Flood Incidences and Their Implication on Rural Riverine Settlements: A Case of Tana River County, Kenya.

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Abstract

Flooding is a significant challenge, affecting livelihoods, infrastructure, and the environment in rural riverine settlements. The study investigates the implications of flood incidences on rural riverine settlements. Specifically, it assesses the extent and effects of flood incidences. It examines the key drivers of flood incidents on rural riverine settlements along the River Tana. Finally, it proposes strategies that can be used to mitigate the effects of flood incidences on rural riverine settlements. The study employed a descriptive survey design with qualitative and quantitative research methods to analyze flood incidences in seven settlements in Lot Two, selected by the County Government of Tana River. The study was grounded on the systems theory of planning as the proponent. Secondary data was obtained from various sources, including peer-reviewed journals, government records, and remotely sensed data. Primary data was collected through key informant interviews, focus group discussions, and observations that included direct observation, photography, and mapping techniques using a global positioning system (GPS) and measuring tape. Data analysis incorporated descriptive statistics, thematic analysis, and GIS-based spatial analysis. Quantitative data was presented in tables, charts and maps. The results reveal, among other things, that the effects of the floods included recurring displacement and destruction of property. The key drivers of flood hazards are, among others, a lack of proper riverine and land use planning and policies to mitigate the effects of flood incidences on rural riverine settlements. The study concludes that flood incidences positively and negatively affect rural riverine settlements. A comprehensive approach integrating structural and non-structural measures is essential for sustainable flood management and riverine settlements.

Keywords: Flood incidences, Flood hazards, rural riverine settlements,

1. Introduction

1.1 Study background

Flooding occurs when water covers dry surfaces, disrupting everyday activities and livelihood. (European Union, 2007).The study indicates factors fueling the increase in flood risks worldwide, including population increase, environmental degradation, and climate variability. It further explains that practices in planning and management are also increasing the risks, exposing some to them.

According to the Kenya Lake Basin Development Authority (1985), floods are abrupt, short-lived occurrences and are most likely to occur at the same instant and in a brief warning. The paper continues to argue that the cause of flooding develops through heavy rainfall in addition to the water-holding capacity of an area or a channel in rivers. Floodings also develop through dam failures, landslide blockages in rivers' channels, or the thawing up of snow (Zonneveld, 1983). According to Zonneveld (1983), the effects of flooding are disastrous. They result in the collapse of buildings, the loss of lives, the displacement of people, and the damage to infrastructure and crop harvest.

Beyond the immediate damage, floods and drought cause long-term economic and environmental impacts. (Kesaba, 2012).According to Kesaba (2012), floods and droughts deplete resources, cause food shortages, and deteriorate the environment. Kesaba concludes that people with low incomes in developing nations are most exposed to these dangers because they live in ecologically exposed areas and are at greater risk. Livelihood resources impacted by the flood are physical, natural, human, social, and monetary. (Masese et al., 2016).

Risk in rural riverine settlements depends on diverse processes, including urbanization, inadequate land use planning, and failure in governance. (UFCOP, 2017). Inadequate infrastructure, unplanned population growth, and inadequate disaster management practices increase flood hazard exposure. (Lewis & Mioch, 2005)Poverty in settlements also increases vulnerability because people experiencing poverty are usually located in flood-hazardous places along rivers and floodplains. (Onywere, 2011).

Like any other river, the River Tana provides numerous ecosystem services, including animal herding, fishing, crop production, and harvesting of Indigenous products. Notwithstanding the significant economic contributions, frequent flooding continues to impact the settlements and the environment, leading to economic losses, displacement, and diminishment in environmental quality. (Mool, 2010).

1.2 Problem Statement

Rivers have attracted settlements because of fertile alluvial soils, free access to water, and irrigation potential, as indicated by (H. Wang & He, 2022). Most rural riverine settlements occur on riverbanks and depend on siltation to sustain productive agricultural land uses, as revealed by (Smith et al., 2017). In Kenya, rivers such as the Tana, Athi, Nzoia, Nyando, and Ewaso Ng'iro flood frequently, positively and negatively affecting settlements in rural areas. Over half a million people were displaced in a ten-year window (2010-2020), with the highest displacement rate among rural riverine settlements (Kenya, 2020). According to NDOC, the floods in the Tana River in 2018 displaced over 140,000 people and overflowed agricultural land and houses.

Whereas riverine settlers appear to think they are in a "win-win" position, as they benefit from the floods, the situation in the Tana simulates Nash (1950), who argues that in game theory, such an arrangement is a better fit in a zero-sum game. In this setup, gain in the short term is balanced with enormous loss. The situation also appears to agree with Lee & Chen (2019), who argue that while agriculturalists obtain river siltation and enrichment in the land, in the longer future, they incur destruction with floods destroying their land, sweeping away their houses, and keeping them in a state of perpetual reconstruction.

However, much of the flood literature is on flood prevention using control structures that block the rich soils. and not on the unique vulnerability of riverine settlements in rural spaces. Substantial research on the resilience of infrastructure in urban space, flood drainage infrastructure, and city adaptation policies has been investigated by scholars including (Khan, 2023). Rural space requires research on the effects of flood risk and disaster preparedness. Rural riverine villages' socio-economic and environmental character is under-researched, and little is comprehensively investigated about what makes them flood-prone and how they could adapt to such floods. Borrowing from Opere (2013), 60% of flood hazards are in the River Tana Basin, yet very little research has been conducted. It is crucial to close the knowledge gap to conceive a holistic, adaptive, and sustainable flood resilience strategy in vulnerable rural settlements.

1.2.1 Significance of the study.

This study is significant on multiple fronts. The Tana River County Government proposed the planning of 14 rural riverine settlements under a lot system under the Integrated Strategic Urban Development Plan (ISUDP), categorized under Lot 1 and Lot 2, with seven under Lot 2: Asako, Maderte, Makere, Nanighi, Mororo, Nyangwani, and Kilelengwani. The researcher was the lead consultant in Lot 2. The high level of relevancy in providing fact-oriented information on flood-related settlement planning makes the research significant. Secondly, despite vast research on flood mitigation in urban areas, little attention has been paid to flood-prone rural riverine settlements. These are highly vulnerable, with little infrastructure, low capacity to respond to times of disaster, and overreliance on flood-induced agriculture.

The research fills the knowledge gap in understanding the implications of flood incidences on rural riverine settlements. It also informs decision-making and policy with fact-oriented suggestions on land-use planning, preparedness in times of disaster, and adaptation policies. By comprehending the socio-economic and environmental costs and implications of flooding, the research contributes to a meaningful understanding of strategies that can ameliorate the research problem. Lastly, the research establishes a foundation for better flood management approaches so that rural riverine settlements in Kenya and other parts of the World can benefit from riverine resources without impairing their social, economic and environmental goals.

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1.2.2 Study Objectives

The specific objectives of this journal article are:

1. To assess the extent and effects of flood incidences on rural riverine settlements in the study area.
2. To examine the key drivers of flood incidences and rural riverine settlements in the study area.
3. To propose strategies to mitigate the effects of flood incidences on rural riverine settlements.

2. Relevant Scholarships

2.1 Theoretical Frameworks

2.1.1 Hydrological Cycle Theory

The Hydrological Cycle Theory explains the ongoing circulation of water, which includes significant processes such as runoff on land, runoff infiltration, evaporation, and transpiration. (Chow et al., 1988). Hydrology regulates the amount of available water in varying landforms, including river basins and floodplains. In river flooding, the hydrological process is significant in flood severity and frequency because when rainfall exceeds land infiltration, land runoff is formed, rivers are filled with excess water and flood risks are formed. (Ward & Robinson, 2000)Land cover alteration, such as deforestation, settlement expansion, and agricultural land, disorganizes the rate at which land naturally infiltrates and increases runoff, increasing flood risk in riverine settlements (Oki & Kanae, 2006). The theory, however, fails to address the effects of flood hazards on human settlements.

2.1.2 Theory of Floodplain Equilibrium

The Theory of Floodplain Equilibrium portrays equilibrium in river runoff, sediment movement, erosion, and floodplain deposits in a state of nature (Leopold & Thomas, 2010). Leopold et al. posit that natural floodplains play a buffer role, temporarily storing floodwaters in excess and discharging them over a longer timescale, reducing the severity of downstream flooding. (Wolman & Miller, 1960) postulate that deforestation, land conversion, and floodplain expansion destroy the equilibrium these forces bring, increasing flood risks. Also, river alteration in the form of dams, embankments, and dredging destroys erosion sequences and deposits and shatters floodplain equilibrium (Kondolf et al., 2014). The theory is critical in addressing the upstream drivers of floods but does not address how riverine settlement affects the equilibrium by altering the river ecosystem. In addition, the effects of the floods, once the equilibrium is affected, are not understood from the theory.

2.1.3 The Systems Theory of Planning

Game theory offers a valuable framework for examining the exchange between settlements and the river system within the study area (Madani, 2010). Madani argues that the latter receives an adverse effect from pollution and soil erosion activities, and the settlements receive an adverse effect from floods and other hydrologic processes. This exchange results in a win-lose situation wherein one side experiences a penalty based on the other side's activities. However, game theory does not fully answer the problem of the study because it mainly emphasizes strategic choice but not the overall strategy of attaining a balance that ensures sustainability.

This study employs the systems theory of planning as the primary framework to attain the win-win situation promoted by game theory in cooperative strategies. The systems theory of planning has a larger integrated analytical framework considering the mutual dependency of settlements and natural systems. The planning interventions enhance the resilience and sustainability of the river and settlements alike.

The system planning approach is applied at the grand scale of the whole conceptual framework. Adopting the set and boundary theory of systems engineering (Madani, 2010), the latter encompasses the set and boundary theory, which recognizes control boundaries within a system. Herein lies the boundary theory that forms an integral part of defining flood boundaries and buffer zones and bringing human activities within the boundaries of sustainability. A symbiotic balance ensues by using limits of the flood effect and regulated farming within limited geographical boundaries based on natural vegetational cues. At the same time, the river "wins” through the conservation of natural processes, farmers "win" with regulated farming activities, and settlers "win" with the alleviated flood threat. This system-informed approach ensures long-term resilience and sustainability of the river environment and human settlements.

2.2 Empirical Literature

Globally, flood hazards have escalated due to the influence of climate change, with the experience of weather extremes affecting developed and developing countries equally. (IPCC, 2021). Severe flood hazards put the coastal cities of Jakarta, New Orleans, and Dhaka at risk of higher sea levels and stronger storm surges (Hanso, 2011). Flood management strategies consisting of flood-resilient infrastructure, natural strategies and a collaborative effort at the world scale toward flood adaptation are required to alleviate flood hazards (World Bank, 2019). The merging of scientific analysis with adaptation at the grassroots ensures that societies prepare against future flood occurrences. (Adger, 2003).

Across Africa, flood hazards intensify with weather and land use variability. The Nile, the Niger, and the Congo River basins experience seasonal floods that displace the population and also damage facilities (UNDRR, 2020). Urban development at a rapid rate, deforestation, and poor drainage further amplify floods and the flood susceptibility of large and small cities and rural settlements alike (Douglas et al., 2008). African countries mitigate such hazards with integrated flood management, including warning systems, floodplain restoration, and good urban planning (Komu, 2018).

According to (Mihaljević & Kajan, 2024)In Kenya, Nyando, Nzoia, and Tana rivers are commonly hit with floods due to high seasonal rainfall, with high frequency in the long rains

(March-May) and the short rains (October–December). According to Onyutha et al., increased temperatures also cause increased evaporation and upset the precipitation process, causing longer durations in parts of the country and sudden high amounts of rainfall, resulting in enhanced flood risk.

In addition, anthropogenic processes such as floodplain encroachment, construction, and drainage infrastructure shortage restrict the free movement of water and cause river overflows and displacement of settled residents on floodplains.(Christopher et al., 2017). Sustainable alleviation of floods, such as conservation in catchments, afforestation, drainage systems, and zoning floodplains, can modulate river runoff. (Mulungo & Adhiambo, 2023). Studies, including Mutua et al., show that decision-makers can predict flood occurrences and design alarm systems in advance with the support of hydrological models. They further indicate that integrating knowledge in flood risk assessment creates a scientific foundation for efficient and sustainable disaster preparedness and rural agro-system water resources management.

According to (Ochola et al., 2010), in Kenya, the floodplain in the Tana River was originally fertile and viable for agricultural production, but land use and population expansion amplified flood risks. An illustrative example is research estimating that over 60% of the population resides in flood-prone households in the lower basin of the Tana River due to dependence on the river in agricultural production and fetching water (Opere, 2013). When floods seasonally arise, such groups are displaced in significant numbers, incur loss of properties, and are food-insecure (Orindi & Eriksen, 2005). (Lokidor et al., 2024) Explains that the loss of floodplain equilibrium brought about by unsustainable land uses underscores the need for integrated flood approaches such as floodplain zoning, restoration, agroforestry, and agricultural conservation.

Applying the Floodplain Equilibrium Theory in flood reduction is made possible with enhanced knowledge of how flood regimes are formed and how balance is regained. Flood reduction is managed with floodplains naturally functioning, with accommodation of controlled flood releases, and with river corridor conservation policies to alleviate flood damage while the land is utilized sustainably. Knowledge about the delicate balance between rivers, floodplains, and riverine settlements as observed by(Naiman & Décamps, 1997) Achieving flood resilience in Kenya's river basins is critical in the long term.

2.2.1 Effects of Flooding on Rural Riverine Settlements.

Flooding is one of the most frequent natural disasters in the world, defined as the spilling of water onto dry ground. According to the European Commission (2003), several things, including river overflow, excessive precipitation, dam failure, and snowmelt, can cause flooding. Floods damage infrastructure, displace people, and interfere with biodiversity; improper land use planning and uncontrolled development frequently make impacted places more vulnerable. (World Meteorological Organization, 2012).

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Riverine settlements that develop along riverbanks are often characterized by their dependence on rivers for cultivation, fishing, and transportation. These settlements mostly emerge in areas with good soil fertility and easy access to water, boosting their economy and ecological advantages. (Anunobi, 2014).However, being close to the river exposes them to flooding risk. If flooding regularly occurs, it can displace people and animals, cause property destruction, and even kill, particularly in regions with inadequate flood management systems. (Republic of Kenya, 1985).

Studies show that poorly developed settlements along rivers lead to over-cultivation, soil erosion, and deforestation. These activities worsen soil erosion, water contamination, and biodiversity loss when paired with natural flood threats. For example, Nyakundi et al. (2010) show that communities living along the Tana experience frequent floods, leading to waterborne diseases and even death.

Human settlements along rivers have been associated with heightened vulnerability to flooding on a global scale.(Lewis & Mioch, 2005). Lewis et al. further argue that poor land use practices and dense floodplain populations create hazards that may be avoided with appropriate zoning and planning. They conclude that if nothing is done about the increasing threats the settlements face, the safety and means of subsistence of millions of people will be in danger.

2.2.2 Flood Risk Factors on Rural Riverine Settlements

According to Verma et al. (2024), the vulnerability of riverine settlements is mostly elevated by natural and artificial elements that lead to flood risk. Verma et al. also indicate that climate change is one of the main factors, as global warming worsens extreme weather events like flash floods and high rainfall. Altering rainfall patterns in already vulnerable areas increases the danger of flooding by disrupting hydrological systems. Due to soil fertility and water availability, the population grows as people build and settle near the rivers. This leads to flooding since populated areas lack the proper infrastructure to control flooding. (Verma et al., 2024).

Other factors that contribute to flooding are changes in land use and deforestation. Water absorption reduces when trees are cut down, and unplanned urbanisation takes over. This increases surface runoff and siltation of the river, reducing the riparian zones' natural flood-buffering capacity. Poor planning and a lack of floodplain management further compound these risks, as settlements encroach on flood-prone areas without adequate safeguards (Management, 2012).

Figure 1 Conceptualization of Factors Contributing to Flood Risks.
Source Author, 2025

Odoyo et al., (2024) observe extreme impacts of flooding on livelihoods, infrastructure, and health. They further indicate that places like Tana River County, fishing activities, crops, and livestock, which are the primary sources of income for people living there, are being destroyed by floods. Infrastructure is frequently damaged, causing economic losses and making it challenging to access services like health, school, and many more (Odoyo et al., 2024). They noted that stagnant water creates waterborne diseases like malaria and cholera. Furthermore, Odoyo et al. argue that environmental degradation caused by soil erosion, sediment deposition, and water contamination reduces the quality of land and water resources, leading to biodiversity loss and ecosystem disruption.

Limited access to healthcare, lack of public awareness, and insufficient disaster preparedness affect the vulnerability of flood-risk areas. (Odoyo et al., 2024). The study by Odoyo et al. proposes that public participation, integration of land use planning, and technologies are the best ways to address these challenges.

2.2.3 Strategies for flood mitigation for sustainable rural Riverine settlements

Global and local literature emphasizes several flood causations and their implications in riverine communities and calls for specific prevention. In Bangladesh, geographical factors like lowland topography, drainage deficiency, and closeness to rivers induce flood hazards fueled by socioeconomic factors like poverty, lack of infrastructure, and weak institutions. (Hossain et al., 2024). Nigeria also faces increased flood risk due to heightened urbanization, land-use malpractices, and drainage clogging. (Nkii et al., 2024). Landscape maintenance, GIS monitoring of floods, and green town planning are advised in these initiatives. (Abali & Nkii, 2024). In Kenya's Nyando Basin, lack of resources, poverty, and underutilization of local knowledge reduce the level of societal resilience, and integration of local knowledge is advised in disaster preparedness and responses. (Nyakundi, 2010).

Flood mitigation is classified under structure, non-structure, and nature-based approaches. Dams, flood bypass channels, and levees are economically and environmentally resourceful and floodwater movement constrictive structure approaches. (Juárez et al., 2021). The policies, zoning legislation, and warnings are non-structural approaches addressing population preparedness and reducing flood loss. (Genovese & Thaler, 2020). Prevention in flood-prone occupations and land policy enforcement are preventive approaches. (Dixon, 2020).

Involving the population and efficient risk communication are significant in flood resilience and evacuating the population promptly and efficiently. (Wang et al., 2022). Nature-based solutions are a sustainable way of managing floods without ruining ecosystems. Green infrastructure, such as permeable roads and urban wetlands, absorbs excess stormwater runoff and minimizes the severity of floods. (Esraz-Ul-Zannat et al., 2024). Wetlands and floodplains are restored with increased natural retention capacity, serving as a buffer during floods. (Serra-Llobet et al., 2022) The "sponge city" strategy in Wuhan, China, incorporates green spaces and sophisticated water management systems to combat flood events. (Mandarino et al., 2023). These rely on balancing human intervention and conservation to attain long-term resilience against flood hazards.

2.2.4 Research Gaps

Hydrological Cycle Theory and Floodplain Equilibrium Theory explain flood formation and equilibrium disruption but fail to address the socio-economic implications of floods on settlements comprehensively. Additionally, Game Theory highlights interactions between human activities and river systems but does not provide a holistic framework for sustainable flood management.

Studies on flood risk in riverine settlements rely on historical flood data and hydrological modelling, often lacking interdisciplinary approaches that integrate socio-economic, ecological, and technological dimensions. Additionally, the limited use of GIS and remote sensing in localized flood risk assessments hinders accurate spatial analysis for better mitigation planning.

2.3 Conceptual Framework

2.3.1 Key Concepts and Variables

The study's independent variable is flood incidences, which are indicated by frequency, intensity, duration, spatial extent, type of soil, and upstream siltation. The frequency determines the number of flood incidences occurring within the settlements. The literature suggests that climate change is intensifying extreme events globally (IPCC, 2021). The intensity of the flooding,

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measured by the velocity and depth of water, contributes significantly to the destruction of infrastructure and agricultural farms since high-velocity water intensifies erosion and the loss of physical structure (Ward & Robinson, 2000). Prolonged flood event durations increase the spread of diseases through water source contamination, promoting the spread of diseases such as cholera and malaria (Odoyo et al., 2024).

The spatial extent of the flood or the surface area covered signifies the extent of economic and social disruption. Rural riverine settlements on flat or gentle slopes, close to the river, inundated by floods, are considered more vulnerable. The soil type is also a flood risk factor since impermeable soils produce excessive surface runoff and extended waterlogging. (Chow et al., 1988). Upstream siltation of dams also enhances flooding through reduced dam and river channel capacity, leading to overflow and exacerbated downstream effects (Opere, 2013). Control of the factors through planned land use, efficient water control, and timely warnings is crucial in mitigating the risks associated with flooding within rural river communities.

The study's dependent variables are the effects of flooding on rural riverine settlements. These are both positive and negative effects. The positive effect is soil enrichment by depositing fertile alluvial sediments containing nutrients that increase agricultural yield. Wang & He (2022) note that riverine settlements are benefited through the process of replenishment of the soil nutrients through flooding. The improvement in the supply of water for irrigation, animal husbandry, and domestic use stimulates rural economies. (Nyakundi, 2010). Floodwaters also present a natural transportation network, facilitating the movement of goods and persons where the network of roads is weak (Lewis & Mioch, 2005). While these benefits are present, the adverse effects of the flooding overshadow the benefits since the level of damage and disruption caused by the flooding is significant.

Household displacement is one of the most immediate effects of flooding (Odoyo et al., 2024). Infrastructure is also highly affected, with roads, bridges, and structures suffering significant damage, thus reducing mobility and increasing reconstruction costs. (Mool, 2010). Flooding results in the loss of crops and livestock and thus directly contributes to food insecurity within the flooded areas (Masese et al., 2016).

The effect on humans is also significant because the floods cause loss of lives, notably within settlements with weak early warning systems (UNDRR, 2020). The economic effect results from the loss of property, reduced agricultural yields, and suspension of businesses (World Bank, 2019). Flooding also aggravates social issues, including household displacement, and increases health risks such as waterborne diseases. (H. Wang & He, 2022), and riverbank erosion, which erodes the soil stability and reduces the arable land (Serra-Llobet et al., 2022). Mitigating the adverse effects through enhanced flood management mechanisms is crucial to developing the resilience of rural riverine communities.

The impact of flooding on rural riverine settlements is significantly moderated by intervening factors, including climate change, natural and artificial features, population increase, land use change, deforestation, and planning. Flood increase is caused by climate change through unpredictable rains and extreme events that enhance flood frequency and intensity (IPCC, 2021)(I. Natural and artificial features such as low-lying floodplains, poor drainage, and dam siltation cause overflow and extended inundation (Zonneveld, 1983). Population increase enhances the risk through enhanced settlement within the risk areas with poor infrastructural capacity and ability for emergencies (Lewis & Mioch, 2005). Land use change and deforestation reduce natural flood absorption, thus leading to increased runoff and sedimentation, such as the case with the Tana River, where deforestation elevated riverbeds and enhanced flooding (Opere, 2013). Lack of planning enhances the problem through the authorization of uncontrolled developments within the flood-risk areas, poor drainage, and poor regulations of the use of the lands, which enhance vulnerability to disaster (UNDRR, 2020). Mitigation through the control of these factors by climate adaptation, conservation-oriented and sustainable land use, and enhanced planning would be vital for reducing flood risks within rural river communities.

2.3.2 Theoretical Linkages

The study is anchored in two proponent theories that provide a foundation for understanding flood dynamics and their effects on rural riverine settlements. The hydrological cycle theory explains how natural water movement contributes to flooding. The independent variable analysis under the theory is supported by Chow et al. (1988), who argued that the hydrological cycle involves precipitation, runoff, infiltration, and evaporation processes regulating environmental water distribution. Changes in these processes, such as excessive rainfall and reduced infiltration due to land degradation, disrupt the natural water balance and lead to increased flood occurrences.

Human interventions, such as deforestation, wetland destruction, and unregulated settlement expansion, disrupt the equilibrium as postulated in the flood equilibrium theory. Once there is disequilibrium, settlements become increasingly susceptible to flood risks and hazards. The study applies these theories to explain flooding processes and human-induced vulnerabilities in riverine settlements. However, the two theories fail to integrate all components of the research problem, which is resolved through the system theory of planning. The theory considers the subsystems with defined boundaries, inputs, processes, and outputs for each activity. A feedback loop helps re-evaluate the system in the context of evolving dynamics.

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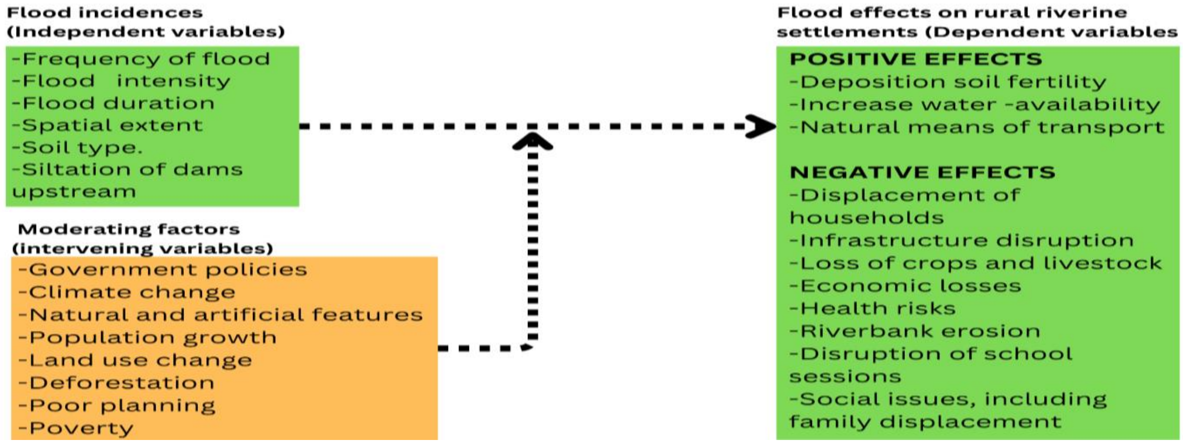

Figure 2 Conceptual framework
Source: Author, 2025

3. Research Methodology

3.1 Overview

The seven selected settlements, Asako, Maderte, Mororo, Nanighi, Makere, Nyangwani, and Kilelengwani, are in the River Tana basin within the Tana River County of Kenya.

3.2 Research Design

This study adopts a descriptive research design to analyze flood incidences and their implications on rural riverine settlements in Tana River County. The research integrates qualitative and quantitative methodologies to comprehensively understand flood impacts, community vulnerabilities, and mitigation strategies. A mixed-methods approach is utilized, incorporating surveys, key informant interviews, focus group discussions (FGDs), and geospatial analysis to gather and interpret data.

3.3 Location

The selected settlements in Tana River County are strategically located along the River Tana, making them highly susceptible to flooding. Asako, the northernmost settlement, lies near the border with Garissa County, followed by Maderte, which is slightly further south, situated close to the river and accessible via road networks. Mororo is positioned along the eastern bank of the Tana River near the Garissa, while Nanighi lies centrally in the county between Mororo and Nyangwani. Nyangwani, located in the southeastern part of the county, is surrounded by several tributaries and water bodies, with Makere positioned further south near Hola, the county's administrative headquarters. Kilelengwani, the southernmost settlement, is situated near the Tana River Delta and the Indian Ocean, an ecologically significant region. These settlements' proximity to the river highlights their vulnerability to flooding, impacting infrastructure, livelihoods, and ecosystems.

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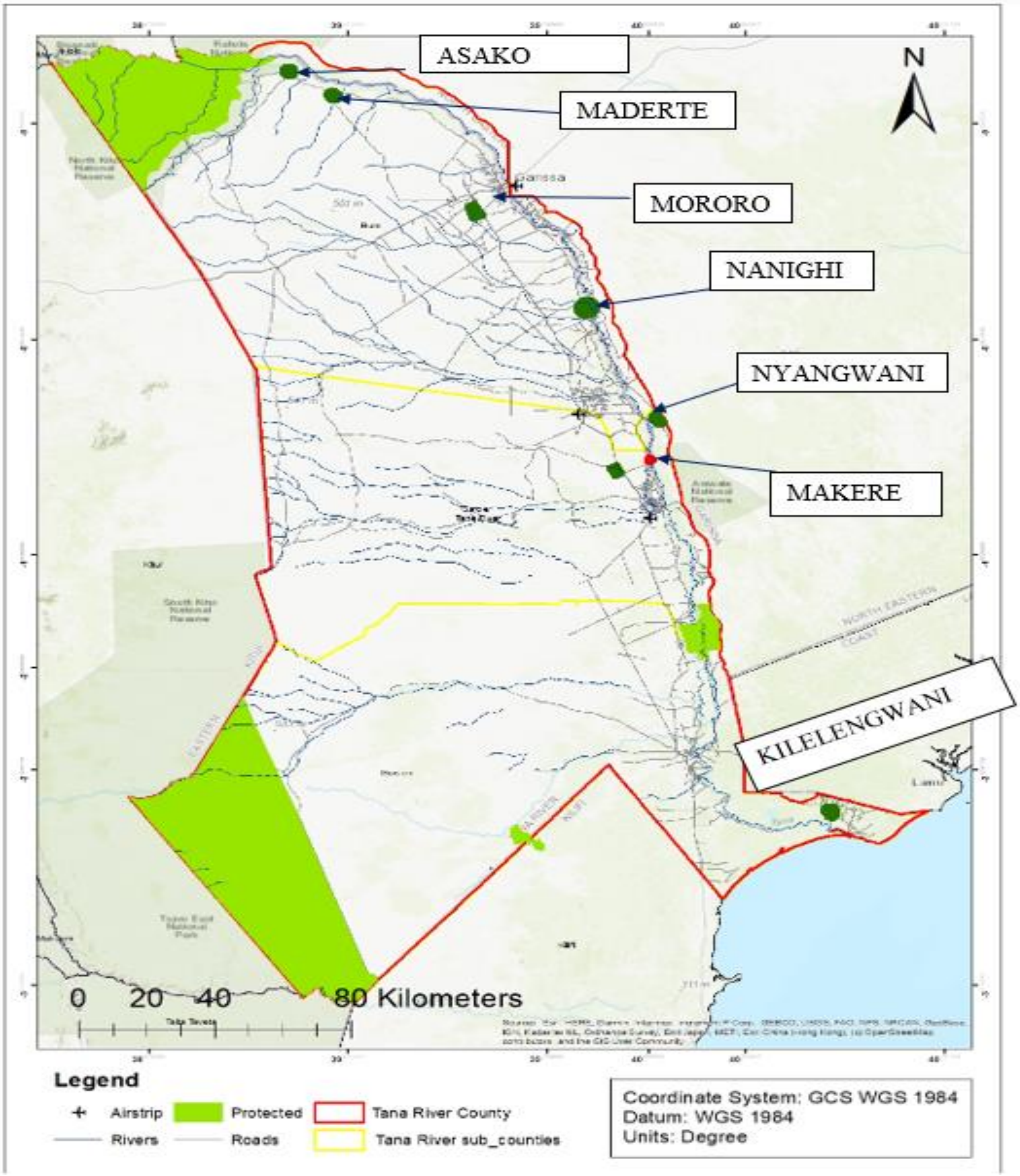

Figure 3 Location Of the study area
Source: County Government of Tana River

3.4 Population and Sampling

The study focuses on the seven selected settlements strategically located along the River Tana floodplain. These settlements were selected through the advice of the County Government of Tana River. According to the County Government of Tana River, the seven settlements (Lot 2) and the other settlements in Lot 1 were selected due to their high exposure to frequent flooding, displacement, loss of livelihoods, and environmental degradation. Table 2 shows the respective population of each settlement, as generated from the 2019 Kenya population census reports.

Table 1 Showing the Population of the seven selected settlements.

Town	**2024**
Asako	4606
Mororo	7307
Nyangwani	5832
Kilelengwani	7066
Maderte	4839
Makere	4253
Nanighi	5145

3.4.1 Inclusion and Exclusion Criteria

The study engages residents and households that have resided in the settlements for not less than one year and can provide firsthand information on flooding and adaptation. The study also includes residents above the age of 18 years. The inclusion criterion provides firsthand information and knowledge on flooding impacts and responses. Government officials, local area leaders, and disaster responders involved in flood risk reduction are included since they were deemed to provide important information on how policies and responses in disaster conditions are developed. Practitioners in flood risk reduction in urban and rural planning, hydrology, and sustainability are included among key contributors since they can provide important information on flood prevention and strategy.

Households that migrated recently to the settlements are not considered in the research because they would not possess firsthand information about flood events and adaptation in the area. Their inclusion would taint the internal validity of deriving the longer-run trends and adaptation reactions. The research excludes institutions and organizations not engaged in flood risk reduction and local support because their opinions would not directly contribute to the research aims.

3.4.2 Sampling

A multistage sampling design was applied to access respondents in each settlement. The settlements were purposively selected based on the requirements of the County Government. The local administrators, key informants, disaster response personnel, and environmental specialists

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were purposively selected because their knowledge significantly represents broader flood risk issues. Secondly, the structures in the settlement were mapped, and a number was assigned for identification. Since the character of each settlement was generally homogenous in terms of lifestyle and language, among others being rural setups, a simple random sampling was used to get respondents for the study. A significant limitation was the nomadic pastoralism practiced in some settlements, which affected the sampling frame. However, this was overcome using other methods, including key informant interviews, focused group discussions and observation for data triangulation.

The study applies a combination of simple random samples, purposive samples, and snowball samples to increase the validity of the results. A simple random sample was applied to the household sample selection to achieve equal distribution in the sample in diverse socio-economic groups. The purposive sample was to obtain key informants with specialized knowledge in flood risk reduction, disaster preparedness, and settlement planning. A snowball sample was applied where access to affected parties, such as displaced people, involved obtaining them through community members' referrals. The combination helped balance representing general experiences in the community and experts' opinions.

3.4.3 Sample Size

The study used households in each settlement to represent the population. The settlements are in rural areas along the river and are generally homogeneous. The sample for the survey was determined by the sample area population with a margin of 10% based on Yamane's (1967) method. The method is aimed at maintaining precision in representing the population's experiences. The settlements are generally homogenous in terms of the characteristics being studied. Therefore, the margin of error was considered lower than if the population was heterogeneous. This explains the 10% margin of error.

$$n = \frac{\mathrm{N}}{1 + \mathrm{N}(\mathrm{e}2)}$$

where: n = required sample size, N = total household population in the study area, and e = margin of error (10%)
After calculating using Yamane's (1967) method, the sample size for each settlement is shown in Table 3. The limitation is that most of the residents in the study area are nomads, thus affecting the meaningful sampling frame since they move from point to point looking for pasture and water.

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Table 2 showing the Sample size for each settlement.

Settlement	2024	Sample size
Asako	4606	97
Mororo	7307	99
Nyangwani	5832	98
Kilelengwani	7066	99
Maderte	4839	97
Makere	4253	97
Nanighi	5145	98

Additionally, highly mobile pastoralist communities might need a larger sample to cater to their mobile lifestyle than agricultural-based settlements, which are relatively less mobile and more convenient to survey. However, a sample size of 30 or more in a normally distributed population was considered adequate. Most settlements are based on single economies: pastoralism or crop farming. Such settlements are more homogeneous populations that need fewer responses.

In addition, settlements that flood frequently and intensely were more likely to have higher levels of participation, affecting sample size. In contrast, less flood-aware settlements needed additional efforts to achieve representation. Together, these differences guaranteed that the study captured the diverse range of flood exposure experiences among the different types of settlements in Tana River County.

3.5 Data Collection Methods

The research analyzed flood risk and community adaptation using primary and secondary data collection methods. Quantitative and qualitative data were collected from multiple sources using multiple methods and multiple research assistants. Due to the vast nature of the study area, four research assistants were trained and engaged for each settlement. This approach allowed for data triangulation and helped improve the validity of the results. The sources of data were primary and secondary, while the methods included document examination, case review, and focused group discussions.

3.5.1 Secondary Data Collection

Secondary data were available in reports within the National Government records, research documents, journals, and satellite imagery. Reports and documents from the Kenya Meteorological Department and the County Government of Tana River were also available on past flood events, policies, and infrastructure design. Published literature on flood risk evaluation, flood reduction strategy, and adaptation to climate change were available in research studies. Changes in land use and occupation and contributors to flood risk were also explored in satellite imagery.

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3.5.2 Primary Data Collection

Primary data were gathered through various methods, such as surveys, key informant interviews, focus group discussions, direct observation, and geospatial techniques. Surveys involved the distribution of structured questionnaires to households to quantify flood impacts, adaptation, and resilience.

The study employs key informants from diverse sectors, such as government officers, environmental planners, hydrologists, and disaster responders like the Kenya Red Cross. These informants helped provide information at a policy level and situate experiences in a broader flood disaster and flood reduction strategy. They were also helpful in specifying gaps in current flood responses and generating ideas on how policies could be enhanced.

Focus group discussions (FGDs) were conducted to gather qualitative and quantitative information by involving community members in discussions of their experiences and proposed solutions. Focus group discussions were conducted in all the settlements with a membership of 8–12 in a group to encourage in-depth dialogue on perceptions in a population, adaptation responses, and local knowledge of flood risk. The dialogue was based on topical themes such as flood experiences and trends in recent flood experiences, adaptation responses currently in progress, flood early warning systems, and flood adaptation plans and implementation issues. The platform was a method in which members shared experiences and dialogue on how floods could be adapted to reduce their repeated adverse impact.

“The Kobo Collect” app was used to collect data since it takes photographs and has GPS that can take the location. `Direct observation allowed the researchers to physically quantify flood-prone areas, damaged infrastructure, and settlement patterns. In addition, geospatial analysis through GPS and GIS and remote sensing was employed to map flood-prone areas, quantify topography, and analyze land-use changes over time

3.6 Data Analysis Techniques

The research employed a mixed technique in data evaluation, integrating quantitative, qualitative, and geographic information systems (GIS) to assess collected information holistically. The survey responses were analyzed using descriptive statistics based on percentages, frequency distribution, and mean score to identify flood events and adaptation trends. Qualitative information in interviews and FGD responses was analyzed with the assistance of thematic analysis and coding responses in the key themes and patterns of flood preparedness, community resilience, and policy gaps. Visualization in flood-prone areas, distribution of houses, and topographical differences were made with the assistance of GIS tools. Trend analysis was also used to assess flood record histories' frequency and severity level over time. Combining these research approaches ensured holistic knowledge about flood risk and adaptation in rural riverine settlements.

4. Results and Discussion

4.1 Extent and Effects of Flood Incidences on Rural Riverine Settlements

4.1.1 Displacement and Loss of Shelter

The evidence demonstrates that floods affected families in the settlements. This data was correlated with the type of housing material, and as highlighted in Nyakundi et al. (2010), poor housing materials increase flood vulnerability in rural settlements. This revealed that households with temporary mud houses were more affected than those with semi-permanent and permanent housing.

Table 3 Number of family members displaced during flood incidences.

Number of family members displaced by flooding	Responses	Percentage distribution
1	1	5.3%
2	7	36.8%
3	8	42.1%
4	2	10.5%
5	1	5.3%

Because most houses are temporary, they are more susceptible to floods. During fieldwork, it was found that the floodwater went through mud houses within the settlements, leaving huge openings. However, where the houses had iron sheets, they were left unscathed. Figure 5 shows the openings on the mud house depicting where the floods went through. In the same building, the iron sheet section remained intact. The figure also shows that mud and wood are most commonly used to construct buildings after stones.

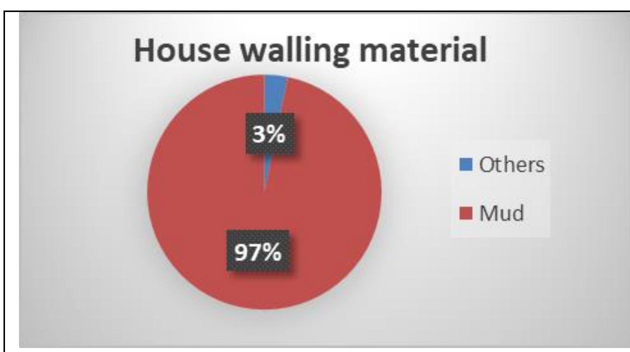

Figure 2 Housing typology
Source: Fieldwork, 2019

4.1.2 Infrastructure Damage

It is evident that in the past years, damage to infrastructure has occurred. The majority, at 50%, took place in 2020. This is evidence that flooding or other disasters struck the infrastructure in the year. In 2019, the second peak was at 35.7%. In 2017, only one was at 7.1%, indicating a low frequency of infrastructure damage. It shows a higher frequency in the occurrence of damages year after year, with the peak being in 2020.

Table 4 Showing the responses on the year in which flood incidences occurred

Year	Responses	Percentage
2017	1	7.1%
2019	5	35.7%
2020	7	50.0%
Total	14	100.0%

Source: Author, 2020

The finding agrees with Mool (2010) and Lewis & Mioch (2005), who argued that inadequate infrastructure planning worsens flood risks in rural areas, leading to frequent road and bridge collapses. Figure 6 shows the percentage of responses on whether flooding affected accessibility.

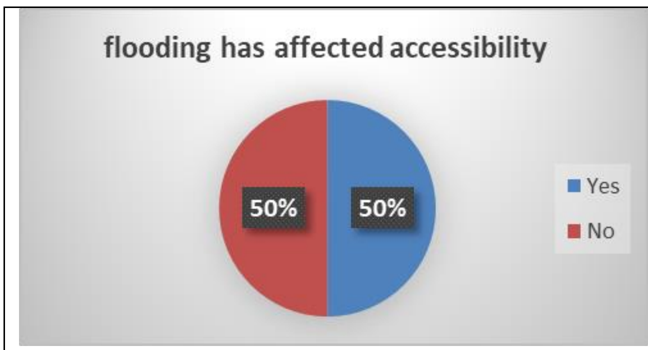

Figure 3 Effect of Flooding on Infrastructure

4.1.3 Livestock and Crop Damage

Livestock losses due to flooding varied across species. For goats, 21.4% of respondents reported no losses, while injuries and deaths ranged from 10 to 70 goats, with 5 and 60 goats being the most common losses (10.7%). For sheep, 17.9% had no losses, while 10 and 40 were the most frequently lost (14.3% and 17.9%). Other losses ranged from 2 to 60 sheep, with 7 and 8 sheep lost in multiple events. For chickens, 74.1% reported no losses, but 7.4% lost 10 chickens, while others lost 1 to 6 chickens, with a single case of 20 lost. These variations show that while many household livestock were unaffected, some suffered significant livestock losses. This effect

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reduces food security, as supported by Odoyo et al. (2024), stating that life disruptions in flood-prone areas affect farming, fishing, and livestock-keeping. It also agrees with Masese et al. (2016), who emphasize that floods disrupt natural and physical capital, leading to long-term food insecurity.

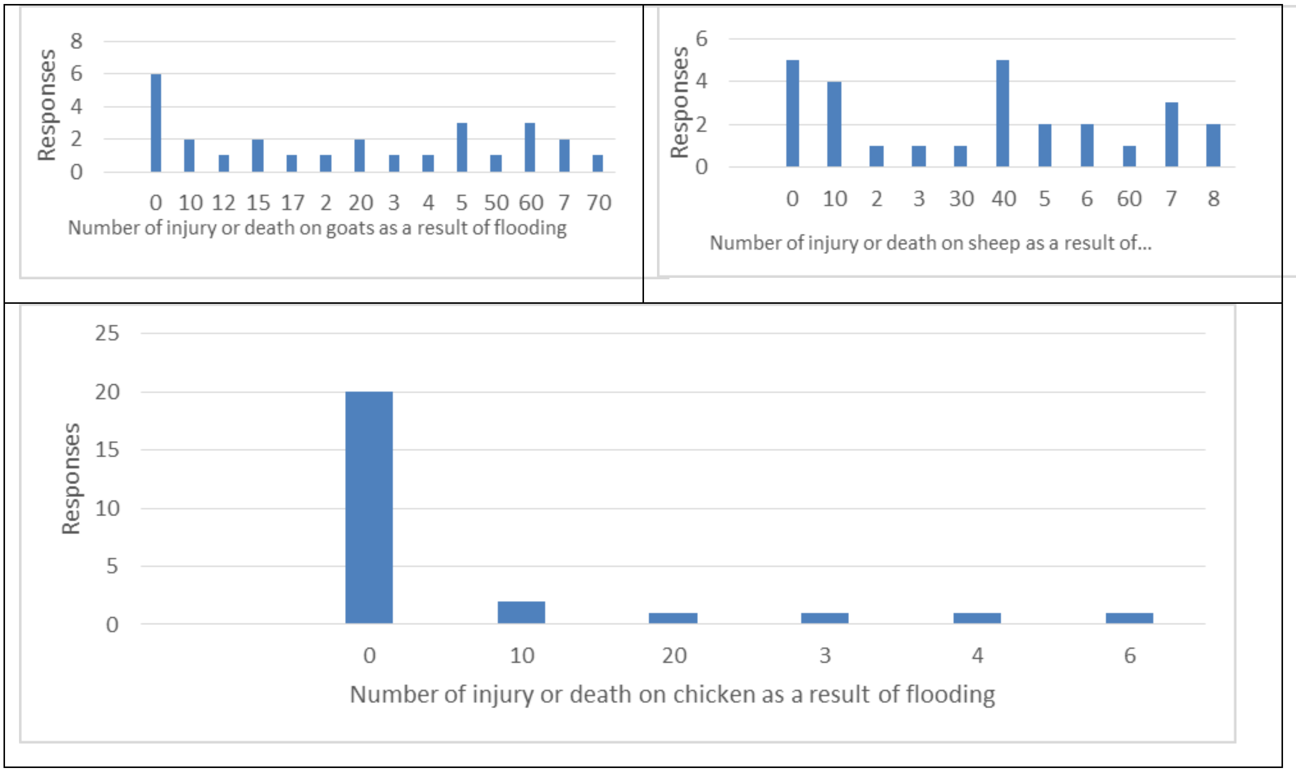

Figure 4 Number of injuries and deaths on livestock

Crop losses, with 24.1% of respondents losing 10 bags of maize, while 17.2% lost 2 or 20 bags. Green gram losses varied, with 18.5% reporting no loss, 14.8% losing 10 bags, and some losing up to 50 bags. 25% reported no cowpea losses, but 17.9% lost 10 bags, with a few losing up to 200 bags. Melon losses saw 33.3% unaffected, 16.7% losing 10 melons, and a few losing up to 200. These variations show that while some households had minimal losses, others faced severe crop destruction.

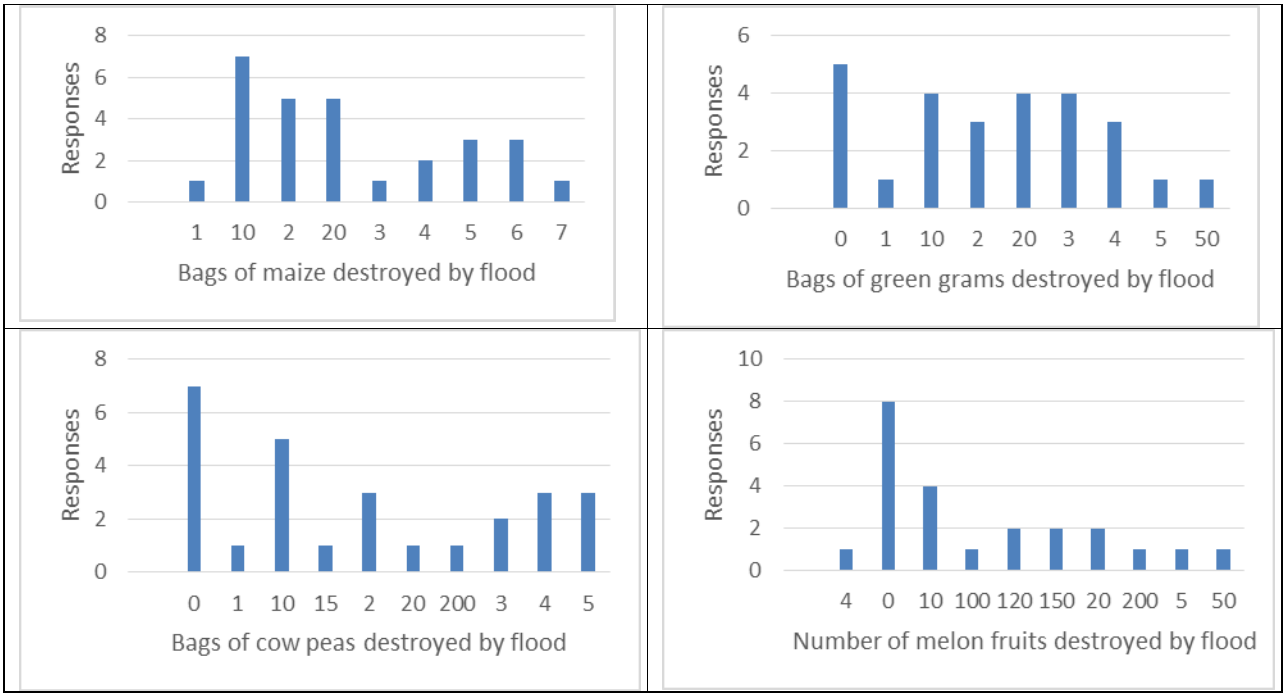

Figure 5 Crops destroyed due to flooding
Source: Fieldwork, 2019

4.2 Key Drivers of Flood Incidents and Rural Riverine Settlements in the Area

4.2.1 Natural and Man-made Features

The topography of selected settlements is generally flat, which prevents natural water runoff and increases flood retention. The areas' altitudes range from 80 to 240m above sea level, with the contour sparsely packed, as shown in Figure 8. This factor leads to flood risk and agrees with Zonneveld (1983), who explains that flooding occurs when river channels overflow due to natural features like lowland topography.

Constructing settlements along riverbanks further worsens flood risks. In Mororo, residences have been settled near the River Tana, as shown in Figure 10, which exposes them to flooding risk.

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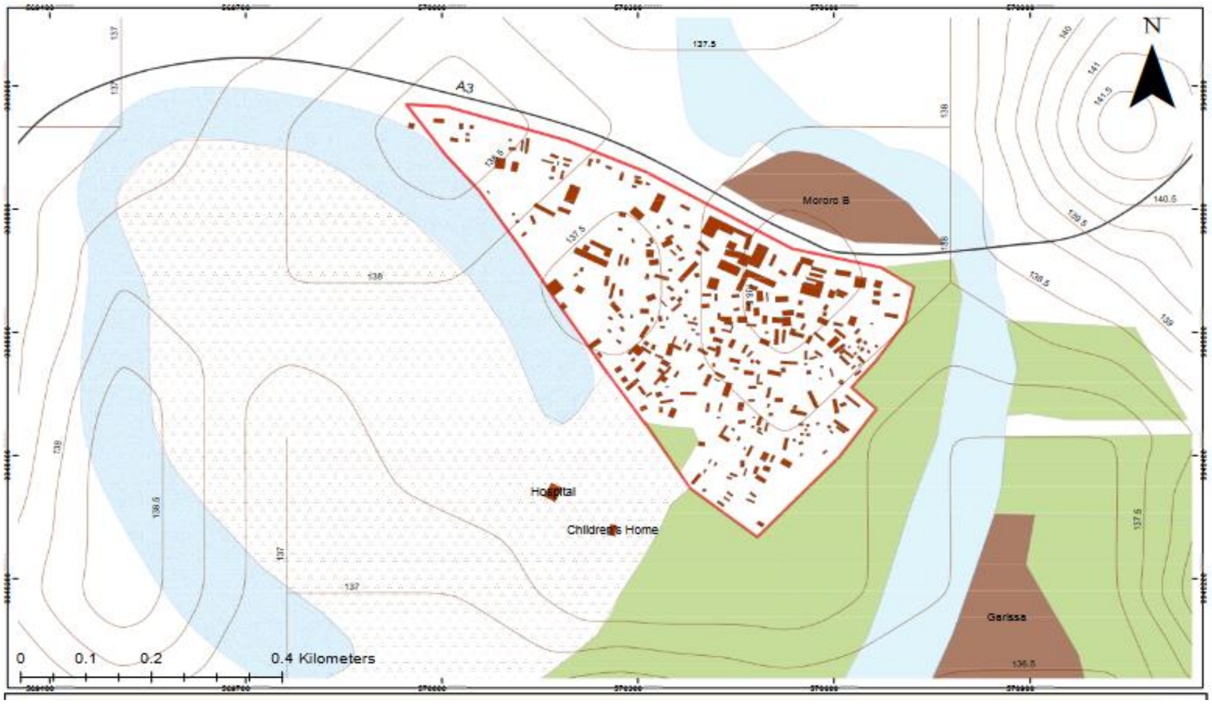

Figure 6 Sparsely packed contours, Makere.

Figure 7 Settlements were established near the river, the Mororo settlements.

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4.2.2 Climate Change

Kenya's annual average mean surface air temperature and precipitation from 1901 to 2023 indicated a general warming trend, especially from the 1970s onward. Rising temperatures contribute to flooding by intensifying rainfall, increasing glacial melt from Mount Kenya, and worsening drought-flood cycles. Higher temperatures lead to more evaporation, resulting in heavier rainfall that overwhelms drainage systems, while prolonged droughts reduce soil absorption, causing rapid runoff and severe flooding. This agrees with Odoyo et al. (2024), who argued that climate shifts have altered flood frequency in Kenya's Tana River Basin.

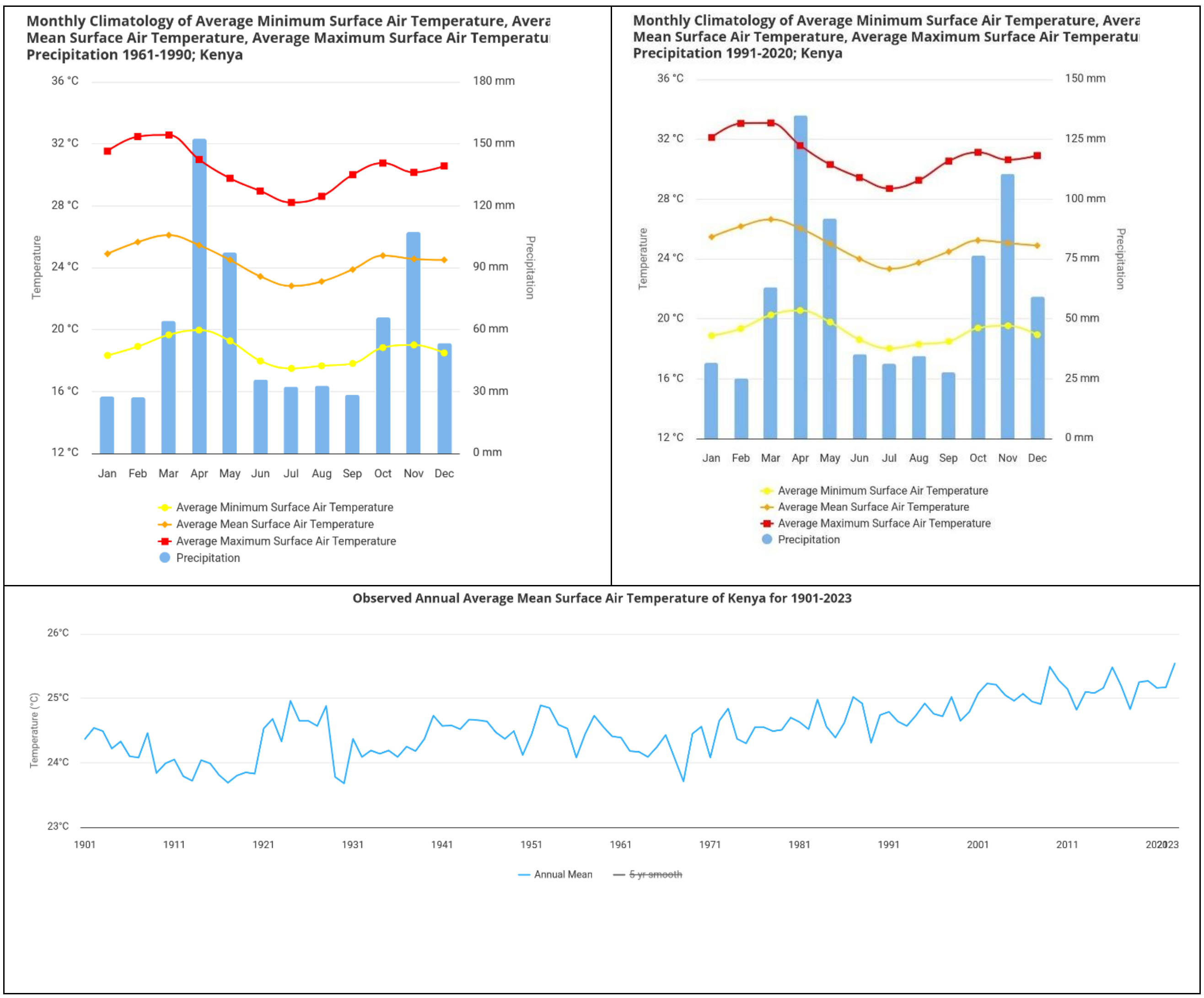


Figure 10 Temperature and precipitation trends
Source: Online, Britannica.

The seven settlements near River Tana are highly vulnerable to moderate rainfall since they are already in high-risk flood zones. Increased upstream rainfall exacerbates the situation.

4.2.3 Population Increase

Asako, Mororo, Nyangwani, Kilelengwani, Maderte, Makere, and Nanighi are steadily rising, with some areas like Makere experiencing rapid growth. This aligns with Lewis & Mioch (2005), who argue that unregulated population growth in floodplains increases disaster risk. Expanding settlements lead to deforestation, reduced water infiltration, and poor drainage, intensifying flood vulnerability. Informal housing in flood-prone areas further worsens the situation. Rising populations will continue to heighten flood risks without proper planning, emphasizing the need for effective land use and drainage solutions.

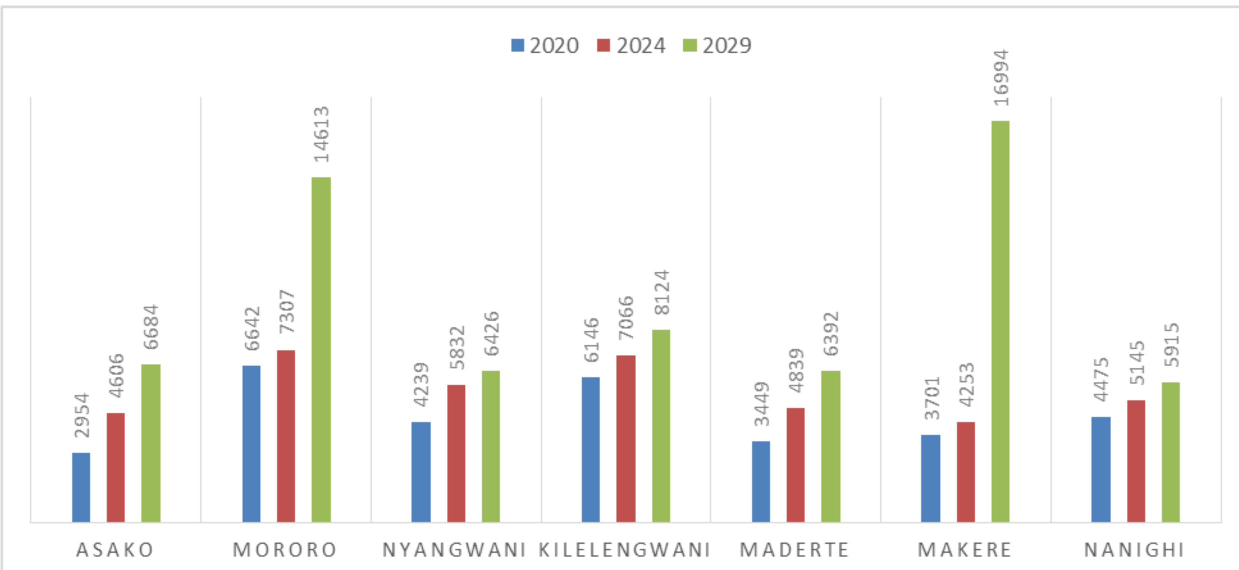


Figure 11 Population trends of the seven settlements

Source: Author, 2025

4.2.4 Land Use and Deforestation

Studies have shown that the Tana River's water-bearing capacity has been appreciably reduced through sedimentation. Deforestation and agricultural activity in upstream regions at the source of the River Tanan erode its upper parts, and eroded sediments settle at its riverbed, piling and raising its riverbed level. With a silted riverbed, even in ordinary rains, its overflows become increasingly intense and frequent, heightening its flood occurrences in and surrounding Mororo. Figure 12 shows how deforestation occurred, comparing 2004 and 2024.

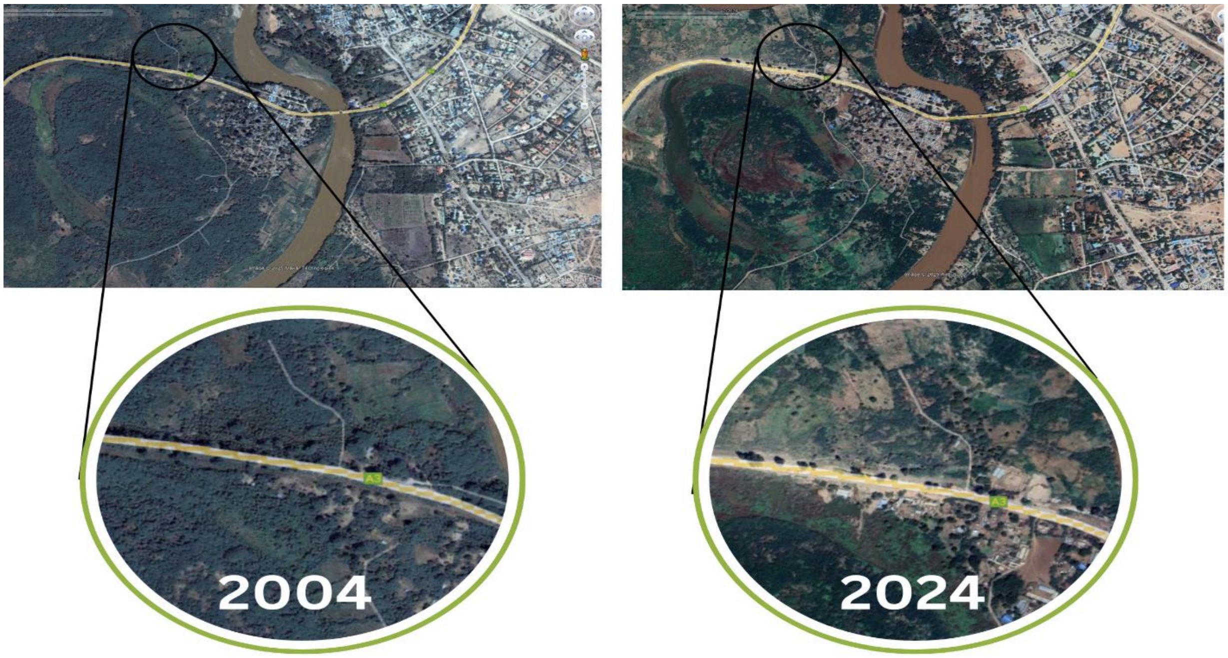


Figure 8 Deforestation at Mororo

4.2.5 Poor Planning and Land Use Policy

Figure 15 shows the poor planning of the Makere and Naghini settlements, where the infrastructure appears haphazardly interconnected without proper channels for drainage. The survey data confirms this, as most respondents reported no flood warning system, further exposing communities to risk. The pie chart illustrates responses regarding a flooding warning system in the study area. The results show that 62% of respondents indicated no warning system,

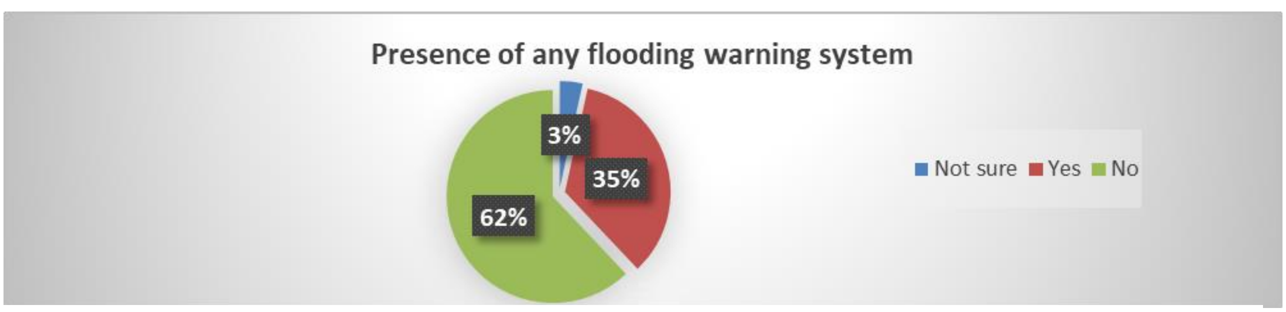
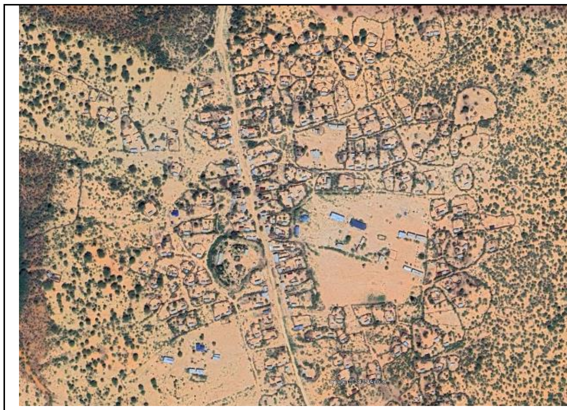


Figure 9 Presence of flooding warning system

Source: Fieldwork, 2019

35% confirmed its existence, and 3% were unsure. This agrees with UNDRR (2020) and Land Use Planning for Urban Flood Risk Management (2017), which argue that poor planning increases vulnerability by allowing settlements in hazard-prone areas.



Naghini

Makere

Figure 10 Haphazardly interconnected infrastructure at Nanigi and Makere, 2020

4.2.6 Natural Solutions

There is little exertion in nature-based flood adaptation measures in the research area. However, there is a high level of contribution towards building resilience and lowering flooding risks. Natural interventions like the restoration of wetlands, reforestation, and riverbank protection have been popularly adopted in flood management. Wetlands function as natural sponges that soak up surplus floodwater and release it over time, keeping river flow stable and avoiding abrupt overflowing. However, studies have shown that wetlands have been destroyed through deforestation, poorly managed agriculture, and human settlement, which lessened their flood-control capacity.

4.2.7 Structural and non-structural

Although structural and non-structural mitigation strategies are one strategy, they come with challenges. The structures often fail and start to block floods, which is useful to the residents regarding soil fertility. The structures also don't protect for a long time due to the nature of the upstream, where the river deposits silts that change the capacity and sometimes go above the structure.

4.3 Strategies to mitigate the effects of flood incidences on rural riverine settlements

Strategic measures must be taken to enhance resilience and reduce vulnerability in rural riverine communities to protect them from flood risk.

4.3.1 Mapping High-Risk Areas

Flood-risk mapping is among the primary strategies for identifying high-risk areas and restricting human settlements. Use of satellite imagery, aerial photograph and drone mapping techniques would offer better solutions to flood risk management. Mapping using these technologies would help buffering of arears of significant flooding. It does not allow the construction of buildings along rivers, restricting exposure to flood risk. With the support of zoning, efficient land-use planning can prevent encroachment into such dangerous areas, which is in agreement with UNDRR (2020) and Land Use Planning for Urban Flood Risk Management (2017).

4.3.2 Flood Monitoring with GIS

Flood surveillance using Geographic Information Systems (GIS) is essential in monitoring flood patterns and predicting future occurrences. GIS technology enables the authorities to analyze flood-risk areas and decide on evacuation procedures, infrastructure development, and disaster response. GIS and early warning systems can warn communities, allowing them to take preventive measures before flooding.

4.3.3 Structural & Non-Structural Mitigation

A combination of structural and non-structural interventions can successfully reduce the impact of flooding. Structural interventions, such as building levees, embankments, and flood diversion channels, provide a physical defence. Non-structural interventions, such as wetland restoration and conservation of natural drainage, take in excess water and reduce the effect of flooding. Climate-resilient infrastructure should support these interventions so that roads, bridges, and buildings are constructed to withstand extreme weather.

4.3.4 Policies & Zoning Regulations

Policy enforcement and zoning regulations are central to flood risk reduction. Governments and local authorities must implement strict building codes, enforce land-use regulations, and implement floodplain management policies. Early warning systems must be incorporated into disaster management plans to provide early warnings and facilitate quick evacuations. Preventive measures like rainwater harvesting and improved drainage systems can also enhance flood preparedness in rural areas.

4.3.5 Community Involvement

Public awareness and community participation are essential in building long-term resilience. Communities must be engaged in flood risk management through awareness, emergency preparedness, training, and participatory planning. Equipping communities with information and capacity enables them to protect themselves and their assets proactively. Rural riverine communities can minimize flood risks and build sustainable resilience by applying scientific approaches to community activities.

4.3.6 Nature-based solutions

Nature-based solutions offer a long-term flood mitigation approach. Wetland rehabilitation, riverbank reforestation, and agroforestry can control water flow, reduce soil erosion, and increase water retention capacity. Natural buffers trap excess floodwater, protecting downstream communities while enhancing biodiversity and ecosystem services. Combining scientific approaches with nature-based and community-based solutions can assist rural riverine communities in reducing flood risk and achieving long-term resilience.

Conclusion

The study establishes that the floods experienced in the seven selected riverine settlements are mainly triggered by proximity and settlement of flood-prone zones, climate change rainfall variability, population increase, land use and deforestation, and poor planning. These factors are the main drivers of displacement, infrastructure damage, and crop and livestock destruction. The economic cost forces affected communities to depend heavily on relief aid, which sometimes perpetuates their vulnerabilities. In the absence of deliberate interventions measured that include enhanced land use management, flood management infrastructure, and harmonization of policies, the settlements will keep experiencing disastrous flood-related problems that will render the pursuit of sustained resilience and sustainable development a hard target to pursue.

Recommendations

To mitigate the recurring floods in Tana River County, the government and relevant stakeholders should implement structural and non-structural measures that enhance resilience and reduce vulnerability. One of the key structural interventions is the construction of bypass and diversion channels to redirect excess water away from settlements and critical infrastructure. These channels should be strategically designed with proper flow regulation mechanisms, such as gates, to ensure controlled water discharge back into the river or other drainage systems. This will help reduce the direct impact of floods on communities while providing an opportunity for irrigation in drier areas.

Settlements must be relocated from high-risk flood zones to safer, elevated areas. This will reduce loss of lives, destruction of homes, and displacement of families. The relocation plan should ensure that only agricultural activities remain near the riverbanks to utilize the fertile floodplains while residential and commercial areas are moved to more secure locations. Proper land-use planning and zoning regulations should be enforced to prevent future encroachment into flood-prone areas.

Investment in nature-based solutions such as wetland restoration, afforestation along riverbanks, and conservation of natural flood buffers should be promoted. These measures will enhance water absorption capacity, reduce soil erosion, and support biodiversity. Strengthening early warning systems, educating communities on flood preparedness, and improving emergency response strategies are essential in building long-term resilience. By implementing these measures while ensuring sustainable development, Tana River County can effectively reduce floods' socio-economic and environmental impacts.

Contribution to existing knowledge

This study adds knowledge to the existing literature by shifting focus from highly studied urban flooding towards the lesser-known flood issues faced by rural riverine settlements. While the current literature has predominantly focused on flood mitigation in urban areas, the study extensively assesses the vulnerability, socio-economic impacts, and adaptation mechanisms within the rural riverine settlements in the Tana River Basin context. It defines the significant contribution towards the increase in flood risks not yet fully captured within the context of rural flood literature through improper planning for land use, poor policy enforcement, and environmental degradation.

The study advocates using integrated geospatial technology such as drone mapping, aerial survey, photography, high-resolution satellite imagery, GPS, and GIS to map flood-risk zones, monitor land use change, and establish predictive patterns for early warnings. These technological interventions will enhance flood preparedness and provide policymakers with data-based solutions for disaster mitigation. The study also highlights the need for structural and non-structural interventions like constructing canals and check dams for water regulation and nature-based interventions like wetland restoration and agroforestry that aim to improve rural settlements' flood resilience.

By promoting smart rural riverine spatial location after mapping floodways, the study adds value to the existing literature on rural disaster preparedness, land use planning, and adaptation to climate change. The study also offers practical recommendations for integrating community-based adaptation strategies with current flood control measures, helping rural riverine settlements live with their river environments safely while minimizing flood damage.

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