ISSN: 2524-1354 (Online), ISSN: 2519-7851 (Print)
Africa Habitat Review Journal
Volume 20 Issue 1 (April 2025)
http://uonjournals.uonbi.ac.ke/ojs/index.php/ahr

Anthropogenic Activities and their Implications on the Physical Extents and Ecological Conditions of Riparian Zones in Nairobi River Basin, Nairobi City County:

A Case of Ngong, Mathare and Nairobi Rivers

***Silas Muketha**

Received on 17th December, 2024; Received in revised form 28th March, 2025; Accepted on 25th April, 2025.

Abstract

Anthropogenic activities have impacted the physical extent and ecological conditions of riparian zones in most urban areas of developing countries. The study investigates the implications of anthropogenic activities on the physical extent and ecological conditions of riparian zones in Nairobi City County. Specifically, the study examines the effects of human land-use activities, and it identifies the drivers of anthropogenic activities on the physical extent and ecological conditions of riparian zones in Nairobi City County. Finally, it proposes strategies that promote the appropriate physical extent and ecological conditions of riparian zones in urban areas. Focusing on the Nairobi, Ngong, and Mathare rivers, secondary data were collected from peer-reviewed journals, government records, and policies and laws on riparian zones. Meanwhile, primary data were collected and analyzed using GIS, observation, interviews, and key informant interviews with, among others, staff from the National Construction Authority. The Kobo Collect tool was used to administer questionnaires digitally and offered spatial locations from its GPS. The camera enabled photography. Findings show that the effects of human activities are the narrowing of riparian zones due to encroachments and the dumping of waste. The problem is prevalent in both formal and informal land uses. The drivers of encroachment and degradation of riparian zones include, among others, weak enforcement of policies and laws, poor demarcation of the zones, and poor mapping and monitoring of the zones. The study concludes that anthropogenic activities, including the construction of structures and the disposal of solid waste and wastewater, have harmed the physical extent and ecological quality of the riparian zones in the Nairobi River Basin. The study recommends demarcation of riparian zones, GIS mapping and monitoring using GIS spatial analyst tools. Utilization of Kobo Collect to gather data on hotspots and the periodic enforcement of policies and laws.

Keywords: Anthropogenic activities, riparian zone, physical extent, ecological condition

INTRODUCTION

Riparian zones are the transitional zones between terrestrial and aquatic environments. They play a crucial role in protecting water quality, maintaining biodiversity, and mitigating flood hazards. However, degradation has been identified as a global concern resulting from anthropogenic activities, including urbanization, pollution, and unsustainable land use (Tickner, 2020). Over 80% of riparian zones in urban areas worldwide are compromised due to encroachment by human-induced activities and degradation of TFR (World Wide Fund for Nature, 2018). In the African context, Gebrehiwot (2019) argues that rapid urbanization and weak governance have been the major causes of increased population in riparian ecosystems, leading to pollution from informal settlements and agro-industrial activities. This finding aligns with a study by Kiwango (2021), which was conducted in Tanzania.

Tickner (2020) argues that it is essential to protect and preserve rivers, as well as their associated resources. This author agrees with Mingjun (2010), who observes that "once the water is polluted, life is polluted; once the water is exhausted, civilization is exhausted; once the water disappears, humanity disappears; protecting water resources is protecting humanity."

**Corresponding author:*
Silas Muketha *Department of Urban and Regional Planning, University of Nairobi, Kenya. Registered Geospatial Engineer (Land Surveyor and Registered Physical Planner (Kenya)*
Email: smmuketha@uonbi.ac.ke

Riparian zone widths are a subject of controversy, with ecological, hydrological, and regulatory considerations influencing decision-making. In the context of this paper, a riparian extent refers to the transverse measurement of the riparian width from the riverbank to a distance that ensures the highest flood level is contained (Muketha, 2014). This exception applies to coastal or low-lying areas adjacent to water bodies. In Kenyan legislation, 30 metres has been used as a fixed distance from various reference points. For purposes of this paper, 30 metres is used. The ecological condition refers to the presence of vegetation cover associated with aquatic ecosystems, as well as the absence of agricultural crop vegetation that is incompatible with the functions of these zones. It entails the absence of incompatible structures, solid and liquid wastes, and building materials. It also denotes the absence of garages, quarry mining and so on.

Native vegetated riparian buffers have a powerful relationship with the presence and integrity of native vegetative cover (Jture, 2018). According to Jture, these vegetated buffers are significant for pollutant filtration, stream bank stabilization, and wildlife habitat. Waste materials and the placement of incompatible land uses have the potential to degrade these valuable ecosystems.

The native vegetation in the riparian area serves a variety of ecological roles, including shading the streams to regulate water temperature, providing organic material to aquatic ecosystems, and stabilizing the soil to prevent erosion (USDA, 2024). The argument is supported by the USDA Climate Hubs, which note that restoration or enhancement of diversity in native tree and plant vegetation in the riparian area increases shading in the streams, creates a source of woody material for the aquatic ecosystem, stabilizes the soil, and improves the wildlife habitat connectivity (USDA, 2024).

Problem Statement

While past research has identified sources of riparian zone encroachment and pollution, few studies incorporate geospatial technologies, such as GIS, remotely sensed data, and the KoBo Collect, to assess the physical extent and condition of these zones in urban areas. For instance, Masese (2021) focuses on rural Kenyan rivers, excluding urban stressors like informal settlements. Similarly, most worldwide riparian investigations focus on developed regions and overlook socio-political dynamics at work in African cities (Allan, 2004). The current study addresses these gaps by combining real-time field data using Kobo Collect, GIS mapping, and policy analysis. The study applies multiple approaches and techniques to assess encroachment and degradation resulting from anthropogenic activities that impact the physical extent and ecological conditions of the riparian zones. The study offers context-specific strategies that refine generic conservation models and address Kenya's unique riparian zone problem.

The legislative and policy environments in Kenya, including the Physical Planning Act (2019), Water Resource Management Act (2007), Physical Planning Handbook (2019), and Survey Act (2012), form a strong basis for assessing and managing the physical extent and ecological conditions of riparian zones in Nairobi River Basin. However, the glaring contradictions in these policies evince the need for the study.

Study Objectives

i). To assess the effects of human activities on the physical extent and ecological conditions of riparian zones in Nairobi City County
ii). To identify the drivers of anthropogenic activities contributing to the encroachment and degradation of riparian zones in the Nairobi River Basin.
iii). To propose strategies that promote the appropriate physical extents and ecological conditions of riparian zones in urban areas.

THEORY

The Common Pool Resource Theory

Common-pool resources (CPR) theory addresses the regulation and management of public goods and collective action (Kolioulis, 2022). The theory targets the community's role in regulating resources, mainly where resources like riparian zones are contentious in their demand (Bingham-Hall, 2016). A study by Ostrom (1990) demonstrated that local communities can manage shared resources sustainably through self-governance systems, contradicting the hypothesis that centralized control or privatization is always the best practice. This model is particularly applicable to the riparian zones of Nairobi, where poor urban settlements encroach into environmentally sensitive regions due to a lack of strict regulatory controls (Karangi, 2017). Through an interface with conservation activity at the grass-roots level, common-pool resources (CPR) theory is bottom-up oriented as a mechanism of reducing human-related pressures via social ownership and management adaptation (Cooke, 2018).

Convergence with the Tragedy of the Commons

The theory diverges from the tragedy of the commons, as Garrett Hardin famously outlined, which argues that individuals seeking their self-interest will overexploit common resources and deplete them (Hardin, 1968). The common-pool resource theory counters by advocating for collective control and regulation of resources and insisting that sustainable practices can be established through social interaction and cooperation. This perspective is based on the belief that adequate common pool resources can prevent the tragedy of the commons by encouraging collective action and shared responsibility among community members (Kolioulis, 2022).

Criticism and Urban Issues

CPR theory has been criticized for its shortcomings in highly urban and politically fragmented settings, such as Nairobi, where numerous stakeholders and institutions are weak, thereby complicating the formation of a consensus. Hardin's (1968) concept of the "tragedy of the commons" suggests that in the absence of strict regulatory controls, shared resources are prone to overuse.

CPR theory addresses these challenges, though, by valuing nested systems of governance, including grassroot committees as opposed to municipal governments especially adaptive mechanisms that merge scientific data with local knowledge (Washington, 2024). Despite these challenges, common-pool resource theory advances this research by emphasizing the importance of participatory planning and management of riparian zones. Involving local communities in Nairobi would help solve problems such as trash disposal and illegal encroachment, while cultivating a sense of ownership of riparian resources, just as described by (Ostrom., 1990).

Urban Political Ecology (UPE)

Developed by Erik Swyngedouw and Maria Kaika in the 2000s, urban political ecology (UPE) studies environmental decline from a political-sociological perspective, focusing on power structures that determine urban ecological outcomes. The theory also highlights that low-income individuals often lack access to waste infrastructure, which exacerbates riparian pollution (Swyngedouw, 2004). However, according to Heynen et al. (2006), a deficiency in UPE is that it focuses too much on power structures at the expense of practical measures, such as grassroots-level waste collection programs. The theory is applicable in this research because it explains why industries and informal sectors, such as the Mukuru Kayaba case in Nairobi, often dump waste in riparian zones. After all, enforcing measures is weak.

Social-Ecological Systems (SES) Framework (solution theory)

The Social-Ecological Systems (SES) Framework, proposed by Elinor Ostrom (2009), is based on the interdependence of social and environmental systems, with a prescription for locally based government and institution-based cooperation in conserving common resources. The approach is to promote local participation and reform in riparian degradation. In the context of this study, locally based measures in conservation, which involve awareness-raising activities and stakeholder participation, are crucial in restoring Nairobi's rivers. For instance, informal settlers, as well as government agencies such as NEMA, are obligated to work on reclaiming riparian areas (Ostrom, 2009). In contrast, however, with a high rate of urbanization in highly populated areas, locally based conservation is not easy due to a fractured government approach (Colding, 2013).

Pressure-State-Response (PSR) Model

The PSR model, developed by Rapport and Friend (1979) and made popular by the OECD (1993), is a framework widely used to examine environmental issues by linking human activities (pressures), environmental state (state), and societal responses (responses) (Smith, 2016), (OECD., 1993). It assumes a cause-and-effect chain in which anthropogenic pressures, such as pollution or land-use change, deteriorate the state of ecosystems and trigger societal responses, including policy efforts or restoration initiatives. (Hu, 2022).

Scholars argue that PSR offers a consistent and straightforward approach to examining environmental degradation, making it an appropriate method for assessing riparian zones in Nairobi City County. For example, urbanization and industrial activities pressure riparian zones, contributing to their degraded state and reduced vegetation cover and water quality, as described by (Mbugua et al., 2020). Responses can include policy reform or reforestation to mitigate these impacts as outlined by Muketha (2020).

However, some researchers accuse PSR of oversimplifying complex ecological systems, taking the example of Carr et al. (2007), who argue that its cause-effect approach is linear and thus cannot account for feedback mechanisms and natural variability in ecosystems (Carr, 2008). Furthermore, Niemeijer and de Groot (2008) note that PSR tends to overlook socio-economic drivers of pressures, which are particularly relevant in urban centers like Nairobi. Despite these criticisms, the PSR framework is suitable for this study in that it provides a structured approach to identifying and examining the anthropogenic pressures on riparian areas, their ecological status, and responses. For instance, one can utilize it to map how informal riverine settlements in Nairobi exert pressure through waste disposal, resulting in water quality degradation and vegetation loss (Muketha, 2020). The PSR and the Socio-ecology system (SES) are the proponent theoretical frameworks of the study, guiding sustainable riparian zone conservation in the Nairobi River Basin as it integrates the pressures, state and responses in the Nairobi River Basin **Figure 1**.

Effects of Human Activities on the Physical Extent and Ecological Conditions of Riparian Zones

Anthropogenic activities are defined as intentional, non-malicious human actions that directly or indirectly alter natural systems, often leading to environmental degradation or hazard interaction (ECOS, 2025). These activities include pollution, deforestation, urbanization, industrialization, and overexploitation of natural resources. The term "anthropogenic" originates from the Greek word anthropogenes, meaning "born of humans," and is used to describe changes in nature caused by human actions, such as rerouting rivers or clearing forests for agricultural purposes (Vocabulary.com, 2025). Gill et al. (2017) categorize these

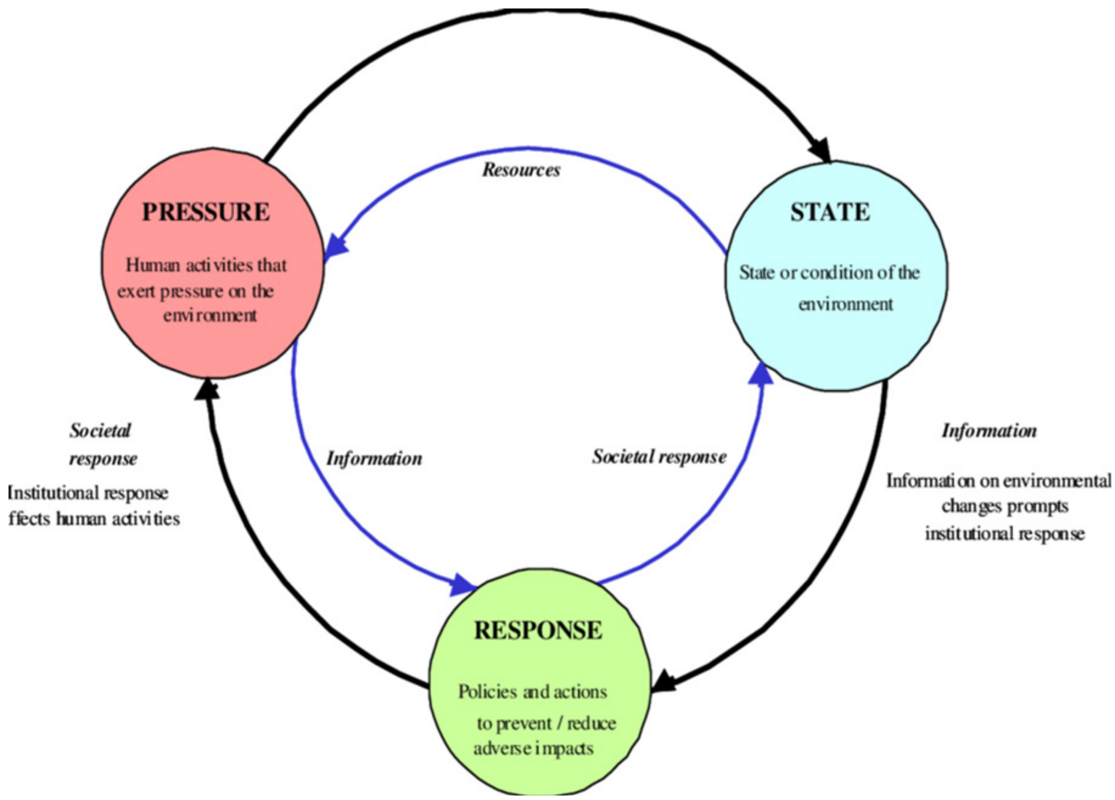


FIGURE 1
Pressure state theory model
Source: Waheed, (2009) adopted from B. Veitch (2009)

processes into subsurface processes (e.g., mining, groundwater extraction) and surface processes (e.g., forest clearing, urbanization), which alter landscapes and disrupt ecological equilibrium. Just as described by Gill et al. (2017) this definition will be very important in the study since it asses the impacts of the anthropogenic activities to the riparian zones of Nairobi River Basin.

The effects of human activities include river pollution. This refers to the introduction of harmful substances into river systems from point sources (e.g., industrial discharges) or non-point sources (e.g., agricultural runoff and urban stormwater). Carr and Neary (2008) explain that contaminants, including solid waste, are made up of non-biodegradable materials such as plastics (bottles, bags, wrappers), Metals (cans, scrap metal), and Glass (bottles, broken pieces). Rubber (tyres, footwear), Synthetic textiles (clothing, fabric scraps). Construction debris, such as concrete and tiles, which is not organic, is clogging the rivers. They went further to describe the bio-degradable waste, which included Organic waste (food scraps, plant debris), Animal waste (manure from livestock), and Paper products (cardboard, paper bags). These materials, although biodegradable, contribute to pollution when disposed of in large quantities, as they decompose and deplete oxygen levels in the water, harming aquatic life and threatening aquatic ecosystems.

River pollution leads to river degradation. It refers to the decline in the physical, chemical, and biological integrity of river systems. It is widely attributed to persistent pollution, hydrological modifications (such as channelization and damming), and sedimentation processes. Fakayode (2005) and Muiruri et al. (2013) demonstrate that continuous inputs of contaminants and alterations in natural flow regimes resulting from urban expansion led to significant morphological and ecological changes. Some authors e.g., NEMA (2004) argue that degradation is an almost inevitable consequence of cumulative human impacts. In contrast, others, such as Palmer (2008), suggest that such degradation can be reversed or mitigated through targeted interventions. Thus, while there is explicit agreement that human activities cause river degradation, a notable contradiction exists regarding its reversibility: one view sees the process as a permanent transformation of the ecosystem, whereas another sees it as a challenge that can be addressed through integrated management and restoration.

Crop production of agricultural products, such as maize and beans, is often incompatible with maintaining ecological integrity (Ngome et al., 2011). Ngome argues that crops lack the suitable root system to keep the soil in place, resulting in excessive soil disturbance that causes erosion and sedimentation in waterways. This finding aligns with a study on the Kenyan rivers Njoro and Kamweti, which found that crop production results in excessive siltation and sedimentation that affect plant diversity and complexity (Koskey et al., 2021). Conversely, the planting of perennial shrubs, such as tea bushes, along riparian areas can be ecologically beneficial, as they have deeper roots that hold the soil in place, decrease erosion, and keep the ground covered year-round (Sepúlveda & Rafael, 2018). Although there are no specific studies on tea bushes in riparian areas, the overall concept of stabilizing riparian areas with deep-rooted perennial vegetation is firmly rooted in riparian management literature.

Solid and liquid waste disposal within riparian zones considerably deteriorates the ecological services. Waste materials have the potential to leach into watercourses, damaging aquatic ecosystems and reducing water levels (James et al., 2000). Reducing soil disturbance and preventing the exposure of mineral soils are key factors highlighted by the USDA Forest Service for maintaining adequate riparian buffers, with special emphasis on keeping waste materials away from the buffer zones (Phillips et al., 1998).

Intensively disturbed soil land use the introduction of chemicals, or the establishment of infrastructure are not consistent with the conservation objectives for the riparian zone (NAP, 2018). These land-use types lead to habitat fragmentation, biodiversity loss, and degradation of water quality. Human occupation or use of the riparian zone for urban development or agriculture has resulted in widespread impacts, altering the hydrology, geomorphology, and vegetation (National Academies Press, 2002).

Throwing away construction waste, such as tiles and rubble, along the riparian strips may inhibit the natural growth of plant life, disrupt the soil's chemistry, and block water flow. It is essential that waste products, such as these, are removed from the strips so that ecological processes within these strips can occur (Alexander & Greber, 1991). Removing dead and dying trees that will eventually fall into the channel or stream should take priority over the demand for construction refuse in these strips (Vermont Fish & Wildlife Department, 2019).

Drivers of Anthropogenic Activities that Contribute to the Encroachment and Degradation of Riparian Zones

Turner et al. (1990) describes human activities as "transformative processes driven by societal needs, such as agriculture, urbanization, and resource extraction, which modify land cover and ecosystem functions." Similarly, Ellis (2015) frames these activities within the Anthropocene, emphasizing their role in reshaping biophysical environments through industrialization and population growth. Vitousek et al. (1997) further categorize human activities as "dominant drivers of global ecological change," stressing their capacity to disrupt biogeochemical cycles and biodiversity. Collectively, these definitions underscore how human activities in the Nairobi River Basin, such as waste disposal and urban expansion, directly compromise the integrity of the riparian zone. The concepts of human activities and anthropogenic activities are used interchangeably in the paper.

Other studies consider anthropogenic activities as human-induced. These are anthropogenic activities that explicitly degrade the ecosystem changes brought about by human actions (Folke, 2011). Prodanova et al. (2023) describe these as deliberate modifications, such as industrialization, urbanization, and the development of transportation networks, that degrade ecosystems through pollution, habitat fragmentation, and hydrological interventions. Steffen et al. (2015) noted that these activities often arise from "short-term economic priorities over long-term sustainability," as exemplified by unregulated industrial discharges into rivers. These scholars collectively argue that human-induced activities compromise riparian zones by fragmenting habitats and altering hydrological regimes.

Lambin et al. (2001) define Land use as "the arrangement of human activities across landscapes, including agriculture, infrastructure, and residential development, which directly influence ecological processes." Foley et al. (2005) link land use changes to "trade-offs between ecosystem services," such as converting riparian buffers to farmland, which erodes flood regulation and water filtration capacities. Turner and Meyer (1994) emphasize that land use patterns reflect "socioeconomic demands and policy frameworks," with informal settlements and industrial zones, such as those in the Nairobi River Basin, leading to riparian erosion and pollution. These perspectives highlight how land use decisions in the basin contribute to the reduction of the physical extent and ecological degradation of riparian zones.

Strategies that Promote Appropriate Physical Extents and Ecological Conditions of Riparian Zones in Urban Areas

Drawing on Urban Political Ecology by Swyngedouw (2004) and the Social-Ecological Systems (SES) framework by Ostrom (2009), effective restoration must simultaneously address the physical and ecological degradation of river systems, as well as the socio-political processes that characterize informal settlements. Technically, River Restoration Theory as prescribed by Palmer (2008), provides a blueprint for restoring natural hydrological regimes, re-meandering channels, replanting native riparian vegetation, and controlling sources of pollutants. These are all required to restore water quality, increase habitat heterogeneity, and resurrect ecological processes suppressed by industrial effluents, sedimentation, and infrastructure modifications.

Globally, the Restoration Project in Seoul, South Korea, is a notable example of how state-driven restoration of a natural stream corridor supported by extensive public involvement transformed a highly channelized and degraded urban watercourse into a successful ecological and social asset (Cheonggyecheon Restoration Project, 2003). At the African level, rehabilitation efforts in the Msimbazi River in Dar es Salaam, Tanzania, have demonstrated that combining infrastructural improvements with community-led interventions can successfully reduce pollution levels and restore the ecological functions of river stretches adjacent to informal settlements (Sawe, 2021).In Kenya, activities of the Nairobi River Clean-Up Organization illustrate how grassroots efforts at the local level in partnership with government institutions have succeeded in reversing degradation along parts of the Nairobi River basin where slum dwellings are prevalent (Nairobi River Clean-Up Organization, 2012).

Fixed versus Variable Riparian Zone Widths

Fixed-width riparian zones have been employed traditionally because they are simple to enforce and administer. However, studies have shown that fixed riparian widths may not adequately consider site-specific conditions, such as slope, soil type, and land use, which are influential parameters that affect the effectiveness of a buffer in filtering contaminants and stabilizing banks (Richard et al., 2000). For instance, the USDA Forest Service recognizes that while fixed-width buffers are easier to manage, they may prove inefficient under non-uniform runoff conditions; therefore, buffer width should be varied according to runoff loads and site conditions. (USDA, 2008).

According to the U.S Department of Agriculture, Variable-width buffers, in contrast, are planned to adjust according to the particularities of the landscape, giving more efficient protection by considering variables such as topography and hydrology. Evidence shows that variable buffers, encompassing several tiers that differ in terms of habitat structure and ecological role, can integrate with the riverscape approach, presenting a judicious method of maintaining biodiversity and ecosystem processes at different spatial scales. (Graziano et al., 2022).

Implications of Riparian Width Variability

Riparian width variability has profound ecological and management implications. Narrow fixed-widths may be inadequate in high-slope or high-runoff situations, where they can enhance sedimentation and nutrient loading into water bodies (USDA, 2008). Variable-width zones that respond to landscape features can enhance pollutant removal efficiency and habitat connectivity. For example, a review of the scientific literature on riparian zone width reveals that wider buffers are more effective at capturing sediments and nutrients, thereby improving water quality (Wenger, 1999).

Geographic Information Systems (GIS) have become essential tools in the precise delineation of riparian zones (Shutter et al., 2020). By examining spatial data, GIS can determine the width of riparian zones, quantify the impacts of land use, and help create management plans that consider both ecological processes and regulatory requirements (Yang, 2007). One notable example is the study of the River Njoro Watershed in Kenya, where GIS was utilized to track the dynamics of riparian buffer strip soils in conjunction with land-use management, underscoring the importance of spatial analysis for effective riparian management. (Enanga et al., 2011).

The Round Table on Palm Oil (RSPO), as best practice recommends variable/adaptive buffer zones to river width, ranging from 5m for rivers 1–5m wide to 100m for rivers over 50m wide, with more extensive reserves around biodiversity hotspots or village water sources (Lucey et al, 2018). The widths of riparian zones vary according to ecological and hydrological needs. However, fixed-width determinations are used and may be inappropriate due to the differences in watercourses, as they widen from their source to mouth as they collect more water from tributaries (Vannote, 1980).

On the other hand, the Government of British Columbia, Canada (2025), in "The Forest Practices Code of British Columbia Act", defines Riparian Management Areas (RMAs) as a function of stream size and surrounding ecosystems. The RMAs comprise a strictly reserved reserve zone and a management zone, which allows for controlled activities. The sizes vary from 10m for minor streams to over 100m for significant rivers or lakes with high ecological value (Government of British Columbia, 2025).

Omollo (2023), concludes that intrusion into the riparian reserves continues to increase due to insufficient development control, the absence of a common unified legislative framework, and a lack of monitoring to curb anthropogenic activities. However, Karangi (2017) observes that the Water Resource Management Rules (2007), derived under the Water Act, define riparian reserves as a minimum of 6 meters and a maximum of 30 meters from the riverbank. The Rules fail to explain under what conditions the minimum or maximum should be used.

Conflicting interpretations of the points of reference when taking riparian width measurements compound the enforcement of policies and laws (Makindi, 2024). The National Environment Tribunal (2006) required measurements from river centerlines, whereas the Survey Act (2012) and Water Quality Regulations (2006) specified distances from the high-water mark. These differences have enabled informal settlements and industrial infrastructure to encroach upon 39.6% of the Nairobi River Basin's urban areas, thereby eroding riparian buffers and destabilizing riverbanks (Muketha, 2012). Mbugua (2020) supports this with his study Conducted on the Ngong, Mathare, and Nairobi rivers, the study found that solid waste resulting from anthropogenic activities, including industrial effluents and encroachments, clogs the rivers, leading to public health issues and threatening water security.

Regulatory Perspectives in Kenya

In Kenya, there have been multiple definitions of the width of riparian zones under various pieces of legislation. EMCA (2006) describes a minimum and maximum distance of 6 meters and 30 meters from the riverbank, respectively, based on the highest recorded flood level. The same is specified under the Water Resource Management Rules of 2007, which also limit this range due to the protection of water resources. However, the Agriculture Act Cap 318 (1965) provides a buffer of between 2 meters and 30 meters, without specifying a point of reference to base the measurement on. This disparity has led to enforcement challenges and potential encroachment into riparian zones. **Table 1** represents different laws with different riparian widths.

Conceptual Framework

This study assesses the effect of human activities on the physical extent and ecological condition of riparian reserves in the Nairobi River Basin **Figure 2**. Residential, commercial, and industrial areas, both formal and informal, have been significant contributors to the encroachment and degradation of riparian zones. This has compromised the

TABLE 1
Different riparian widths

Law/Regulation	Riparian Zone Requirement
Survey Act, Cap. 299	Section 111. Reservation on all tidal rivers to a minimum width of 30 meters above the highest water mark. No mention of other smaller rivers. However, non-tidal rivers are not considered in the legal definition
Water Resource Management Rules, 2007	A minimum of 6m and a maximum of 30m from the riverbank. The riverbank is subject to erosion. The Act does not specify when to use 6m or 30 metres
EMCA (Conservation and Management of Wetlands) Draft Amendment Regulations, 2017	9(1) Shores of lakes are protected zones of 50m from the highest water mark, the shore of the ocean is 60m, and rivers are 30m.
EMCA (Water Quality Regulations), 2006	Minimum 6m and maximum 30m from the edge of the river, based on the highest recorded flood level.
Lands Act, 2012	Land adjacent to the ocean, lake, sea, rivers, dams and watercourses as provided in the Survey Act or any other written law. The Survey Act is yet to be aligned with the Constitution of Kenya 2010
Physical and Land Use Planning Act 2019	A minimum reserve of 10 meters or twice the river's average full width (whichever is greater), capped at 30 meters from the highest water mark.
Physical Planning Handbook, 2008	Land on either side of the watercourse must be at least 2 meters wide, or the river's full width (up to 30 meters for seasonal and perennial rivers) between banks.
EMCA 1999 (Amended 2015)	Minimum of 6m and maximum of 30m from the edge of a river.

Source: (Makindi, 2024) and the Republic of Kenya Acts and Regulations

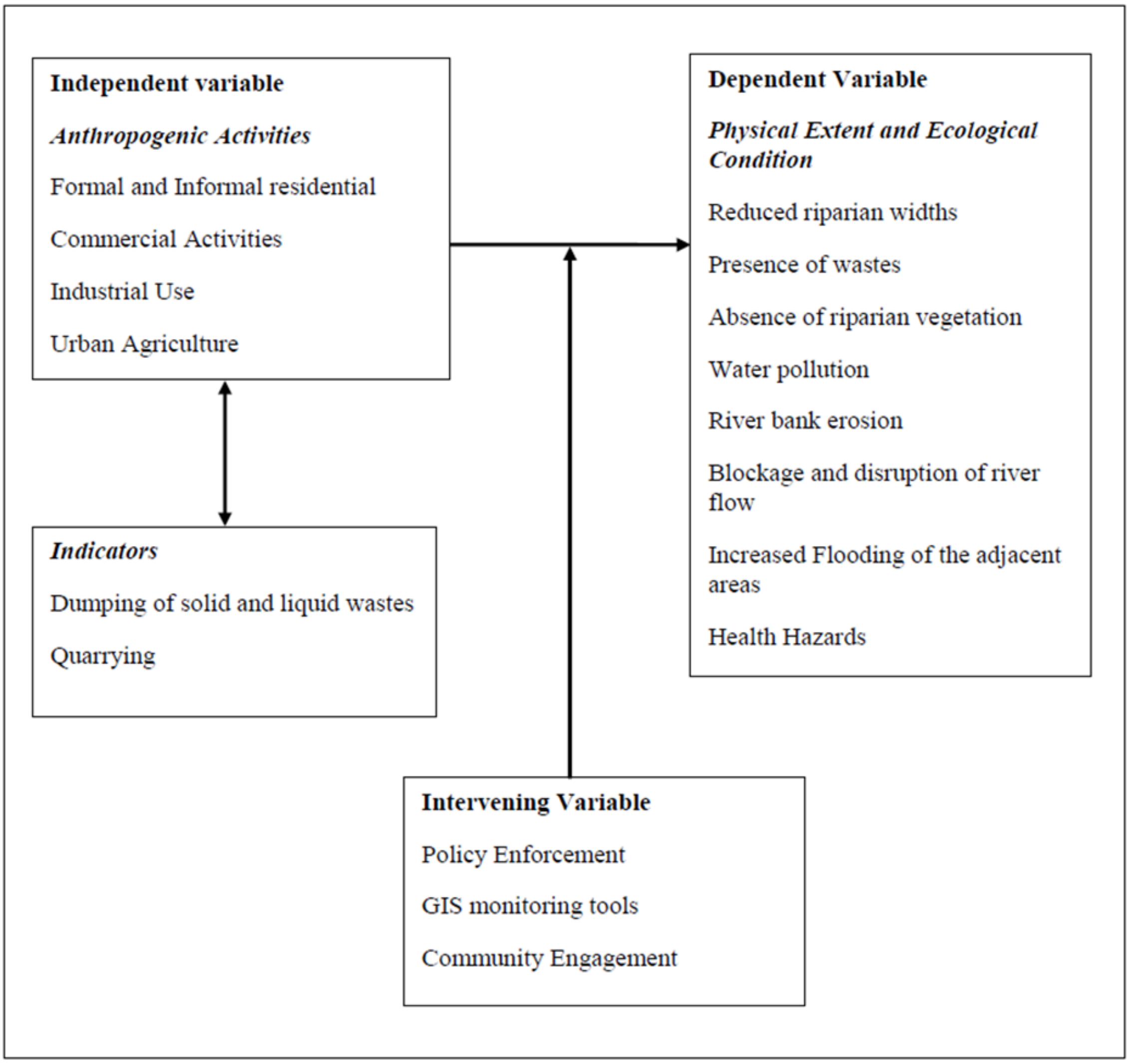


FIGURE 2
Conceptual framework
Source: Field survey, 2025

integrity of the rivers in Nairobi city. Industrial and domestic pollution, including the presence of structures that reduce riparian widths, as well as the presence of plastics and untreated effluents, contributes to poor water quality and a decline in riparian biodiversity. These indicators are measured using geospatial analysis, observations, and surveys to track changes in vegetation cover, soil erosion, and the extent of pollution. Extraneous variables, including government policy and public awareness, influence the rate of riparian zone encroachment and degradation. These were measured through legal framework analysis, public participation surveys, and historic socio-spatial data to determine their role in reducing or increasing human activities on riparian zones.

RESEARCH METHODS

Research Design

Reviewed studies reveal several approaches, including qualitative and quantitative. The study primarily employs a mixed-methods approach, utilizing GIS mapping and a descriptive survey. It employed a de-scriptive cross-sectional study to investigate the implications of anthropogenic activities on the physical extent and ecological quality of riparian zones. Therefore, the study adopted a descriptive research de-sign, utilizing both quantitative and qualitative approaches.

Location of the study

Population

Nairobi City County is the capital of Kenya, which is experiencing rapid population growth **Figure 3**. The formal city covers approximately 30 percent of the total area, leaving the rest to grow informally. Poor enforce-ment and lack of a riparian zone policy have exacerbated the riparian zone problem. Studies have shown that over 60 percent of the areas remain informal, and this is considered the leading cause of encroach-ment and degradation of the zones.

Sampling

A purposive sampling strategy was employed to select the rivers for the study. Nine significant rivers traverse the city. However, three rivers, specifically the Nairobi, Ngong, and Mathare Rivers, were se-lected for study because they are the longest and most expansive. Secondly, they traverse through histor-ically high-density zones of the city. Thirdly, most informal settlements in the city are situated along the three. Convenient sampling of river sections was conducted, depending on accessibility and the river's steepness. Areas considered risky for data collection were excluded. However, spatial data collection using Kobo Collect was not to exceed 100 metres apart.

Inclusion and Exclusion Criteria

Data was collected from the rivers traversing Nairobi City County. However, the study focused on Nai-robi, Ngong, and Mathare rivers. The three rivers were selected because they are the primary and most degraded rivers in the Nairobi River Basin. The study excluded the following areas: Ruiruaka, Gitathuru, Mbagathi, Kamiti, Kiuu, Kirichwa, Riara, Mutuari, and Kasarani. These are small in width, with some measuring only two metres. Additionally, some areas are located at the city's periphery and are less de-graded.

Data Collection

A mixed-methods approach was employed to investigate the implication of anthropogenic activities on the physical extent and ecological quality of riparian zones in the Nairobi River Basin. The study uti-lized both primary and secondary data collection methods to ensure comprehensive analysis. The meth-ods integrate geospatial technologies (GIS, satellite imagery, Kobo Collect) for spatial analysis of physi-cal extent changes, coupled with field surveys to collect primary data on ecological quality/conditions.

Secondary data sources, including policy documents and historical records, were analyzed

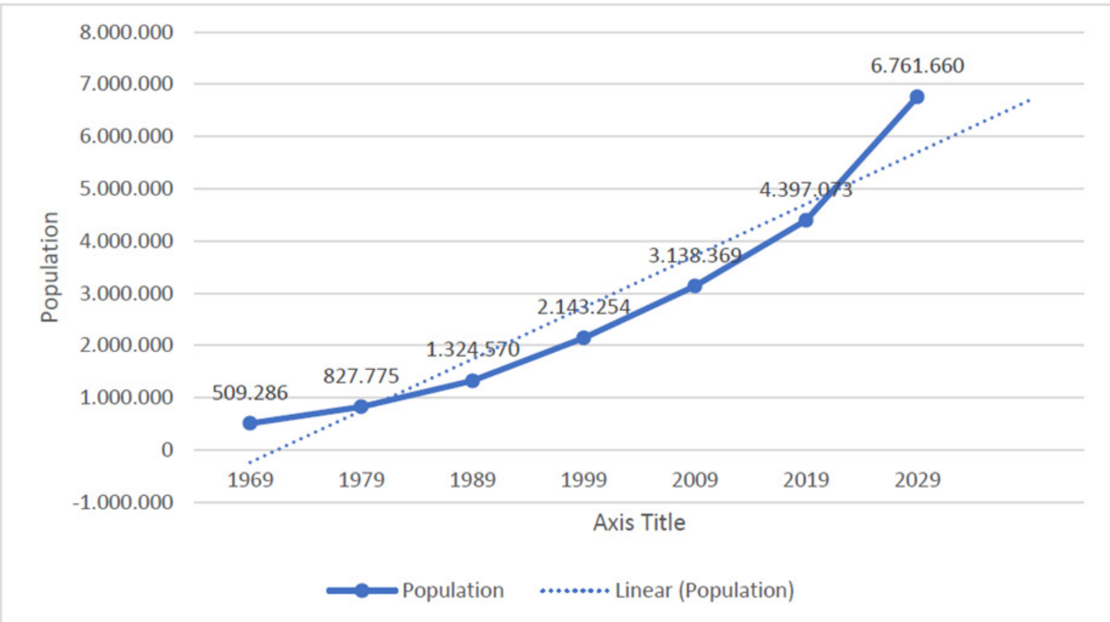


FIGURE 3
The population of Nairobi City County from 1969 to 2029 as compiled from economic survey
Source: KNBS, 2025

to provide context for understanding enforcement challenges. Secondary data collection included government re-ports and documents sourced from the Physical Planning Act Legal Notice No. 140, sections (c) and (d) of 1996, the Water Resources and Management Act 2007, and the Survey Act of 2012, among others, to assess past policy responses. Published research, cadastral maps and satellite imagery were reviewed for evaluation of physical extents and ecological conditions.

Primary Data Collection was conducted using the Kobo Collect mobile App, which enabled digital input of answers to questions, GPS mapping and photographic documentation. By triangulating spatial, eco-logical, socio-political and policy data, the study provides a comprehensive diagnosis of riparian en-croachment and degradation, while proposing context-specific strategies that align with its objectives to analyze, explain, and mitigate anthropogenic pressures in urban riparian systems.

Research Instruments

The study employed geospatial tools, including the Kobo Collect toolbox. The toolbox contains GPS, which gives the point of data collection. It also enables photography and data entry. Kobo Collect is a mobile application that was used for data collection and analysis. Further descriptive data analysis was conducted using Microsoft Excel. GIS data analysis and modelling tools were employed for spatial visu-alization. Google Earth imagery was used to create the base map for the fieldwork. Strip plans were cut out to form a continuous strip of the river channels. The imagery was overlaid with the cadastral plans along the rivers.

Google Earth Pro was also used to capture the current trend and state of the zones. Key informant inter-view schedules and direct observation checklists were the other instruments.

Threats to Internal Validity

Data availability, especially the cadastral maps, was a challenge as not all maps could be accessed. This was overcome by picking walls and hedges as they existed in the Google Earth imagery. Some areas along the rivers were inaccessible for data collection. Once again, Google Earth proved to be of great use. The involvement of multiple researchers could have unintentionally influenced the data output, po-tentially leading to biased results that may have compromised the data integrity. To mitigate these risks and biases, the study employed structured data collection tools to compare information from various sources and ensured consistency in the recording and analysis of data. These steps helped improve the validity and reliability of the findings.

Data Collection Procedures and Analysis Techniques

KoBo Toolbox was the primary data collection tool in the field. It is an open-source tool for mobile data collection, available online for free. The tool enables data collection using mobile devices, including smartphones, tablets, and laptops. The data-driven application enables the collection of real-time data. It ensures efficiency in data collection and complete integration. It features a mobile application (app) that includes a GPS (Global Positioning System), digital compass, camera, voice recorder, and barcode read-er.

The tool was customized to capture information needs for the study. The versatility of the tool enabled the digital input of questions, thereby avoiding the need for physical questionnaires. The data was ac-cessed from a remote database. One advantage of the tool is that the areas covered were automatically reflected in the database. This capability ensured that no gaps were left along the rivers, resulting in a representative output. This proved helpful because various teams were used during the study.

To install and set up Kobo Collect or Kobo Toolbox, the Google Play Store was opened on a mobile de-vice. In the search bar, “Kobo Collect" or "Kobo Toolbox” was typed. and the corresponding application from the results was then selected. The Install button was clicked, and the app was downloaded and installed successfully on a mobile device. Once the installation was complete, the Kobo Collect app was opened.

In the top-right corner of the screen, the three-dot menu was clicked and navigated to General Settings. Under Server Settings, the URL field was located and updated to https://kc.kobotoolbox.org/nairobiriverbasin to ensure the app connected to the correct database source.

After configuring the server settings, “Get Blank Form" was clicked to retrieve the available survey forms from the server. From the list of available forms, the 'Nairobi Rivers Mapping Demo' was select-ed, and then the 'Download' button was clicked. Once the download was complete, the Fill Blank Form section was opened and the team proceeded with data collection.

Data Presentation Techniques
The data were presented qualitatively through descriptive-analytical reports and journals, and quantita-tively through bar graphs, pie charts, photographs, figures, and tables. Quantitative data were presented using Tables, graphs, charts, and maps. Qualitative data were presented using descriptions of physical and ecological conditions, photographs, mapping, and testimonies from residents.

RESULTS AND DISCUSSION

Effects of human activities on the physical extent and ecological conditions of riparian zones in Nairobi City County

Anthropogenic Activities on Physical Extent
a) Disruption of River Flow
The accumulation of solid waste, particularly in the Ngong and Nairobi Rivers, has altered the natural flow of water, leading to blockages and stagnant water pools. Dumping waste has narrowed river chan-nels, reducing their capacity to handle the amount and intensity of rainfall, and increasing the frequency and severity of flooding in low-lying areas, such as Kayole, Mukuru, and Mathare **Figure 4**. This finding agrees with Gebrehiwot (2019) and Kiwango (2021), who argue that urbanization and weak governance in Afri-can cities lead to severe encroachment, resulting in the narrowing of river channels.

b) Increased Flooding and Erosion
The study found that occupation of riparian reserves by informal settlements and commercial develop-ments has reduced the natural flood buffer zone, making urban areas highly vulnerable to flash floods **Figure 5**. This agrees with Mbugua (2020), who identified informal settlements in riparian zones as a significant cause of reduced buffer zones, increasing flood risks. In areas such as Mathare, Kariobangi, and Korogocho, informal settlements built on riparian land are directly exposed to flood risks, resulting in loss of life, property destruction, and community displacement during rainfall. Encroachment removes natural vegetation, which plays a crucial role in stabilizing riverbanks, thereby leading

FIGURE 4
Mathare River narrowed by solid waste
Source: African Cities Research Consortium, 2025

FIGURE 5
Destruction of properties after the Nairobi River flooded
Source: Reuters, 2024

to erosion and sedimentation, and ultimately disrupting river flow.

Anthropogenic Activities on Ecological Conditions

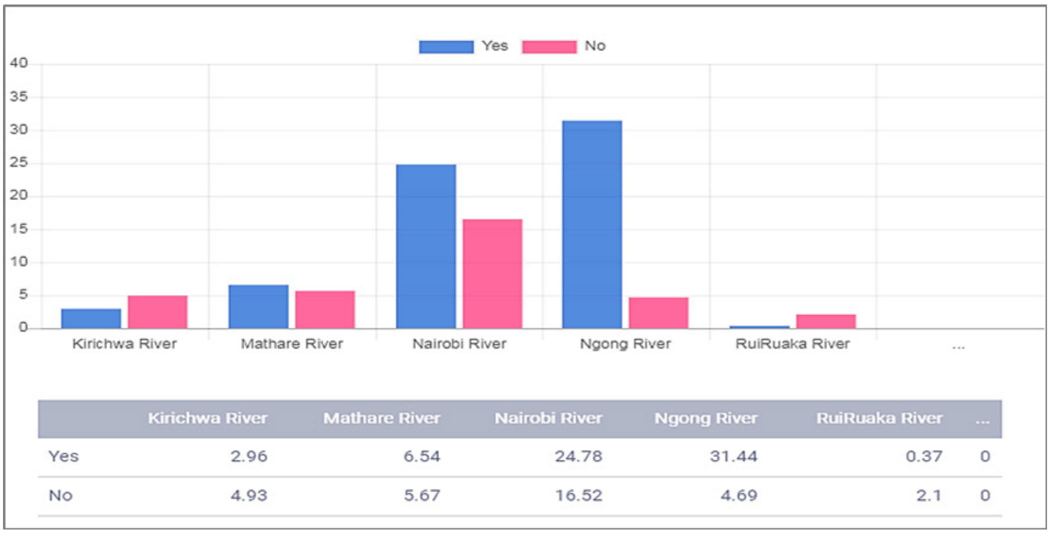
a) Pollution of rivers
The study findings highlight the severe impact of anthropogenic activities on Nairobi's riparian zones, primarily due to the disposal of solid and liquid waste into river systems, which affects the ecological conditions of these zones. The three rivers of Ngong, Nairobi, and Mathare exhibit varying degrees of contamination, depending on the surrounding land-use patterns.

Solid Waste Pollution
Solid waste pollution in Nairobi's riparian zones is a primary environmental concern, primarily from in-formal settlements, planned residential areas, and industrial and commercial establishments. The study found that the most disposed of solid waste are non-biodegradable materials, including plastics (bottles, bags, wrappers), Metals (cans, scrap metal), Glass (bottles, broken pieces), Rubber (tyres, footwear), and Synthetic textiles (clothing, fabric scraps). The finding agrees with Carr and Neary (2008). **Figure 6** illustrates the response regarding the presence or absence of solid waste **(Figure 7).**

Pollution on the Ngong River
The river is the most affected by solid waste dumping, with large heaps of waste altering the river's course and, in some cases, blocking its flow. The most common pollutants include plastic bags, food waste, and other non-biodegradable materials **Figures 8 & 9**.

Condition of Pollution on the Nairobi River
The river is polluted by solid waste in informal commercial areas, such as Gikomba market in Kamukun-ji, and in informal settlements like Kariobangi and Korogocho. Waste is frequently dumped from bridg-es, contributing to extensive river pollution. **Figure 10** shows solid waste at Kiambiu slums.

Pollution on the Mathare River
The Mathare River suffers from the illegal dumping of solid waste, particularly in informal settlements like Mathare and Lucky Summer **Figure 11**. Solid



	Kirichwa River	Mathare River	Nairobi River	Ngong River	RuiRuaka River	...
Yes	2.96	6.54	24.78	31.44	0.37	0
No	4.93	5.67	16.52	4.69	2.1	0

FIGURE 6
Graph showing the presence or absence of solid waste on the riparian
Source: Field survey, 2025

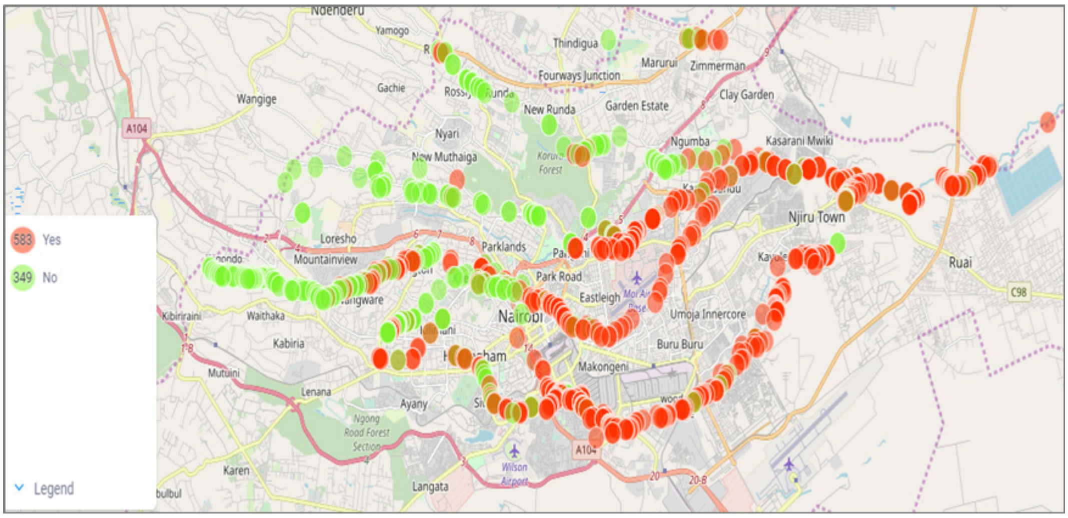


FIGURE 7
Map showing the areas with disposed solid waste in the three rivers
Source: Field survey, 2025

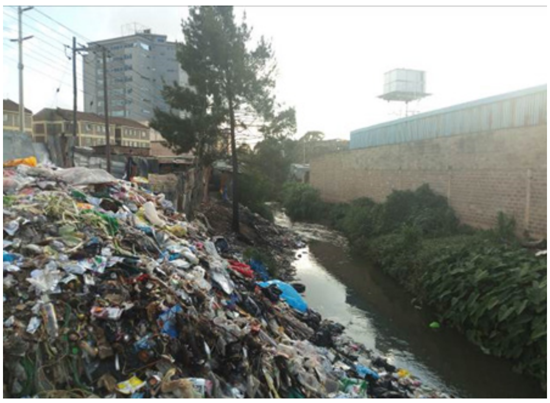


FIGURE 8
Dumping of solid waste on the Ngong River in the South C estate
Source: Field survey, 2025

FIGURE 9
Dumping of solid waste on the Ngong River in Kayole
Source: Field survey, 2025

FIGURE 10
Solid waste disposal in the Kiambui section
Source: Field survey, 2025

FIGURE 11
Pollution in the Mathare River
Source: Christ Hope Mathare, 2025

waste accumulates in the riparian zone, posing seri-ous health risks to residents. Pollution from liquid waste is another significant threat, mainly originating from domestic sources.

Liquid Waste Pollution
Liquid waste pollution is another significant threat, primarily due to the discharge of domestic, industri-al, and commercial waste. The study observed that sewage discharge is common in informal settlements where sewer lines are either nonexistent or poorly maintained. This is evident in areas such as Mathare North, Kariobangi, and Soweto, where raw sewage flows directly into the rivers **Figures 12, 13 & 14**. Industrial pollution is a significant issue in Mukuru Kayaba and Njiru, where factories discharge untreat-ed effluents into nearby water sources. Planned high-density estates, such as Nairobi West, were found to channel wastewater directly into the river, further exacerbating pollution levels. The discharge of in-dustrial effluents and untreated sewage into riparian zones aligns with Gebrehiwot's (2019) observation, which attributes such pollution to weak governance and rapid urbanization in African cities.

FIGURE 12
Sewer from apartments in Ngara draining into the Nairobi River
Source: Field survey, 2025

FIGURE 13
Sewer draining into Mathare River in Mathare North Informal Settlement
Source: Field survey, 2025

FIGURE 14
Sewer draining into Mathare River in Kosovo
Source: Field survey, 2025

b) Public Health Risks

The study found out Stagnant and polluted water bodies in the rivers serve as breeding grounds for dis-ease-carrying pests, including mosquitoes, houseflies, and rats, leading to outbreaks of diseases such as Malaria and dengue fever (from mosquitoes), Cholera, typhoid, and dysentery (due to contaminated wa-ter consumption), Respiratory infections (from toxic fumes and decaying waste). In Dandora near the dumpsite, the Nairobi River has attracted pigs, birds, and other scavenging animals, further spreading waste-related diseases **Table 2**.

c) Loss of Green Spaces and Reduced Ecological Functions

Riparian zones play a crucial role in maintaining urban biodiversity and ecosystem balance by

TABLE 2
Health Issue and the affected population

Health Issue	Affected Population	Prevalence/Incidence	Source
Respiratory Problems	Children and adolescents near Dandora dumpsite	154 out of 328 tested individuals (approximately 47%) suffered from respiratory issues.	ISWA Report
Waterborne Diseases	Residents along the Nairobi River	High prevalence of typhoid, malaria, amoebiasis, and diarrhea due to polluted water sources.	CARI Journals
Blood Lead Levels	Children in Korogocho	Fifty percent of the tested children had blood lead levels above 10 micrograms per deciliter, indicating significant exposure.	UNEP Report
Respiratory Tract Infections	Residents near Dandora dumpsite	Between 2003 and 2006, 9,121 cases were treated for respiratory tract-related problems.	ISWA Report
Skin Disorders, Abdominal Problems, and Eye Infections	Residents near Dandora dumpsite	Common among individuals tested in the area, though specific prevalence rates are not provided.	ISWA Report
Air Pollution-Related Deaths	Nairobi residents	Approximately 2,500 premature deaths (about 15% of the total) in 2019 were attributable to air pollution.	Clean Air Fund

Source: (Chebet, 2017), (Clean Air Fund, 2025), (ISWA Report, 2017),(UNEP Report, 2007) providing habitats for flora and fauna. Due to encroachment, green areas along the Nairobi River, particularly near Kamukunji, Gikomba, and Mathare, have been replaced with buildings, roads, and commercial activi-ties. The destruction of these ecological zones has eliminated natural filtration processes, allowing pollu-tants to enter water systems without being absorbed by vegetation. This finding agrees with Tickner et al. (2020), who reported that urbanization replaces riparian vegetation with concrete infrastructure, thereby removing natural ecological services **Figure 15**.

Drivers of Anthropogenic Activities on the Physical Extent and Ecological Conditions of Ripari-an Zones in Nairobi City County

Physical Extent

a) Rapid Urbanization and Population Growth

The study found that Nairobi's population is increasing at a higher rate on a fixed area of land (696 Km^2) **Figure 16**. Most informal settlements are located close to or within the riparian zones of rivers, primarily due to the availability of affordable housing. Just as highlighted by Makindi (2024). The lack of afforda-ble housing in Nairobi exacerbates this issue, forcing low-income populations to settle in ecologically sensitive areas a phenomenon also noted by Swyngedouw (2004) under Urban Political Ecology (UPE), which links socio-economic inequities to environmental marginalization. In areas such as Mathare, Mukuru, Kariobangi, and Korogocho, anthropogenic activities associated with informal settlements have expanded into riparian zones, thereby reducing the buffer area for flood control and water filtration. Ris-ing urban population has put immense pressure on riparian lands, leading to illegal settlements and commercial activities along the riverbanks as noted by Gebrehiwot (2019).

b) Riparian Zone Encroachment

The study findings reveal that encroachment is a significant physical and ecological challenge affecting riparian zones in Nairobi. Encroachment occurs due to human activities such as informal settlements, commercial developments, and industrial expansion, which gradually reduce the riparian buffer zones meant to protect river ecosystems. The study found that Ngong, Mathare, and Nairobi River are the riv-ers with the highest concentrations of informal settlements near their riparian zones **Figures 17 & 18**. Physical extent reduction due to encroachments aligns with Omollo (2023).

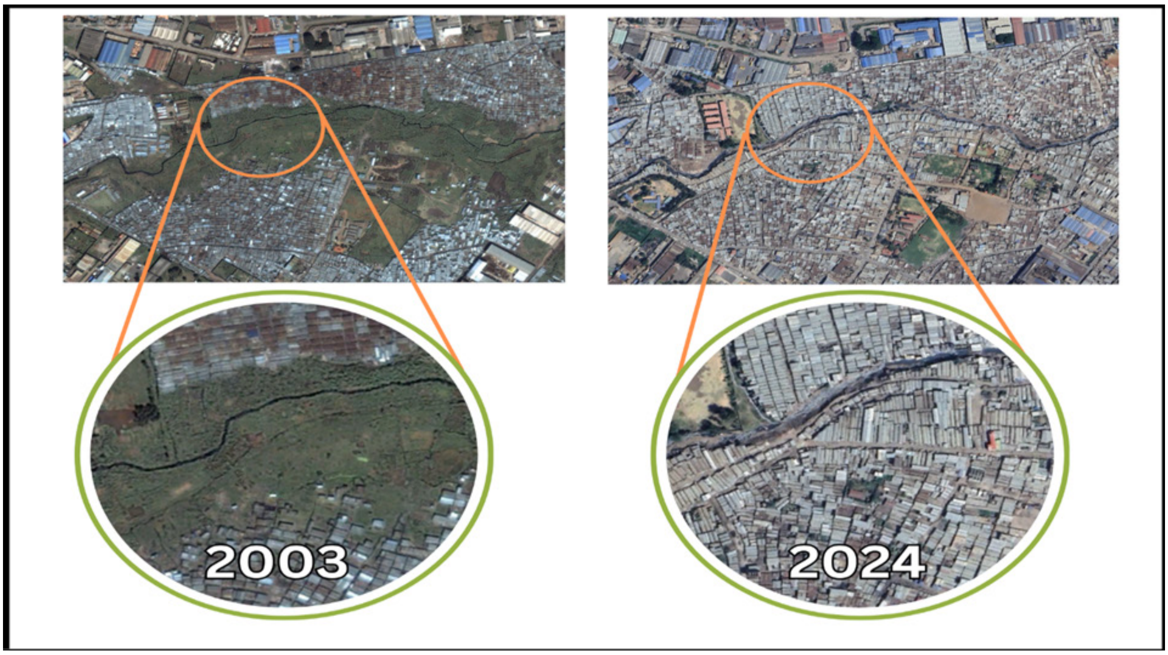


FIGURE 15
Green space replaced with settlements along the Ngong River
Source: Google Earth Imagery, 2003 & 2024

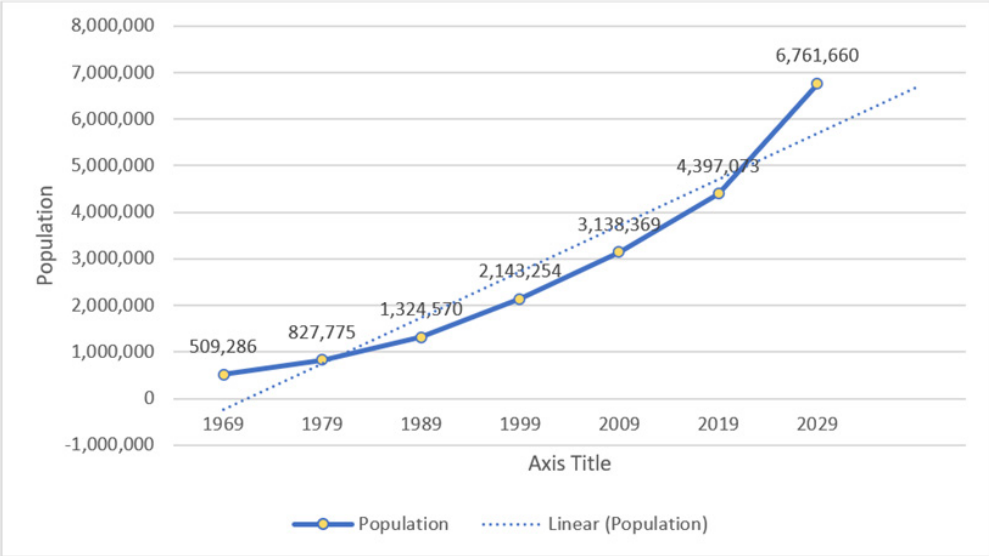


FIGURE 16
Nairobi's Population (1969-2019)
Source: KNBS, 2025

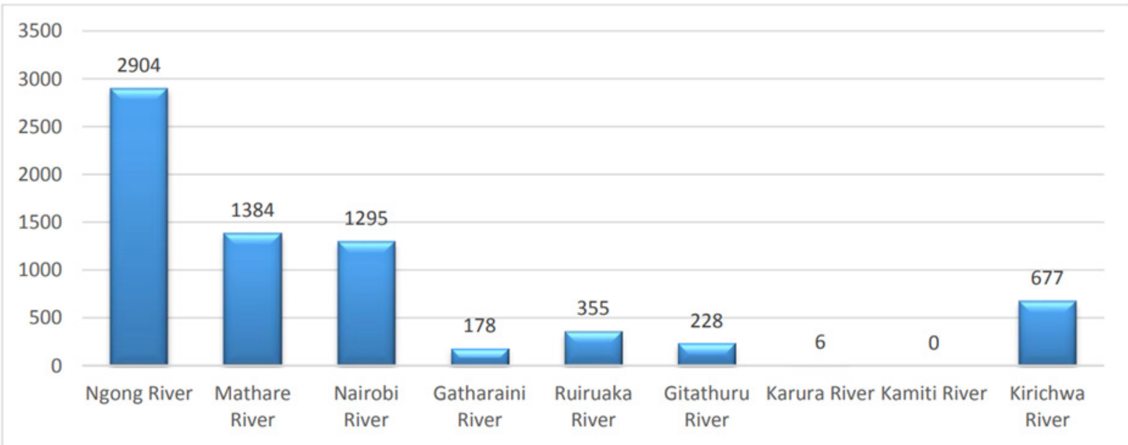


FIGURE 17
Number of Informal settlements near the rivers
Source: Field survey, 2025

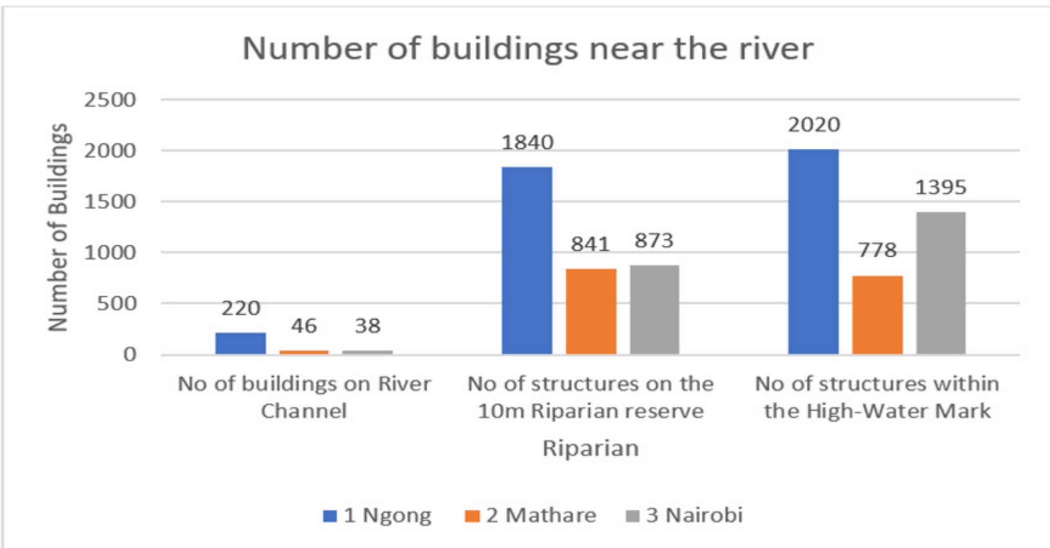


FIGURE 18
Number of buildings along Ngong, Nairobi and Mathare River
Source: Field survey, 2025

a) Encroachment on Ngong River
The Ngong River has numerous riparian settlements, as it is the heart of many informal settlements, such as the Mukuru villages, which house over 600,000 residents who built homes in the area near the facto-ries where they work. Many families live in corrugated iron shacks measuring 10 feet by 10 feet, high-lighting the level of poverty in the area (Rubencentre, n.d.)

Some of the informal buildings have houses built just near the river's riparian zone, which is hazardous, as shown in **Figures 19 to 25**.

b) Encroachment on Mathare River

c)Encroachment of the Nairobi River
Industries in Njiru and Mukuru Kayaba have encroached on riparian reserves, resulting in large-scale pollution from both liquid and solid industrial waste. Markets like Gikomba and Kamukunji have taken over riparian zones, where traders dispose of waste directly into the rivers.

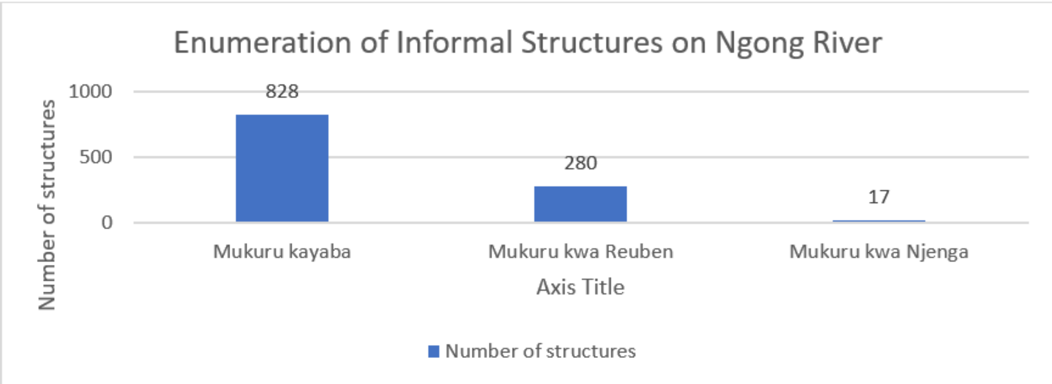


FIGURE 19
Number of informal settlements along the Ngong River
Source: Field survey, 2025


a


b

FIGURE 20 (a & b)
Mukuru informal settlements along the riparian of the Ngong River
Source: Field survey, 2025

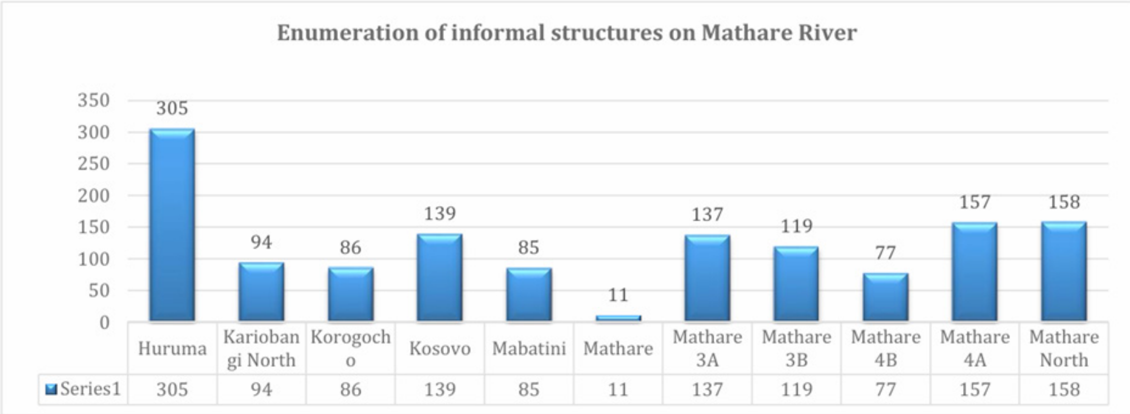


FIGURE 21
Number of informal settlements in the Mathare River
Source: Field survey, 2025

a b

FIGURE 22 (a & b)
Informal settlements in Mathare, Nairobi River
Source: Field survey, 2025

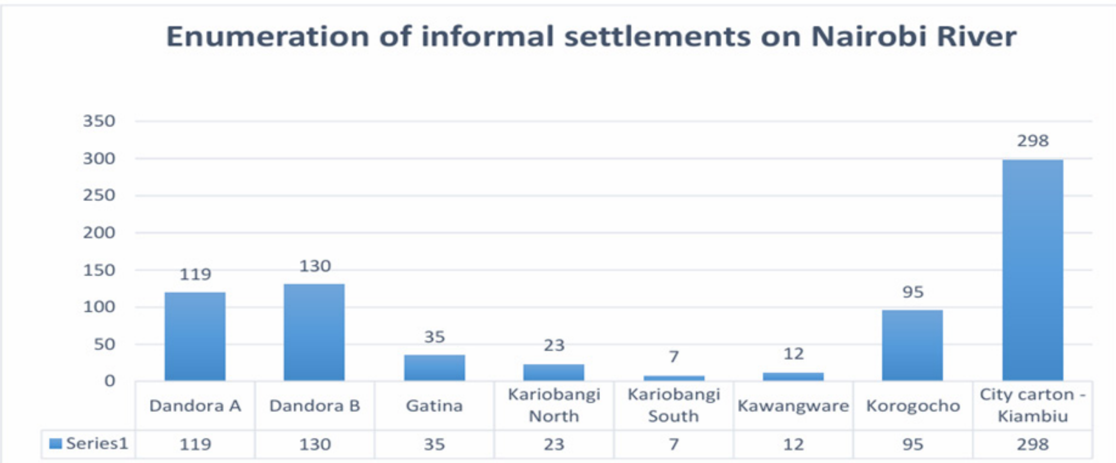


FIGURE 23
Number of informal settlements in the riparian of the Nairobi River
Source: Field survey, 2025

a b

FIGURE 24 (a & b)
Nairobi River's encroachment
Source: Field survey, 2025

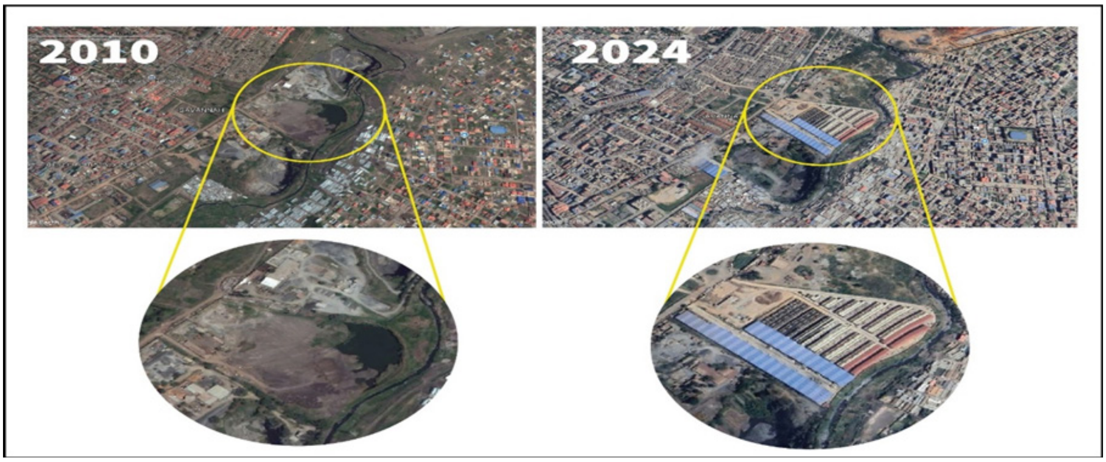


FIGURE 25
A new industry was constructed near the Ngong River
Source: Google Earth, 2025

d) Weak Governance and Conflicting Legislation
The study highlights the inconsistent enforcement of riparian regulations due to conflicting interpreta-tions of laws (e.g., the Water Act 2007 vs. the Survey Act 2012), which enables encroachment. This supports Omollo (2023) and Karangi (2017), who highlight Kenya's weak legislative framework and insufficient monitoring. For example, the ambiguity in defining riparian boundaries (high-water mark vs. centerline) aligns with Makindi (2024) and Muketha (2014), who have criticized Kenya's fixed-width riparian policies as ecologically inadequate. The lack of unified governance echoes Ostrom's (1990) cri-tique of top-down regulatory failures, underscoring the need for adaptive management, as proposed in British Columbia's RMAs (Government of British Columbia, 2025).

Ecological Quality of Riparian Zones
The study identifies anthropogenic activities, including untreated industrial effluents, solid waste dispos-al, and agrochemical runoff, as key drivers of ecological degradation in riparian zones. This sup-ports Mbugua (2020), who documented similar pollution impacts on Nairobi's rivers. The findings also align with those of Tickner (2020) and the WWF (2018), who attribute global riparian degradation to urbanization and unsustainable land use. The UPE lens, as described by Swyngedouw (2004), further explains how industries evade regulations due to weak enforcement, as seen in Mukuru Kayaba's case, where marginalized communities bear the brunt of pollution.

Poverty-driven activities, such as waste disposal in rivers and riparian farming, were identified as critical drivers. This resonates with Muketha (2012) and Gebrehiwot (2019), who linked the lack of waste infra-structure in informal settlements to riparian pollution. The Tragedy of the Commons (Hardin, 1968) is evident here, as individual survival needs take precedence over collective ecological responsibility. However, the findings also highlight opportunities for community-led solutions, aligning with Ostrom's SES Framework (2009) and the theory of common-pool resources, which advocates for participatory governance to counter resource overexploitation.

Strategies that Promote the Appropriate Physical Extent and Ecological Quality of Riparian Zones in Urban Areas.

a) Legislative Frameworks and Enforcement Mechanisms

To mitigate anthropogenic encroachment, Kenya needs to harmonize conflicting definitions of riparian buffers in legislation, including the Water Act (2006), Survey Act (2012), and Physical Planning Act (2021). According to Makindi (2024) and Karangi (2017), inconsistencies in buffer widths (e.g., high-water mark and river centerline) leave room for illegal settlements and industrialization. Having a uni-form standard, such as the Water Act's 6–30m from the high-water mark, would ease enforcement when considering the water catchment region, particularly with the use of geospatial tools like GIS and remote sensing. To complement this, NEMA's special enforcement units, equipped with geospatial technologies such as drones, would be able to track hotspots (e.g., Mukuru slums) in real-time. This complements the Pressure-State-Response (PSR) model (OECD, 1993), with added controls and penalties as a reaction to urban pressures, reversing riparian degradation.

b) Increase Public Awareness and Community-Based Conservation

It is essential to engage local communities in the management of riparian zones to foster effective stew-ardship. Community committees can co-manage buffers through waste cleanup campaigns and the plant-ing of native trees (e.g., Syzygium cordatum) with unity, leveraging Ostrom's common pool resource theory. Capacity building of the locals in green practices, e.g., waste segregation and agroforestry, re-duces reliance on polluting activities, which resonates with (Cooke, 2018). Concurrently, public aware-ness campaigns—using social media, local radio, and influencers—can educate residents about riparian legislation and environmental benefits (e.g., flood reduction). This aligns with Mbugua (2020), who found that poor awareness of regulations drives encroachment; therefore, targeted outreach to informal settlers and industries is crucial to change behavior and foster collective responsibility.

c) Embrace Geospatial Technologies and Adaptive Buffer Design

Fixed-width buffers are unable to address Nairobi's diverse topography and hydrology as highlighted by (Vannote, 1980). Adopting GIS and remote sensing, just as illustrated in the Njoro River catchment in Kenya, as observed by (Enanga et al., 2011) enables precise mapping of encroachment and pollution hotspots. This can inform adaptive buffer zones, such as in the RSPO model. (Lucey et al, 2018), with buffer widths varying from 5 m (small streams) to 100 m (large rivers), based on ecological sensitivity. For instance, gentle slopes along the Mathare River may require wider-width buffers with deep-rooted vegetation (e.g., tea bushes) to maintain soil stability, aligning with Sepúlveda & Rafael (2018). Such adaptability enhances filtration of pollutants and habitat connectivity, which are the shortcomings in Kenya's rigid 6–30m width rule.

d) Revitalize Ecology and Decentralize Waste Infrastructure

Ecological restoration should prioritize native vegetation (e.g., Ficus sycomorus) for restoring riparian processes. School and NGO-sponsored replanting programs, on the other hand, can sieve out contami-nants and reinforce banks. This would agree with Jture (2018) and USDA (2024). Decentralizing infor-mal settlements' waste management through biogas digesters and recycling centers, in contrast, allevi-ates the issue of riverside dumping, one of the primary pressures identified by Muketha (2012). An ex-tended producer responsibility (EPR) policy can compel industries to finance clean-up, adhering to Ur-ban Political Ecology (UPE) theory, which aims to mitigate power imbalances in waste management, as noted by Swyngedouw (2004). Alternating such programs with green public spaces (e.g., riparian parks) balances urban needs with conservation, with long-term ecological and social sustainability.

CONCLUSION

This study successfully achieved its three objectives by comprehensively investigating the implications of anthropogenic activities on the physical extent and ecological conditions of riparian zones in Nairobi City County. To start with, it confirmed that anthropogenic activities, such as the littering of solid waste, intrusion by informal settlements, and industrial pollution, have significantly undermined the physical space of riparian buffers within the Ngong, Mathare, and Nairobi Rivers. Second, the study identified key drivers, including rapid urbanization, weak governance, and conflicting legislation on the extent of the riparian reserve, which contributed to ecological degradation. Universal trends, as noted by Tickner (2020) and Gebrehiwot (2019), who relate such pressures to systemic urban sprawl and rule failures, corroborate the findings. Third, the recommended approaches, which harmonize laws, community con-servation, and adaptive geospatial planning, are addressed directly through the gaps in Kenya's riparian management systems, resonating with Makindi's (2024) and Ostrom's (2009) suggestions. The degrada-tion observed in all three rivers underscores that these issues are not accidental but systemic, reflecting broader urban challenges where socio-economic inequities and institutional fragmentation perpetuate ecological harm, as argued by (Swyngedouw, 2004), (Omollo O. W, 2023).

The consistency of anthropogenic pressures across the Ngong, Mathare, and Nairobi Rivers echoes global trends in urban riparian degradation, documented in Dar es Salaam by Kiwango (2021) and Addis Ababa by Gebrehiwot (2019), validating the study's universality beyond Nairobi. The findings are con-sistent with the Pressure-State-Response (PSR) model. (OECD., 1993) , showing how urbanization (pressure) degrades riparian ecosystems (state), necessitating legislative and community responses (re-sponse). Moreover, the research supports Urban Political Ecology (UPE) by demonstrating how inequali-ties of power, such as companies evading regulations and poor communities lacking waste infrastruc-ture, lead to ecological marginalization. (Swyngedouw, 2004). By coupling geospatial technologies with political insights, the research closes gaps in African urban riparian studies and offers a blueprint for cities confronting similar issues. Lastly, the systemic nature of riparian degradation in Nairobi necessi-tates adaptive, context-specific responses that balance ecological restoration and the needs of urban de-velopment, as advocated by the Social-Ecological Systems (SES) approach. (Ostrom, 2009) .

RECOMMENDATIONS

Implication to Theory

This study underlines the necessity to integrate socio-political and ecological approaches to ad-dress riparian degradation. The findings corroborate the Common-Pool Theory, as proposed by Ostrom (1990), emphasizing collective stewardship in response to the "tragedy of the com-mons" (Hardin, 1968). For instance, grassroots conservation activities in Mathare and Mukuru demonstrate the capacity of collective action to reverse anthropogenic pressure, aligning with Ostrom's participatory governance norms.

Similarly, Urban Political Ecology (UPE), as explained by Swyngedouw (2004), helps contex-tualize power imbalances, such as industries ignoring laws and informal settlements lacking ac-cess to waste management services. The pollution and penetration found in all three rivers high-light how economic inequalities perpetuate environmental exclusion, a core belief of UPE. The Social-Ecological Systems (SES) framework, proposed by Ostrom (2009), advocates for a sys-tem-level approach that integrates urban needs with nature restoration to protect the riparian zone, as evident in proposals for adaptive buffer zones. Theoretical future uses of decentralized waste management need to ensure that methods are applied across multiple disciplines, bringing together technical restoration (such as geospatial mapping) and local governance to address the complex relationship between urban areas and rivers.

Policy Recommendation

To address the systemic degradation of Nairobi's riparian zones, Nairobi City County Government and other key stakeholders must harmonize conflicting legislative frameworks by unifying buffer definitions (e.g., 6–30m from high-water marks) across the Water Act (2016), Survey Act (2012), and Physical Planning Act (2019), while using geospatial technologies like GIS and drones for precise boundary de-marcation and real-time monitoring.

This should ensure that the GIS tools mark the highest water point of rivers over a long period, allowing for the measurement of riparian extent from that point. NEMA must be empowered further to sanction pollution and encroachment in such hotspots as Mukuru and Mathare. Concurrently, community conser-vation needs to be institutionalized through the platform of riparian management committees, which co-formulate waste measures (e.g., indigenous reforestation involving Syzygium cordatum, biogas digest-ers) and initiate awareness creation measures to compensate for knowledge deficiencies.

Adaptive planning must replace rigid buffers with variable zones (e.g., 30–100m for erosion-prone areas like Ngong River), guided by hydrological risk maps and models like RSPO as discussed by Lucey (2018), while retrofitting zones with green-gray infrastructure (e.g., bioswales, wetlands) inspired by Seoul's Cheonggyecheon Restoration (2003). Decentralizing waste management through Extended Pro-ducer Responsibility (EPR) policies and partnering with informal recyclers can prevent dumping, along with incentives for riparian-friendly land uses (e.g., agroforestry, eco-tourism) under SES principles (Ostrom, 2009). By policy, technology, and grassroots compatibility, Nairobi can transform degraded riparian landscapes into resilient socio-ecological assets that serve as a replicable model for African cit-ies facing similar urban-ecological crises. The common Resource pool approach would then become a reality in the basin.

Recommendation for Planning Practice

To enhance planning in Nairobi and other riparian zones, scaling up the utilization of geospatial technol-ogy, such as the use of Drones and GIS in mapping riparian encroachment and pollution hotspots in real-time, is advisable. The resulting data can be incorporated into Nairobi's Urban Development Plan, with a focus on high-priority areas in riparian zones, such as the section along the Ngong River in Mukuru. In addition, adopting hybrid green-gray infrastructure through the retrofitting of riparian buffers in informal settlements with bioswales, constructed wetlands, and urban green corridors would help absorb pollu-tants and minimize flood hazards. The Restoration Project in Seoul can be emulated in terms of a com-bination of ecological restoration and urban functionality. Last but not least, residents can be engaged in participatory mapping to inform participatory-based zoning, aiming to design areas that are secure for both waste collection and urban farming, thereby reducing congestion in riparian areas.

Implications to Academia/Suggestions for Future Research

Future research should focus on more interdisciplinary studies that address gaps in African urban an-thropogenic drivers of riparian degradation. These studies should concentrate on the varying riparian ex-tents and explore practical solutions to address this issue. Scholars can analyze how power imbalances, as defined by Urban Political Ecology, between policymakers, industries, and informal settlers contribute to poor environmental law enforcement. In addition, prediction models that integrate hydrological inputs (for example, pollutant loads) with socio-economic variables (for example, migration trends) can predict trajectories of degradation in scenarios with different forms of government. Longitudinal studies over an extended timeframe, following the impact on grassroots-led projects such as the Nairobi River Clean-Up Organization, are necessary to determine the drivers that enable grassroots resiliency in contexts of rapid urbanization.

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