land Use Planning Act and the Water Act, the Commission should have clear statutory authority to coordinate river basin management, enforce compliance, and align multi-agency actions. It should bring together key stakeholders, including the County Government of Laikipia, National Environment Management Authority, Water Resources Authority, Nanyuki Water and Sewerage Company, WRUAs, the private sector, and civil society, under a streamlined governance structure with clearly defined roles and accountability. Supported by a hybrid financing model combining county allocations, national grants, and mechanisms such as environmental levies or payments for ecosystem services, the Commission would oversee integrated planning, enforcement coordination, data sharing, ecological monitoring, and sustainable resource mobilization for river restoration. Given the current institutional fragmentation, this intervention represents the most critical and urgent governance reform for effective river restoration.

ii) Strengthening Riparian Protection and Pollution Control

Strict enforcement of riparian buffer regulations, integration of green infrastructure and nature-based solutions within urban planning, and upgrading of wastewater treatment systems are critical measures for reducing pollution and restoring ecological integrity. These interventions should be prioritized according to feasibility, with riparian enforcement and wastewater management representing immediate actions, while green infrastructure integration may require medium- to long-term implementation.

iii) Integrated Land Use Planning and Development Control

County planning authorities should integrate river conservation objectives into land use planning frameworks and development control processes. Future urban expansion should be guided by ecological sensitivity assessments to prevent further encroachment into riparian reserves and environmentally fragile areas. Development approvals should incorporate environmental safeguards and compliance monitoring to minimize adverse impacts on river ecosystems.

iv) Restoration of Degraded Riparian Habitats

Targeted ecological restoration programmes should be implemented to rehabilitate degraded sections of the river corridor. These programmes should focus on reforestation with indigenous species, removal of invasive vegetation, stabilization of riverbanks, and restoration of ecological connectivity. Habitat restoration will enhance biodiversity, improve water quality, and strengthen ecosystem resilience.

v) Enhancement of Wastewater and Stormwater Management Systems

The County Government of Laikipia and Nanyuki Water and Sewerage Company should prioritize investment in modern wastewater treatment infrastructure and sustainable stormwater management systems. Upgrading existing facilities and promoting decentralized treatment technologies will reduce direct discharge of pollutants into the river and improve overall water quality.

vi) Enhancing Community-Based Conservation

Strengthening community-based conservation through structured participation, environmental education, and incentive mechanisms will enhance local stewardship of the river ecosystem. Greater collaboration between communities, government agencies, and other stakeholders is necessary to ensure long-term sustainability and improved environmental outcomes.

vii) Upstream Catchment Management

The detection of bacteriological contamination at upstream abstraction points such as NAWASCO Intake and Mt Kenya Bridge indicates that the river is already polluted before entering the urban core, pointing to diffuse upstream sources including livestock activity, agricultural runoff, and poor rural sanitation. This finding underscores the need for a comprehensive upstream catchment

assessment to guide integrated river basin management. It also expands the conventional urban-centric understanding of river pollution by demonstrating that degradation begins beyond municipal boundaries and therefore requires interventions at the broader catchment scale.

viii) Establishment of Long-Term Environmental Monitoring and Research Programmes

A coordinated environmental monitoring system should be established to continuously track changes in land use, water quality, hydrology, biodiversity, and ecosystem health. Regular monitoring will provide evidence for adaptive management, facilitate early detection of environmental degradation, and support evidence-based policy decisions. Universities, research institutions, and government agencies should collaborate in generating and sharing environmental data.

Areas for Further Research

Further research should focus on seasonal variations in water quality and hydrology, detailed ecological assessments of biodiversity and habitat conditions, and evaluation of the effectiveness of existing land use and environmental governance frameworks. Such efforts will strengthen the evidence base required to support adaptive and long-term conservation of the riverine ecosystem. Future studies should also prioritize comparative analyses with other secondary urban rivers in Kenya and similar contexts across Sub-Saharan Africa to improve generalizability and policy relevance.

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