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A Planning Framework for Flood Mitigation in Nakuru City, Kenya

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Abstract

Flooding has become an increasingly critical challenge in Nakuru City exacerbated by both natural and human-induced factors. This study aimed to develop a comprehensive planning framework for flood mitigation within Nakuru City by examining the causes and proposing potential solutions to flooding. Observations on flooding roads in Kaptembwa, emerging of fault lines in Eveready and sink holes in Rhonda was captured through photography. Annual rainfall data was acquired from Kenya Meteorological Department with an interval of five years from1985. Sentinel 2 data from Copernicus Data Hub was used in land use analysis and determining the topography of the area while Landsat 8 image was used to examine the extent of Lake Nakuru over years and mapping flood hotspot areas. SPSS was used to analyze both spatial and statistical data for floods. Findings revealed that Nakuru City's flooding is primarily driven by intense rainfall, topography, poor drainage infrastructure and unregulated urban development. The paper proposes a flood mitigation framework focused on sustainable land-use planning, environmental conservation, stakeholder collaboration, and early warning systems. The study will give guidelines for urban planning practices in areas that were found to be highly susceptible to flooding. Policies can then be crafted through various departments to tackle environmental planning, disaster management and urban resilience. Residence of affected areas can also use this research to plan ahead and mitigate dangers of flooding.

Keywords: Flooding, urban planning, mitigation framework, geographic information systems and spatial analysis, Nakuru City, resilience, urban flooding and land use change

INTRODUCTION

Flood-related disasters have been increasing at an alarming rate of 134% since 2000 (WMO, 2016). Floods pose both natural and anthropogenic threats, alongside climate change, which happens to be the main driver in the aggravation of water cycles and the frequency of floods in the already flood plighted regions in cities. Rising global temperatures lead to changes in atmospheric moisture content resulting in more intense and erratic rainfall events.(Hirabayas,2023) outlined deforestation and rapid urbanization across the world as major contributors to collective Increase in flood risk from observation in Kashmir India. Industrial developments such as paved of services and construction of impermeable structures increased surface run off during intense rainfall. This coupled with alteration of river channel cause catastrophic damages and widespread displacement of people as witnessed in Ahr Valley, Germany. Strategies like Integrated Flood Management (IFM) and Climate Resilient Development (CRD) are multi-scalar in nature and emphasize community based flood control programs where water systems, land, and people can coexist for orderly flood management (EWFD, 2020). The larger Lagos city is documented as one of the most flood prone areas in Africa, Ikeja in Lagos experienced rapid change in urban settlement, burgeoning population's infrastructure development and interference with the natural environment making it a flood prone areas (Ndimele & Ayodele, 2024).

In Kenya, changes in climate, rampant urban sprawl, and environmental degradation culminate into the deeply rooted issue of flooding. Cities in Kenya such as Nakuru are susceptible to flooding due to lake expansion and poor drainage systems.

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These systems converge in the lower-lying areas, with increasing urban sprawl in places like Mwariki, Rhonda, Kaptembwa, and Eveready. Frequent flooding has resulted in submersion of critical infrastructure in addition to displacing residents. Soilo and Rhonda are two areas which have witnessed displacement of residents due to a combination of fault lines and rising lake water levels. Ineffective management of solid waste and high levels of runoff from paved surfaces have compounded the challenge.

The importance of the research stemmed from its contribution to sustainable urban development and planning, climate change adaptation, community resilience and preparedness, advocacy, and policymaking. Justified by rapid population growth, outdated planning frameworks, and a persistent gap in flood management research in Nakuru, it aimed to fill the research void. For this paper, the exploratory approach was adopted based on field observation, interviews, and focus group discussions. Some challenges, such as community resistance, were addressed through the involvement of community leaders and the requisite research permits. The paper is ultimately expected to aid Nakuru in its evolution towards a flood resilient and sustainable urban ecosystem. Existing legal frameworks are broad based with emphasis on structural interventions whereas it is evident there is need for more non-structural intervention. Limited research on flooding has been conducted in Nakuru city with no clear foresight on its future existence with increased flooding instances. However, little research has examined how the interaction between physical and social factors influences the occurrence and impacts of flooding in Nakuru City."

THEORY

Climate change

Climate change is a significant factor contributing to flooding, presenting a complex web of challenges to global hydrological systems (UNEP, 2020). Future flood risk in Kenya is likely to increase due in large part to increasing populations living in flood-prone areas (Abdrabo, 2022).Climate-resilient infrastructure, if implemented, serves as a robust shield against the adverse impacts of flooding (Heo, 2018). Sadly, only 40% of Africa is covered by such systems, and even those are compromised by quality issues (UNDRR, 2022). Land's ability to absorb and retain water has been affected (UNEP, 2019). Opined avoiding of construction in high-risk flood zones, preserving natural buffer zones, and planning for changes in water flow patterns as ways of flood mitigation (James, 2014). The fluvial flood hazard is projected to increase over Kenya due to projections of an increase in rainfall especially during the short rains season (Rowell, 2022). (IPCC, 2020) underscores the compounding effects of climate change on flooding exacerbated by industrial activities and urban run-off. A Flood Early Warning System provides a set of capacities needed to generate and disseminate timely and meaningful warning information that enables warning of at-risk populace. (Kiptum, 2023).

Infrastructural development

Infrastructure, such as buildings, roads, and bridges, should be designed and constructed to resist flooding (Lehner, 2021).Fluvial and pluvial flooding is expected to increase vulnerability to inhabitants in both riparian and informal settlements due to projected increases in rainfall intensity from climatic changes (Masson-Delmotte & Zhai, 2021).Improper storm water management can result in localized flooding, particularly when infrastructure is unable to handle increased runoff reducing the land's capacity to absorb and retain water(Smith & Johnson, 2019). The use of permeable pavements, which allow water to seep into the ground, can significantly reduce surface runoff in urban areas (Antoniou, 2022). Poverty and improving infrastructure resilience are fundamental strategies to reduce the socio-economic disparities associated with flood impacts(WHO, 2020). Afforestation refers to the process of establishing a forest, or stand of trees, in an area where there was no forest. (Umar & Gray, 2022). These areas also act as habitats for wildlife and improve water quality (Anguelovski, 2019). Education initiatives encourage communities to adopt sustainable practices, such as proper land use planning and infrastructure development, to reduce the risk of flooding and enhance long-term resilience (Aldrich & Meyer, 2015).

Land use and urban green infrastructure

Network of green (land) and blue (water) spaces can improve environmental conditions and therefore, citizens' health and quality of life is important. They also support a green economy, creates job opportunities, and enhance biodiversity (Curran

& Hamilton, 2020). For decades, cities have implemented smaller-scale green infrastructure projects, such as green roofs, rain gardens, and bioswales, to mitigate stormwater pollution and urban heat islands. Green infrastructure can be adopted in Nakuru to curb flooding by integrating nature-based solutions that enhance water absorption, storage and slow run-off. Creating urban green spaces, restoring wetlands around Lake Nakuru, establishing vegetated swales along roads and promoting permeable pavements can reduce surface runoff while enhancing groundwater recharge.

In the USA, green infrastructure promulgated since the 2000s to manage cities' stormwater pollution and urban heat island effects (Tzoulas 2017). It is attracting new interest as a way to cope with increasing flood risks (Carter et al. 2018; Matthews et al. 2015; Seddon et al. 2020). An estimated 15 million people live in flood-prone areas, with as much as $106 billion of real estate at risk of chronic flooding by 2050 (Flavelle 2020). Meanwhile, many states now restrict new shoreline hardening projects like seawalls, bulkheads and dykes due to their environmental impacts, yet lack the political will or financial capacity to engage in managed retreat or relocation (Dyckman., 2014). As a result, green infrastructure presents a politically palatable option to replace seawalls with sand dunes within existing epistemological, operational, and governance structures (Escobedo et al. 2019).

Theoretical Framework

Ecological resilience Theory

Ecological resilience stands out as the most comprehensive and foundational for addressing flood mitigation in Nakuru City. Unlike the other theories that focus on behavioral, social or structural aspects, Ecological Resilience Theory directly tackles the core natural system that regulate flooding. Ecological resilience refers to the capacity of a system to absorb disturbance and reorganize to maintain essentially the same functions, structures and controls. Resilience is the capacity of environmental, economic and social systems to cope with a hazardous event, disturbance or trend through reorganizing or responding in ways that maintain their identity, structure and essential functions. Nakuru can build adaptive capacity that enables ecosystems and communities to withstand extreme rainfall events and recover more quickly from flood disturbance. In the context of Nakuru City, the principles of Ecological Resilience Theory are reflected in local planning responses that emphasize adaptation through green infrastructure and flexible land-use regulation

Conceptual Framework

The conceptual framework illustrates the key components of flooding and their interconnections, establishing a systematic approach to creating a flood mitigation framework. The framework describes three broad areas of interest: Flood risk factors, Flood risk, and Flood control mechanisms. Land use, poor waste disposal, topography and rainfall have been shown to be factors contributing to flooding. It involves many risks such as health risks, environmental risks, economic risks, and psychological risks. In kind of reciprocal relationship, steps like keeping drainage systems clear, developing flood barriers and taking on early warning systems assist alleviate these impacts. The combined results of these elements contribute to the construction of a parallel approach to flood mitigation which accounts for causes, other risks and mitigation approaches as shown in **Figure 1**.

RESEARCH METHODS

Several optical satellite images from Landsat TM, ETM+ AND Landsat 8 as well as Sentinel-1 radar iamges were downloaded to map the land use changes, land cover and hydrological indices. The Landsat images acquired was from 1980 to 2023 while Sentinel data was provided from 2014 to 2023.False-color composite images of optical satellite imagery were produced for purpose of identification and mapping the various surface features. Land use classification was identified using optical satellite which focused on six classes (Forest cover, built up Areas, Agricultural Fields, Water bodies, Bareland and Rangeland). Several formulas and techniques were applied during LULC analysis for mapping, classification and change detection. Change detection techniques of the six land classes were used to measure the changes in intensity of spectral indices classifying land use into unique features of the same reflectance. A ten year interval land use map was produce from the year 1985 to 2023.The proportion of a specific LULC percentage in the

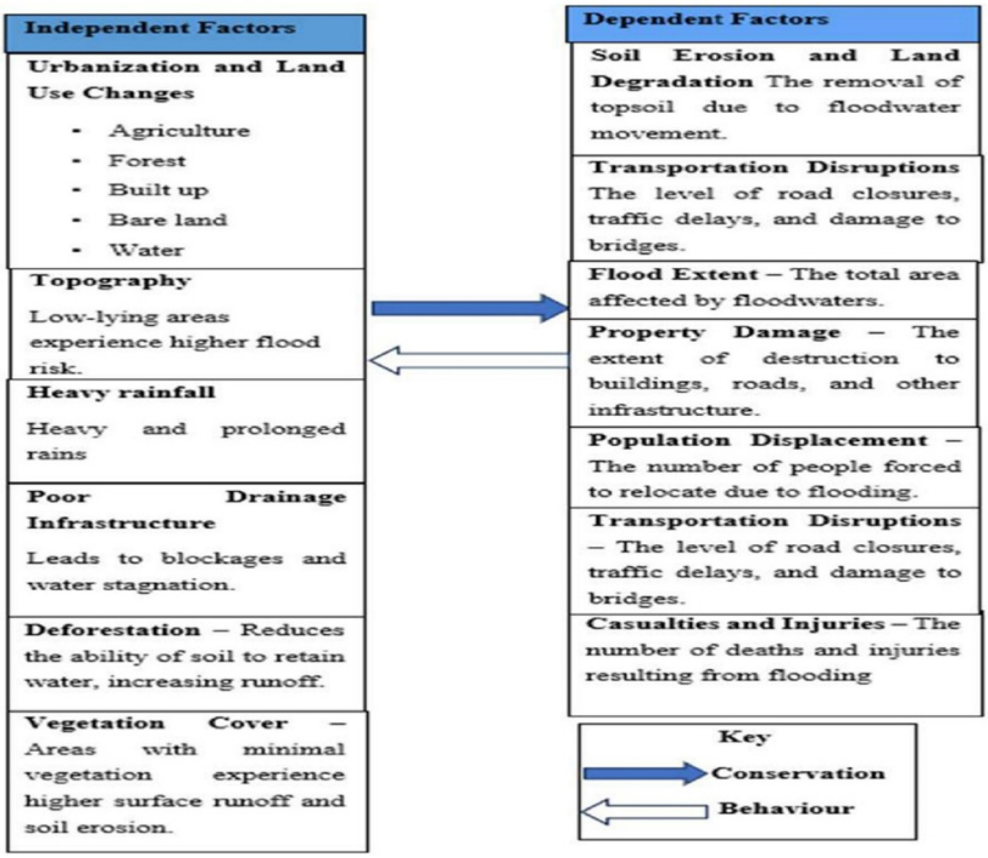

FIGURE 1
Conceptual framework
Source: Author Analysis, 2025

research was calculated as shown in the formulae below:

$$LULC\ Percentage = \left(\frac{Area\ of\ specific\ LULC\ Class}{Total\ area\ of\ the\ region}\right) * 100$$

NDVI was chosen to identify the reflectance of vegetation cover on the study area proving timely change of land use over years. To identify Forest cover, Rangeland and Agricultural areas in the study area Normalized Difference Vegetation Index (NDVI) was used. NDVI is a popular remote sensing index that quantified the density and vigor of vegetation based on how plants reflected light in the red (R) and near infrared (NIR) portions of the electromagnetic spectrum. Healthy vegetation absorbed much of the red light (which is used for photosynthesizing) and reflected near infrared (NIR) light well which made NDVI a strong indicator for photosynthesis, plant health and biomass. NDVI was calculated as

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Built-up Index was used to quantify buildings and development structures.

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$$

Water bodies was also analyzed using a remote sensing index which helped to identify and monitor surface water feature. NDWI was used to enhance water-related features by taking advantage of the reflectance properties of water in a specific spectral band with the formula:

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

Confusion matrix was used to assess errors during data analysis. The confusion matrix error assessment was used to evaluate the accuracy of land cover classification by comparing actual land cover categories with classified results as shown in **Table 1**. Forest, Bareland, and Water have the highest classification accuracy, with most of their values correctly assigned (8/12 for Forest, 6/6 for Bareland, and 6/6 for Water), indicating minimal misclassification. Built-up areas and Agriculture exhibit moderate classification errors, where built-up land was confused with agriculture (1 misclassification) and natural land cover types (2 misclassifications). Rangeland has the highest classification confusion, with only 7 out of 11 correctly identified and misclassifications occurring with built-up, agriculture, and forest. The overall accuracy is 81.4%, suggesting a reasonably reliable classification, but improvements could be made by refining training datasets, using higher-resolution imagery, or integrating additional classification methods to reduce confusion among mixed land cover types like agriculture and rangeland.

ArcGIS software by ESRI was used to extract the various hydrological parameters of the studied area. Digital Elevation model (DEM) produced from Shuttle Radar Topography Mission (STRM) enabled in extracting topographic undulation of the tarrain.The "D-8" algorithm enables extracting the parameters of hydrology. The flow accumulation of a given cell was determined based on flow direction and its gradient downstream. Interpolation method in ArcGIS was used to generate the DEM, Inverse Distance Weighting (IDW) technique was applied whereby the different elevation were estimated using the formulae:

$$\mathbf{Z(x,y)} = \sum_{\mathbf{i}}^{\mathbf{n}} \mathbf{Z}\frac{\mathbf{Zi}}{\mathbf{di}}$$

Slope represents the steepness of terrain derived from the DEM, GIS slope calculations use the elevation differences between a given cell in the DEM and its neighboring cells, usually within a 3-by-3 grid. Using these elevation differences, rates of Vertical Change in the x (east-west) and y (north-south) directions were calculated to obtain the gradient. The slopes were created using the formulae:

$$S = \tan^{-1}\left(\sqrt{\left(\frac{\partial y}{\partial x}\right) + \left(\frac{\delta z}{\delta y}\right)}\right) 1$$

The generation of contours was based on interpolation techniques applied between grid cells of the DEM; the mathematical principle underpinning this was expressed by finding points where the elevation value z equaled the specified contour intervals to satisfy;

$$z_1 < z_c < z_2$$

The interpolation to locate the contour position was calculated linearly:

$$x_c = x_1 + \frac{(z_c - z_1).(x_2 - x_1)}{(z_2 - z_1)}$$

$$y_c = y_1 + \frac{(z_c - z_1).(y_2 - y_1)}{(z_2 - z_1)}$$

TABLE 1
Confusion matrix

	Forest	Built up	Bare land	Water	Agricul-ture	Rangeland	User
Forest	8	0	0	0	0	0	8
Built up	2	3	0	0	1	0	6
Bareland	0	0	6	0	0	0	6
Water	0	0	0	6	0	0	6
Agriculture	1	0	0	0	5	0	6
Rangeland	1	2	0	0	1	7	11
Producer (Total)	12	5	6	6	7	7	81.4%

Source: Author's analysis (2025)

Contours showed the low and high altitude which was crucial to identify places which are prone to flooding.

Raw annual rainfall data was acquired from Kenya meteorological department which was provided inform of numerical data in excel sheet. The data was in 5-year interval from 1980 to 2023. The rainfall data helped to understand the trends for rainfall in Nakuru for the decades. SPSS was used to conduct both descriptive and statistical analysis in order to establish the relationship between rainfall variability, Land use changes and topographic orientation in Nakuru. Descriptive analysis in SPSS was performed to compute measures for rainfall and each land use class enabling the identification of general trends and patterns over the study period. Statistical analysis involved Pearson Correlation to determined strength of the relationship between flood factors and multiple regression analysis helped to quantify the contribution of these factors.

Focus Group Discussions (FGDs) were conducted with 24 participants drawn from community leaders, county planners, and residents of flood-prone zones in Rhonda and Kaptembwa wards. Participants were purposively selected to ensure representation of both gender and diverse livelihood groups.

RESULTS

Heavy Rains

Rainfall is one of the dominant factors contributing to flooding in Nakuru City due to its intensity, duration and seasonal concentration.

Figure 2 illustrates average rainfall in millimeters at five-year intervals from 1980 to 2023, showed otable fluctuations over time.

Topographic Analysis

High-resolution satellite imagery from Sentinel-2 and Landsat-8 was used to analyze Nakuru's topography, revealing elevation variations that significantly influence flooding. In places like Mwiriki, characterized by urban landscapes and residential settlements, the DEM highlights relatively flat terrain interspersed with gentle slopes and valleys, which experience frequent floodings. As can be seen in **Figure 3** the green part of the map shows low altitude areas around the Lake and red part shows high altitude areas of above 1900m above the sea level. The DEM of Nakuru revealed elevation variation ranging from approximately 1754m to 2084m above the sea level. The central area depicted in dark green represents the lowest elevation forming a basin that host Lake Nakuru and surrounding flatlands while the eastern escarpment and western highlands appear

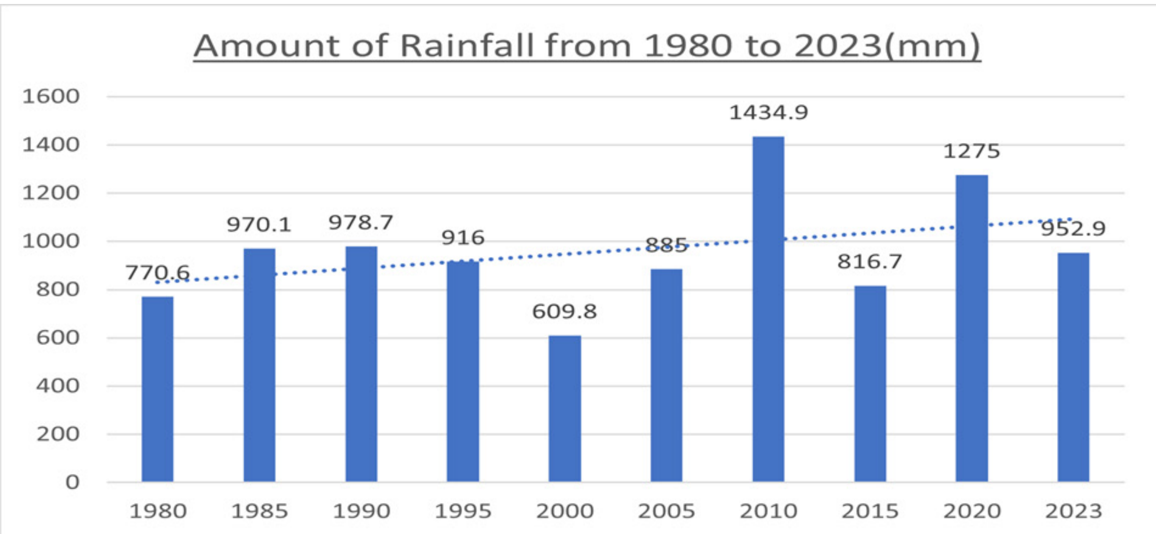

FIGURE 2
Average rainfall graph from 1980 to 2023
Source: Author Analysis, 2025

yellow to red shades indicating higher elevations as shown in **Figure 3**.

Land Use Trend analysis

From 1985 to 2023, Nakuru City experienced declining agricultural and rangeland areas, rising bare land and built-up zones, and fluctuating forest cover. Urban expansion drove consistent growth in infrastructure, while water bodies increased recently after earlier decline. These trends reflect significant urbanization and shifting land use patterns over time as shown in **Table 2**. The land use analysis indicates significant spatial and temporal variations across different classes. Agriculture and rangeland dominate the landscape with values fluctuating between 4059-9747.18

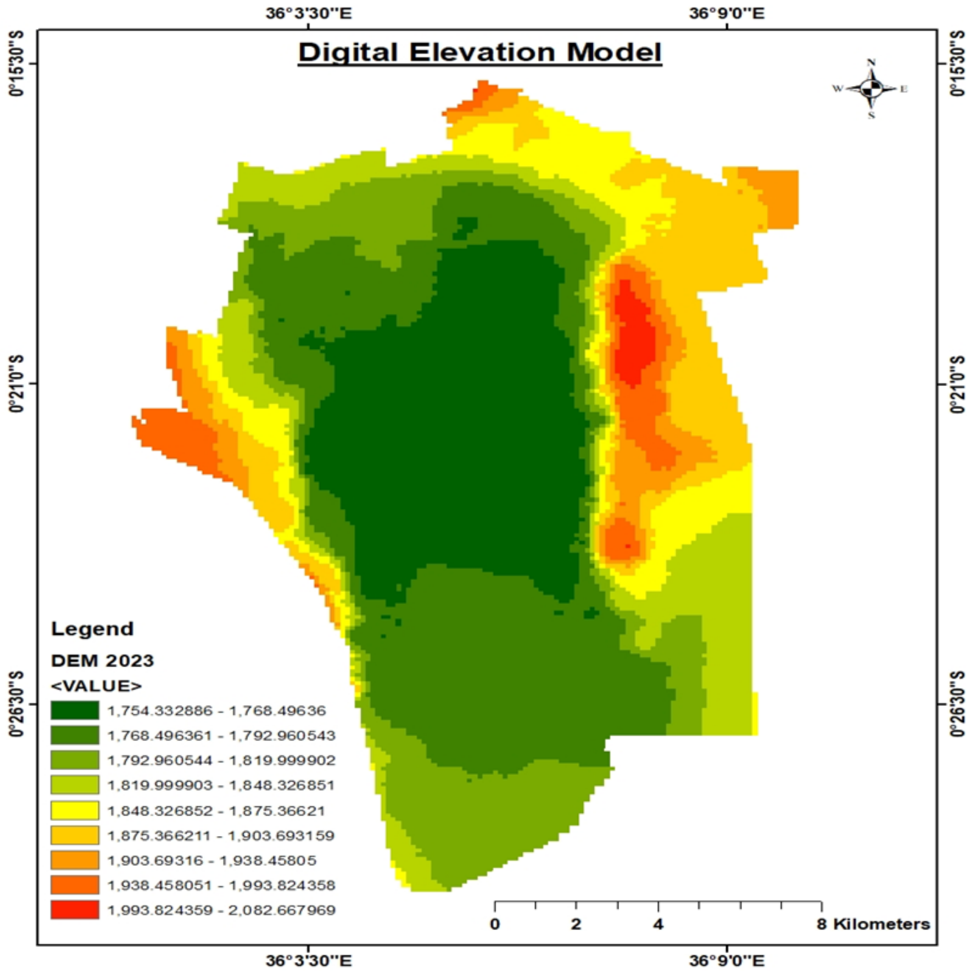

FIGURE 3
Digital Elevation Model (DEM) of Nakuru City
Source: Author's 2025 analysis based on SRTM/USGS data

TABLE 2
Classification results for land use in (Hectares)

Agriculture	Bareland	Forest	Buillt up	Rangeland	Water
4675.59	2089.17	2597.94	1041.66	10684.71	3947.13
9747.18	1030.95	4582.17	1111.14	5460.84	2732.76
4503.96	2242.17	2540.79	1482.3	11279.97	3358.17
8463.78	2998.08	2602.44	1798.56	3922.92	5250.42
4059	4735.17	2890.44	2234.61	5109.66	6007.32

Source: Author's analysis (2025)

and 3922.92-11279.97 hectares respectively, reflecting dynamic shifts between cultivation and grazing activities. Forest cover showed moderate stability while bareland suggested degradation process. Built-up areas steadily increase drastically highlighting urban expansion. Water bodies indicated fluctuating hydrological conditions.

Table 3 displays the results of a regression analysis examining the relationship between various land-use categories and port development indicators using both standardized and unstandardized coefficients.

Land Use Land Cover Change Detection

Change detection helped to identify how land cover changes affect flood susceptibility. The research shows that rangeland is still dominant, with 43.22 sq. km unchanged, while 26.78 sq. km of bareland has transformed to rangeland, probably due to natural regrowth or land management practices. But 12.79 sq. km of forest being converted to rangeland means deforestation, increased erosion, and decreased water retention.

Water body dynamics also undergo high alterations: 33.47 sq. km remained unchanged, whereas 9.73 sq. km of bareland and 7.07 sq. km of rangeland were transformed into water bodies referring to flooding or lake expansion. Agricultural dynamics include 16.79 sq. km transforming to rangeland via soil erosion and 10.5 sq. km of bareland transforming into agriculture, which refers to probable expansion. All these transformations refer to environmental stresses that can intensify flood risks as shown in **Figure 4**.

Accuracy Assessment

Nakuru City urbanization is defined by the conversion of 2.42 sq. km agricultural land and 0.94 sq. km bare land into built-up areas with greater impervious surface and flood risks. Minor reforestation activity added an increase of 4.38 sq. km of forest, although deforestation still exists with losses to agriculture and bare land. Classification accuracy for Forest, Bareland, and Water while Built-up and Agriculture had moderate error. Rangeland was most inaccurately classified.

Flood Prone Areas in Nakuru City

A combination of field visits, Digital Elevation Model (DEM) analysis, and focus group discussions was used to identify flood-prone areas in Nakuru City. Areas of Kaptembwa, Rhonda, Mwariki, and Eveready were assessed. Overflow from Lake Nakuru has rendered parts of Mwariki uninhabitable, displacing residents. Runoff from Menengai Forest and hilly areas like Njoro contrib-

TABLE 3

Standardized and unstandardized Coefficients for Land use

Unstandardized Coefficients	Standardized Coefficients	t	Sig.	Unstandardized Coefficients	Standardized Coefficients
B	**Std. Error**	**Beta**		**B**	**Std. Error**
Water	.321	.104	.871	3.076	.054
	168.487	461.254		.365	.739
Bareland	.962	.194	.944	4.948	.016
	-1479.880	860.965		-1.719	.184
Forest	-.639	.944	-.364	-.677	.547
	4022.710	1507.759		2.668	.076
Agriculture	-1.039	.922	-.545	-1.127	.342
	9010.229	2667.357		3.378	.043
Built up	-.075	.072	-.518	-1.050	.371
	2081.529	565.870		3.678	.035
Rangeland	-.134	.219	-.334	-.613	.583
	3597.071	1729.106		2.080	.129

Source: Author's analysis (2025)

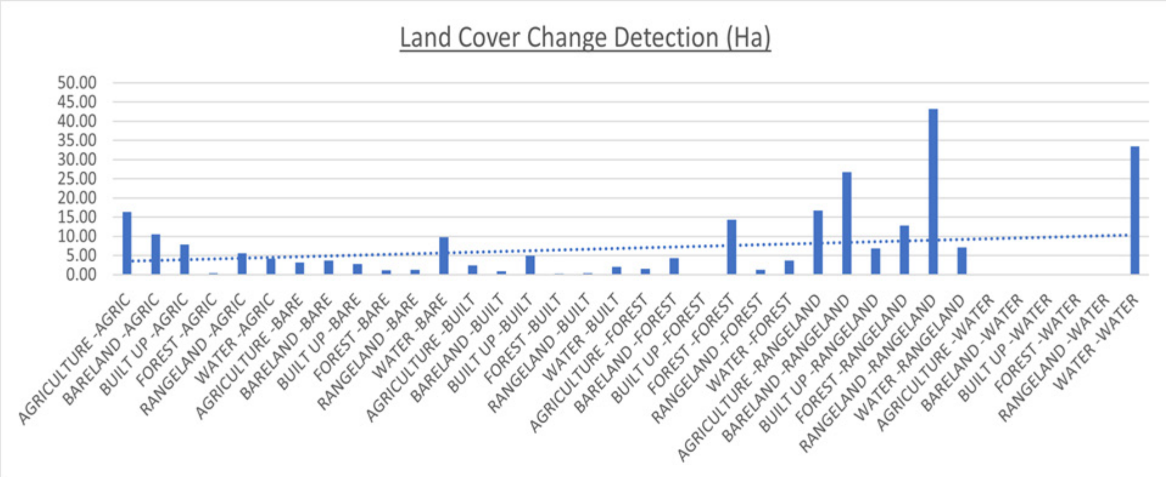

FIGURE 4
Change detection spatial analysis
Source: Author Analysis, 2025

utes to flooding, with silt-laden inflows into Lake Nakuru causing its expansion. Flooding in Nakuru City has caused significant loss of life, injuries, and property damage, especially in the low-lying areas of Kaptembwa, Mwariki, and Rhonda. Residents in these areas have often been evacuated during peak flooding events shown in **Figure 5**.

In response, Nakuru City has undertaken measures such as constructing and upgrading 20 kilometers of stormwater drainage systems and conducting regular maintenance to prevent clogging. At the community level, sandbags are used as temporary barriers to redirect floodwaters, offering short-term protection during emergencies. Rainfall data from the Kenya Meteorological Department, covering the period 1980 to 2023 in five-year intervals, was analyzed to understand precipitation trends. The year 2010 recorded the highest rainfall at approximately 1,434 mm, while 2000 recorded the lowest at 609 mm—an increase of 136.67% over ten years. Although rainfall alone requires large volumes to trigger flooding, the 2023 data indicated significant flood events even with lower rainfall, highlighting the combined effect of other contributing factors **Table 4**.

Impact on Infrastructure

Statistical measures mean, median, mode, standard deviation, skewness, kurtosis, and range for variables like population density, destroyed buildings, areas, and individuals, provided information on flood impacts and data variability. Low-lying areas of Kaptembwa, Eveready, Rhonda, and Mwariki have high flood impacts due to poor drainage and urbanization. In Rhonda and Kaptembwa, houses, shops, and roads are normally destroyed by floods. Waterlogging is exacerbated by clogged drainage, resulting in floods, destruction of property, and displacement. Flooding drains expose people to sewage, raising waterborne diseases risks.

Eveready and Mwariki suffer in the same way as floodwater will destroy roads and affect traffic. Debris accumulation and silt strain transport

TABLE 4
Flood prone areas analysis

	Name	Population (/km2)	Affected Buildings	Area Affected (km2)	Affected people
1	Mwariki	160	31	8.5	269
2	Eveready	280	16	2.1	112
3	Rhonda	200	21	3.9	126
4	Kaptembwa	400	29	4.8	176

Source: Author's analysis (2025)

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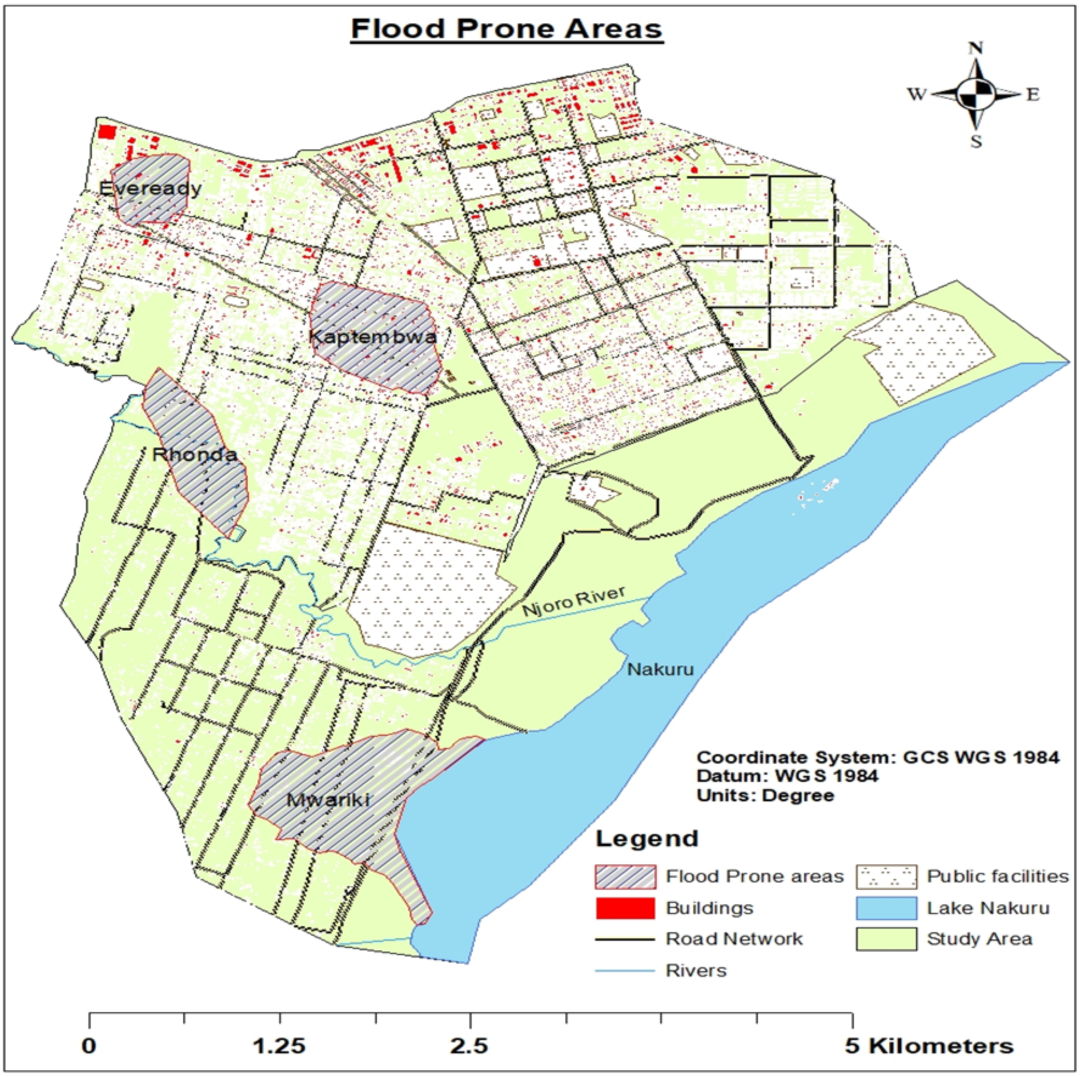

FIGURE 5
Flood hazard map for Nakuru City
Source: Author Analysis, 2025 using Landsat and field data

infrastructure, while flooded-out utilities contribute to water contamination and power outages. Repeated damage to the infrastructure and displacement occur despite ongoing mitigation in these regions. NASA satellite images from 1985 to 2023 report variations in Lake Nakuru's area falling until 2005, rising in 2015, and by 2020, substantially increasing with slight recession by 2023. It is attributed to rainfall variation, river inflows, groundwater, deforestation, and urbanization. Growth of the lake contributes to dilution of alkalinity, which threatens the flamingos and changes the ecosystem of Lake Nakuru National Park as shown in **Figure 6**.

Adapted from (USGS), the statistical analysis of Lake Nakuru's area and extent reveals moderate variability and near-symmetric distribution, though the mode deviates significantly. High dispersion in percentage area and boundary extent, along with negative values and outliers, indicates inconsistencies or possible data errors that warrant further investigation, despite general trends being evident in **Table 5**.

DISCUSSION

From the findings,the peak rainfall occurred in 2010 with approximately 1400 mm, coinciding with severe flooding events. Other significant rainfall years include 2020 (1275 mm) and 2023 (952.9 mm), both associated with intense flooding despite lower totals than in 2010. The city experience bimodal rainfall with long rains and short rains. During heavy downpours especially in April and May, large volumes of water accumulate

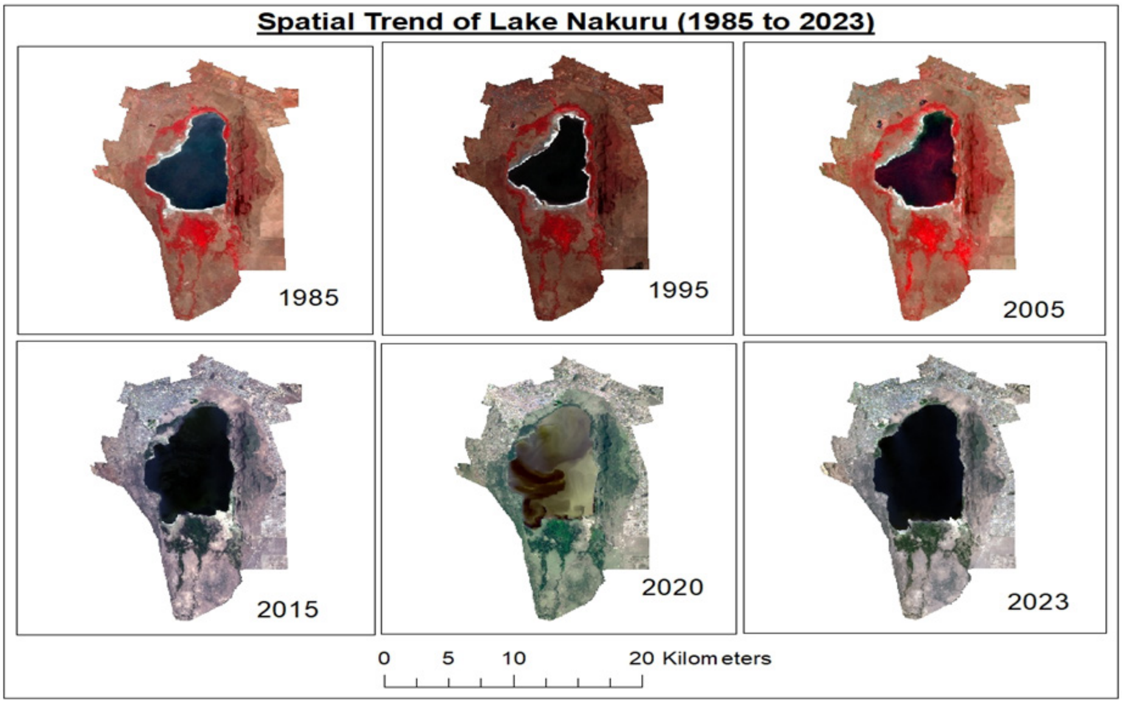

FIGURE 6
Satellite images showing water levels variation for Lake Nakuru
Source: Author's analysis (2025)

TABLE 5
Lake Nakuru assessment analysis

Lake Nakuru	Area (km2)	Percentage area	Boundary extend	Lake Nakuru
1985	40.11	0%	0	1985
1995	30.85	-23.09%	-265.94	1995
2005	35.68	15.65%	425.55	2005
2015	54.47	52.70%	941.65	2015
2020	60.9	11.80%	244.34	2020

Source: Author's analysis (2025)

rapidly overwhelming the existing drainage infrastructure.Additionaly, the county's proximity to Laker Nakuru means that prolonged rainfall raises water level causing backflow and flooding in adjacent settlements. (Zhou, Leng, Su & Ren, 2019) clearly acknowledge rainfall as a central factor influencing flooding, emphasizing that rainfall amount, duration and intensity distribution critically determine flood risks in urban drainage systems. Their simulation show that flooding occurs when rainfall exceeds drainage capacity with heavier and shorter storms generating higher flooding volumes due to intensity runoff while longer rainfall duration reduce peak flooding by allowing more infiltration and dispersion.

The city ranges from 1,740 to 1,950 meters above sea level. Low-lying zones below 1,800 meters, mainly near Lake Nakuru and river catchments, account for 30% of the landscape and are highly flood-prone. Mid-elevation areas (1,800–1,900 m) such as Eveready and Kaptembwa make up 50% of the terrain and experience moderate flooding. High-altitude regions like Menengai Crater (above 1,900 m) are least affected due to steep slopes. Digital Elevation Model (DEM) was utilized to explore Nakuru terrain and topography, which unveils a rich tapestry of geographical features across distinct locations within the region. From the analysis of (Ahmed, Hoque, Howlader, & Pradhan, 2022) they strongly agreed that topography is a key factor influencing flooding vulnerability since low-lying and flat terrain areas are highly prone to prolonged inundation while higher elevation and steeper slopes are less vulnerable to floods.Landsat-8 satellite image provided high resolution Land use land cover maps giving a time series for previous years. Analytic Hierarchy Process determine the relative importance of flood factors assigned a specific weight to each factor. Weighted factors were integrated using a weighted sum overlay technique to generate a comprehensive flood hazard map (Al-Omari, Shatnawi, Shbeeb, Istrati, Lagaros, & Abdalla,2024).Remote sensing provided critical data for mapping water, measures hydrological fluxes and monitoring flood due to continuous, large-scale and cost-effective observation of the earth's surface (Wang & Xie ,2018).

Mwariki was the most affected, with 8.5 sq. km impacted, 31 buildings affected, and 269 people displaced. Eveready, despite a higher population density (280/sq. km), had 16 affected buildings and 112 people impacted over 2.1 sq. km. Rhonda experienced 21 affected buildings and 126 people impacted across 3.9 sq. km, while Kaptembwa, with the highest population density (400/sq. km), saw 29 buildings affected and 176 people displaced over 4.8 sq. km. These findings highlight both geographic and demographic contributions to flood vulnerability.Occurence of occasional flash floods induced by heavy storms can gillhave a devastating impact if appropriate measures are not implemented (Hermas, Gaber & Bastawesy, 2021). Land use and land cover changes revealed a significant increase in human settlements and corresponding decline in grassland, bare soil and soil in Nakuru.(Kaburu, Koech, & Manguriu,2019) similarly concluded in their research that changes in land use and land cover affect grassland, bare land, soil and water bodies which are natural flood buffer zones. It is therefore a corroboration that land use and land cover changes play a vital role in exposing an area to flood risks.

Regression analysis revealed that bare land had the strongest correlation (R^2 = 0.891), followed by built-up areas (R^2 = 0.759), suggesting these categories can be reliably predicted using linear models. Forests displayed weak correlations across all models, while agriculture and rangeland had moderate to weak predictive power with high standard errors. These findings highlight the complexity of modeling land use change, indicating the need for multifactorial approaches for natural land types and suggesting that urban and bare land patterns are more predictable due to anthropogenic influences. SPSS regression analysis examined relationships among land cover types using linear, logarithmic, and exponential models. Water showed a strong influence on built-up areas (R^2 = 0.759, p = 0.054) and bare land (R^2 = 0.891, p = 0.016), indicating water availability significantly predicts changes in these categories as shown in **Table 3**.

Flood Mitigation Framework

Stakeholder Engagement is a critical pillar that ensures the inclusion of various societal groups such as Community-Based Organizations (CBOs), the business community, youth, women, persons with disabilities (PWDs), faith-based organizations (FBOs), and both county and national departments. The novelty of the planning framework for flood mitigation in Nakuru lies in its integration of Kenya's Vision 2030, which advances science, technology, and resilient infrastructure through early warning systems, modern drainage, and geospatial mapping. The findings align with Kenya's Vision 2030 objective of promoting sustainable urban development and with the Climate Change Act (2016), which mandates integration of adaptation strategies into county planning frameworks. Strengthening flood resilience in Nakuru therefore supports national priorities on climate adaptation and urban safety. Nakuru City Urban Resilience Strategy emphasizes sustainable land use, risk-informed planning, and community preparedness which translate flood priorities into localizes and practical action. Climate Change Act (2016), which mandates mainstreaming climate resilience and adaptation in development planning which ensures long term adaptive capacity to climate variability. Together, they provide a novel, future-focused governance framework that strengthens Nakuru's ability to proactively manage flood risks while supporting sustainable urban growth.

Environmental Conservation and Land Use Planning serve as the framework's environmental and spatial planning arms. Environmental strategies focus on solid waste management, tree planting, and storm water infrastructure like catch basins and drainage channels to reduce runoff and increase absorption. Meanwhile, Land Use Planning covers action area plans, building standards, emergency/rescue centers, and adoption of innovative concepts like the Sponge City, which enhances the city's natural ability to absorb rainwater. Urban Planning, positioned at the base of the diagram, ties all components together by ensuring spatial alignment of policies, infrastructure, and community needs. Collectively, this framework promotes resilience through harmonized planning, inclusive participation, and sustainable environmental management as indicated in **Figure 7**.

CONCLUSION

The study has exposed close relationship between natural and anthropogenic factors contribution towards flooding in Nakuru City. Based on the analysis, the outcome of the analyzed data has pinpointed heavy rains and topography as two primary factors causing flooding while land-use changes, and poor solid-waste management are amplifiers. The study though recognizing the efforts that have been made to deal with flooding has exposed the shortcomings of the interventions undertaken so far, the structured intervention proposed are aimed at achieving immense and recognizable results to deal with the flooding menace.

Additionally, recognizing and pinpointing areas prone to flooding will assist in refocusing mitigation undertakings to the would be affected areas first before consideration of the larger area. These will lead to significantly reduce impacts and effect of increase precipitation in future flooding events.

RECOMMENDATIONS

The County should align flood mitigation strategies with the Climate Change Act (2016), the Nakuru Urban Resilience Strategy, and Kenya's Vision 2030 by integrating climate resilience,

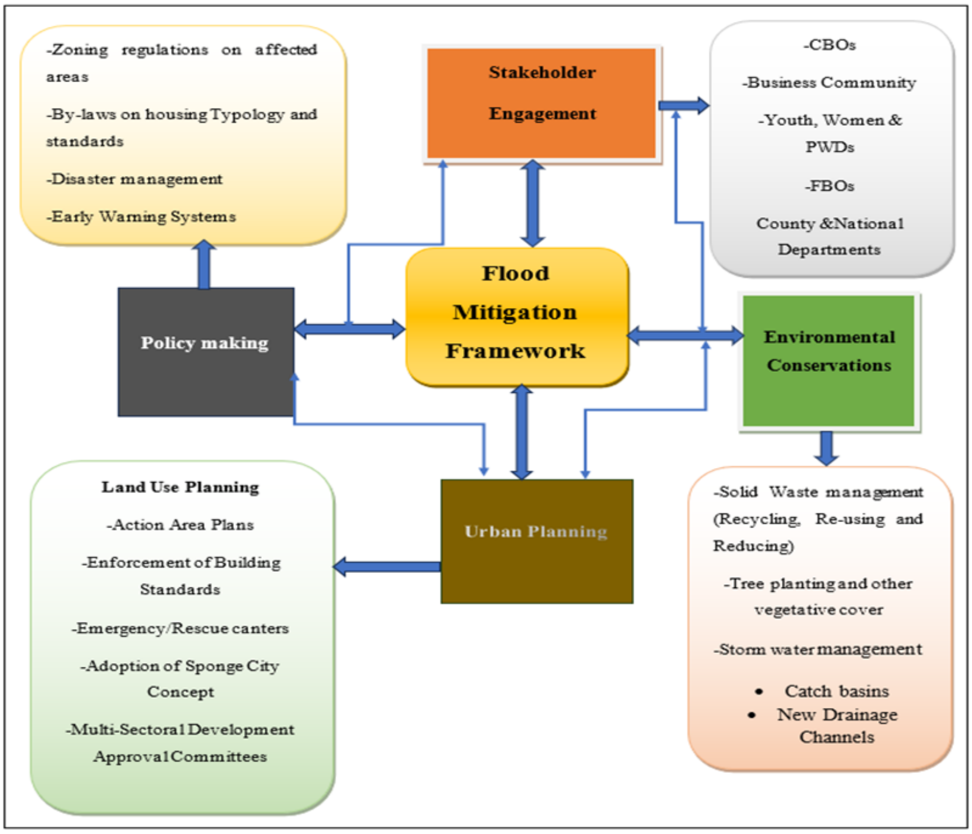

FIGURE 7
Flood mitigation framework
Source: Author's analysis (2025)

sustainable infrastructure, and technology-driven planning into policy implementation.

The County should invest in smart drainage systems, permeable pavements, rainwater harvesting facilities, retention ponds, and green infrastructure such as urban wetlands and green roofs to improve water infiltration and reduce surface runoff.

Modern ICT-based early warning systems should be developed, including mobile alerts, community sirens, and real-time dashboards. This should be coupled with community awareness programs to build preparedness and resilience.

Flood mitigation should incorporate ecosystem restoration, including reforestation of catchment areas, protection of wetlands, and rehabilitation of riparian buffers along River Njoro and Lake Nakuru basin to regulate stormwater naturally.

A centralized flood data management system should be established, bringing together government agencies, research institutions, and communities. Universities and technical institutions should partner with the county to advance hydrological studies, modeling, and climate adaptation research.

Community engagement should be emphasized through public participation forums, training, and participatory GIS mapping to ensure that local knowledge informs planning while building resilience at the grassroots level.

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