Drivers of Urban Sprawl Along River Rupingazi Ecosystem, Embu County, Kenya

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ABSTRACT

Urban sprawl is commonly associated with the outward expansion of built-up areas into peripheral and environmentally sensitive locations. This study examined the drivers of urban sprawl toward the Rupingazi riverine zone in Embu Municipality, Kenya, and assessed associated land-use and land-cover (LULC) changes between 1989 and 2019. Data were collected from 398 residents using structured questionnaires, supplemented by key informant interviews, google satellite images and field observations. Descriptive statistics were used to assess residents' perceptions of the drivers of urban sprawl, while ordinal logistic regression was employed to determine the statistical association between the identified predictors and the ordinal measure of urban expansion. The regression results showed statistically significant positive coefficients for proximity to the river ($\beta = 0.710$, $p < 0.001$), lack of strict zoning regulations ($\beta = 0.680$, $p < 0.001$), housing shortages ($\beta = 0.546$, $p < 0.001$), and population growth pressure ($\beta = 0.502$, $p < 0.001$). The LULC analysis further demonstrated substantial spatial transformation along the Rupingazi riverine zone. Vegetation cover declined from 4.61 km² (69.11%) in 1989 to 2.82 km² (31.58%) in 2019, representing a substantial reduction in vegetated land. In contrast, built-up areas increased from 1.97 km² (29.54%) in 1989 to 6.04 km² (67.64%) in 2019, indicating a marked expansion of urban development into areas previously dominated by vegetation. The findings demonstrate that urban sprawl along River Rupingazi is associated with proximity to the river, weak zoning regulation, housing demand, and population pressure, with the observed LULC changes providing spatial evidence of the expansion of built-up areas and decline in vegetation. The study recommends strengthening land-use planning and development control, enforcing zoning regulations, improving housing provision, and establishing continuous GIS and remote-sensing-based monitoring of urban expansion in environmentally sensitive riverine areas.

Keywords: Land-use dynamics factors; Population pressure; Environmental sustainability

INTRODUCTION

Urban sprawl is an occurrence that has significantly impacted on the social, economic and natural environments over decades (Zippier, Northrop & Andreu, 2020). This has been accelerated by growth in human population with a sizeable proportion moving to urban areas. The world's population was 1.6 billion in the year 1900 with 13% of this population living in urban areas by then. The world's urban population grew to 50% by the year 2008, with close to 3.9 billion of the total population living in urban areas (UN, 2019). According to the United Nations (2014), the urban population is expected to escalate to 6.4 billion by the year 2050 representing 60% of the total world population. Most of the population increase is expected to take place in Asia and African (UN, 2019).

Previous studies revealed that rapid population growth and rural urban migration increase demand for housing and push development into peri-urban zones (Njiru ,2016; Maina,2024). Improvements of transport infrastructure especially new roads and highways opens previously inaccessible land to developers (Hassan, 2023) leading to encroachment of previously in habited land. Market forces such as low land prices on urban fringes, housing shortages in cores, and speculative land markets encourage outward expansion as households and developers seek cheaper plots and larger lots (Hassan,2023; Yiran,2020). Weak land-use governance, inadequate zoning enforcement and fragmented institutional coordination make it easier for informal and unplanned settlements to establish on riparian and agricultural lands (Yasin,2021; Njiru,2016). Economic growth and rising incomes change residential preferences toward lower-density, single-use housing (Angel,2023; Kim,2020), while limited provision of core services in central areas (or high central rents) drives both public and private investment to peri-urban locations (Omasire,2024; Maina,2024), such as riparian ecosystems. Agricultural land conversion, often driven by both formal subdivision and informal occupation, is a recurrent proximate cause of sprawl in many Kenyan and wider-African cases (Omasire,2024; Maina,2024). Previous studies also noted that, social factors including perceptions of security, aspirations for home-ownership, and cultural preferences for larger plots coupled with weak planning regulations accelerate outward expansion (Hassan,2023; Dadashpoor,2024). The research gap addressed by this study was the identification and statistical assessment of residents' perceived drivers associated with urban expansion toward the Rupingazi riverine zone. The study sought to answer the question which drivers do residents identify as important in shaping urban expansion toward the Rupingazi riverine zone, and which of these drivers are statistically associated with the study's ordinal measure of urban expansion?

Urban sprawl in Kenya is largely driven by numerous factors that interact to shape the unplanned outward expansion of urban areas. According to Maina and Waiganjo (2024**)**, weak urban governance frameworks and inadequate enforcement of zoning regulations have been primary enablers of uncontrolled spatial growth across major towns. Kyeni (2020) further emphasizes that poor implementation of development control and ineffective zoning policies have led to the encroachment of riparian reserves and agricultural land in Nairobi. Rapid population growth and rural–urban migration had also contributed significantly to the expansion of urban boundaries. Omasire et al (2020), noted that the growing housing demand in Wote Town pushed settlements beyond planned limits. Similarly, Ogude et al (2024**)** observed that rising urban population densities in Siaya Town had increased informal settlements and pressure on existing infrastructure. Economic factors such as the growth of informal industries had promoted expansion toward less regulated peri-urban areas (Kinyanjui, 2014). Environmental and locational factors, including proximity to rivers, roads, and cheap land, had further stimulated riparian and fringe development, as indicated by Rotich (2022) in Eldoret and Nyongesa et al (2022) in Voi. Omollo (2023) and Ngetich (2021**)** assert that weak institutional coordination and speculative land development practices by private investors exacerbate unplanned urban growth. Rupingazi riverine ecosystem had been experiencing significant challenge as evidenced by numerous dumping sites, clearing of vegetation and increased infrastructures along Rupingazi riverine (Nyaga,2021, Bonareri (2017), Kitur *etal* ,2017, Kareithi,2016). The study analyzed the influence of urban sprawl on Rupingazi riverine ecosystem

1.1 Theoretical Framework

This study is anchored on the Urban Metabolism Theory, which conceptualizes an urban area as a system of resource flows and transformations, and the urban–rural gradient theory, which explains how ecological conditions vary along a continuum from urban to rural environments.

1.1.1 Urban Metabolism Theory

The study used urban metabolism theory (1960). The theory has several proponents such as Abel Wolman, Herbert Girardot and Paul James. The theory was formulated in the year 1960 by Abel Wolman who viewed urban areas as organisms that can consume the resources, transform them and release their waste products. This concept helps in studying how urban areas interact with the environment and how their activities influence ecological systems.

This current study examined how urban sprawl influenced Rupingazi riverine ecosystem. In the process of interacting with it, it transformed its original states to other states, thus, degrading it. Urban sprawl resulted to increased demand for resources such as water and riverine vegetation. This resulted to deforestation, habitat loss,

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changes in biodiversity, and degradation of water quality. According to the theory, urban areas are viewed as organisms that release waste; therefore, based on this theory, it can be concluded that urban sprawl transformed vegetation, influenced the physical-chemical properties of the Rupingazi and generated waste, and also altered the Rupingazi riverine ecosystem.

1.1.2 Urban–Rural Gradient Theory

To measure the influence of urban sprawl, the study adapted Urban–Rural Gradient Theory, advanced by Mark J. McDonnell and Steward T. A. Pickett in 1990. This theory explains how ecological patterns and processes change along a continuum from densely built urban centres to sparsely populated rural areas or non-urban areas. It suggests that increasing urbanization leads to systematic alterations in land use, habitat structure, biodiversity, and ecosystem functioning. In the context of riverine systems, the theory suggests that sections of a river passing through highly urbanized zones are more likely to experience degradation due to pollution, channel modification, and loss of riparian vegetation, while upstream or rural sections tend to maintain relatively natural ecological conditions.

1.1.3 Conceptual Framework

Based on the study objectives and guided by the cited literature review, the study developed a conceptual framework (Figure 1).

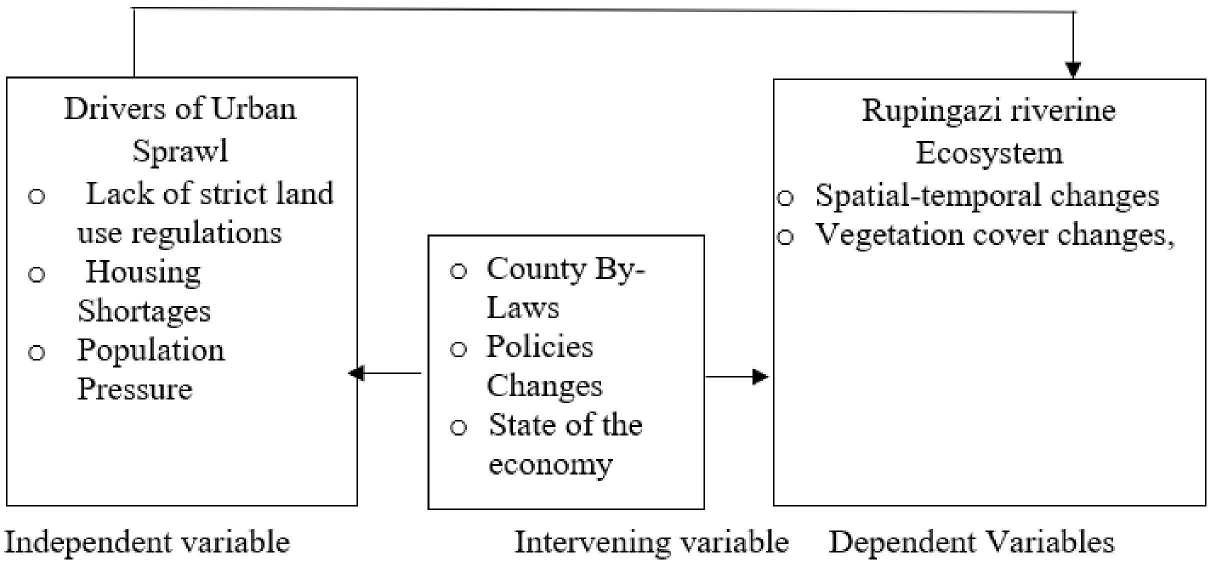

Figure 1. Influence of Urban Sprawl on Rupingazi Riverine Ecosystem

The arrows on the conceptual framework show the relationship between the independent, intervening and dependent variables. The arrows did not indicate the causality. The information presented on Figure 1, shows drivers of urban sprawl as the independent variable, encompassing elements such as lack of strict land use regulations, housing shortage and population pressure . These sprawling developments often resulted in increased impervious surfaces, uncontrolled land use, and encroachment into Rupingazi riverine ecosystem. Nevertheless, the magnitude and nature of the influence was shaped by intervening variables such as county by-laws, policy changes, and the state of the economy. County by-laws, change of policies and state of the economy were considered as intervening variables since they could either encourage or discourage the encroachment of riverine ecosystem. Change of county by-laws mitigating urban sprawl would reduce the negative influence on the ecosystem. On the other hand, a well performing economy would encourage more developments within the municipality outpacing the available space. This would consequently make the developers to look for any available space including along the riverine ecosystem. Ineffective zoning laws or lax enforcement may allow construction near riparian zones, leading to habitat loss, vegetation degradation, and water quality deterioration due to runoff and pollution. Conversely, sound policies and strong economic planning can sustainably manage

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urban sprawl. Ultimately, these interactions significantly influence the dependent variable. Negative influence may be manifested by degraded vegetation and degraded physical-chemical water properties as revealed in this study.

METHODOLOGY

2.1 Study area

The study was conducted in Rupingazi riverine ecosystem, Embu Municipality in Embu County, between Latitude $0^{0}32'24''$& $0^{0}32'46''$ South and Longitude $37°27'01''$ to $37^{0}27'31''$ (Figure 2). The Municipality occupies an approximate area of 80 $km^{2.}$ and is located approximately 150 km North East of Nairobi. Embu County is positioned East of Mt. Kenya, whose summit passes across the southern border's periphery. The county is bounded to the North by Tharaka Nithi and to the East, by Kirinyaga Counties (Embu CIDP 2022-2027) . It is served by two permeant rivers namely; River Rupingazi and River Kapingazi. The most conspicuous feature from the Municipality is Mt Kenya. It is the 8^{th} largest municipality in Kenya.

The Municipality has been experiencing rapid population growth with a population of 64,970 (in the year 2019) to a population projection of (75,711) in the year 2027, according Kenya National Population and Housing Census (2019). The population comprises of Embu community though there are other tribes such as Kikuyu, Kamba and Ameru. The Municipality experiences rainfall in two distinct seasons. The long rains are experienced between March and June while the short rains are experienced between October and December. The region experiences an average rainfall of about 1499mm annually. July is the coldest month while September is the warmest month. Embu County experiences a moderate tropical climate with temperatures ranging between 12°C and 30°C, varying by altitude from the cool highlands of Runyenjes to the warmer lowlands of Mbeere. The county's economy is primarily agricultural**,** producing coffee, tea, macadamia, and food crops, alongside livestock keeping.

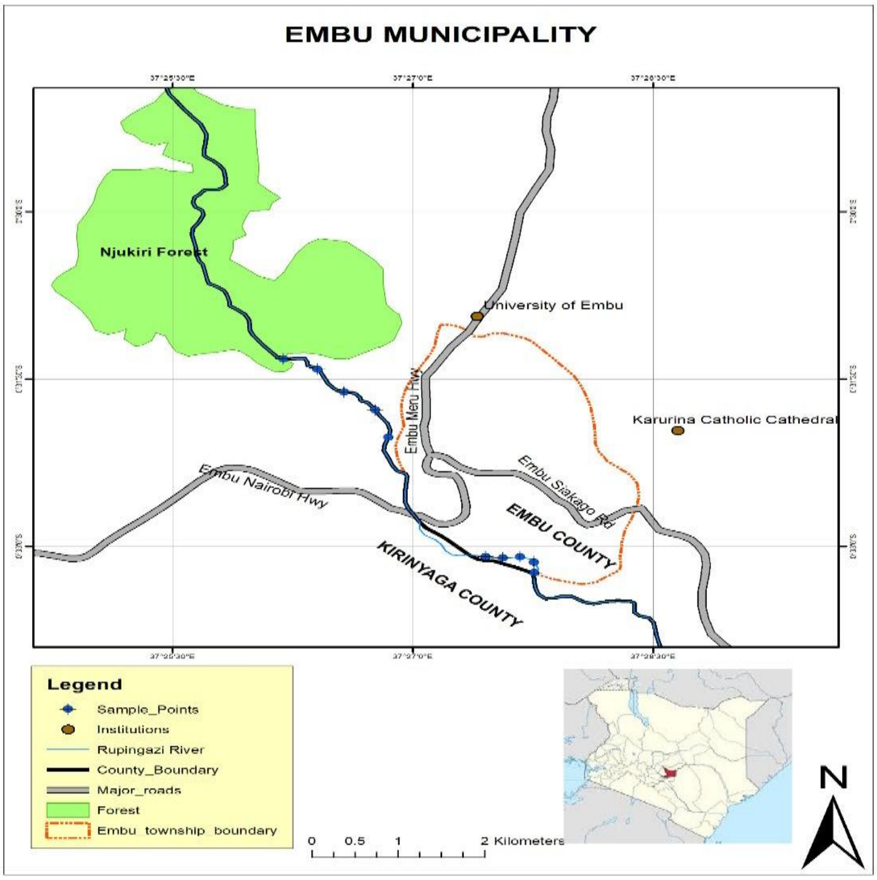

Figure 2**.** Map of Embu Municipality

2.2 Research design

The study adopted a mixed method research design to systematically describe residents' perceptions of the drivers of urban sprawl and their influence on the Rupingazi Riverine ecosystem. The descriptive approach enabled the study to capture the existing conditions and patterns of urban development without manipulating any variables.

2.3 Data sources, preprocessing and analysis

Data were collected using structured questionnaires, key-informant interviews, Google satellite images and field observations. The questionnaire was administered to 398 residents of Embu Municipality. The sample size was determined using Yamane's formula. The questionnaire captured respondents' perceptions of factors potentially associated with urban expansion toward the Rupingazi riverine zone. Two key-informant interviews were conducted with relevant urban planning, environmental and local administrative actors to provide institutional and contextual perspectives.

Google satellite imagery was used to complement the questionnaire and field-based evidence by providing spatial evidence of changes in land-use and land-cover (LULC) along the Rupingazi riverine zone. Satellite images representing the study area for the years 1989, 1999, 2009 and 2019 were examined to identify changes in major LULC categories, particularly vegetation, built-up areas and other land-cover types. The images were georeferenced and visually interpreted using identifiable features such as buildings, roads, cultivated areas, vegetation and other surface characteristics. The study area was delineated consistently across the different observation periods, and the identified LULC classes were digitized and their respective areas calculated in square kilometers. The resulting LULC information was used to quantify temporal changes in vegetation and built-up areas to provide spatial evidence supporting the assessment of urban expansion along the riverine zone. The LULC results were subsequently compared across the four periods to establish the direction and magnitude of land-use transformation between 1989 and 2019.

Field observations were used to document visible settlement, infrastructure and human activities occurring near the riverine zone. These observations were used as contextual evidence to complement the satellite imagery and questionnaire findings. Completed questionnaires were screened for completeness and consistency before coding and entry into SPSS version 27.

Descriptive statistics were first used to summarize the proportion of respondents agreeing or disagreeing with statements concerning potential drivers. Ordinal logistic regression was subsequently used to assess the statistical association between the predictor variables and the study's ordinal outcome. Statistical significance was evaluated at $p < 0.05$. The regression coefficients are interpreted as associations with the ordinal outcome and not as proof that an individual predictor independently caused actual spatial expansion or ecological degradation.

The predictor variables were selected from the study's conceptualization of urban expansion drivers and included: river proximity, zoning regulation, housing shortages, population pressure, informal settlements, Juakali industrial development, infrastructure projects, urban farming, cloth-washing activities, riverine-resource use, land prices, waste-dumping sites and recreational activities

2.4 Data Collection Instruments

The study observed the influence of urban sprawl on vegetation along Rupingazi riverine ecosystem and changes on riverine land use patterns. Remote sensing was used to obtain Google earth satellite images on spatial temporal changes along Rupingazi riverine ecosystem between 1989 to the year 2019. Landsat-4 imagery (30m resolution) was used, suitable for macro-scale land-use mapping. Questionnaires were used to seek information from Embu municipality residents on the influence of urban sprawl on the Rupingazi riverine ecosystem.

2.5 Piloting

Pilot study was conducted to enhance the degree of reliability. Residents' questionnaires were administered to residents within Meru municipality to determine its influence on Kathita River. According to Mugenda and Mugenda (2003), a correlation coefficient of 0.7 between the pilot area and the study area is sufficient for research purpose. Further, Mugenda and Mugenda (2003) recommended 10% of the total sample size of the study area for piloting. This study administered 40 questionnaires from study area sample size of 398 to Meru Municipality urban residents.

2.6 Reliability of the Research Instruments

Pilot study was done in Meru municipality along River Kathita riverine ecosystem to enhance the reliability of the research instruments. Reliability was achieved by carrying out a test-retest survey where the same research instruments were administered to the same group of urban residents, in an interval of two weeks. The findings between the two intervals yielded a correlation coefficient of 0.8 which was above 0.7 recommendations by Mugenda and Mugenda (2003). Questionnaires achieved a Cronbach's alpha of 0.85, indicating high reliability. Therefore, the study considered the data sufficient for research. After carrying out test retest at an interval of two weeks on the same group of urban residents; a correlation of 0.8 was arrived at, hence the validity of the research instrument was ascertained.

2.7 Validity

Input from the environmental experts from Chuka University and Embu municipality urban physical planning officers were sought to enhance content validity. More so, data collection instruments were subjected to piloting in Meru municipality along Kathita riverine ecosystem to determine whether they were appropriate for data collection.

2.8 Accuracy Assessment Results

Table 1 presents the accuracy assessment results for the classified Land Use and Land Cover (LULC) for the years 1989, 1999, 2009 and 2019. The assessment was based on the computation of producer's accuracy (PA), user's accuracy (UA), overall accuracy (OA), and Cohen's Kappa (κ) for three dominant land use classes: Built-up, Vegetation, and Others (bare land, water, urban farming and other additional land uses).

Table 1. LULC Accuracy Assessment;

Year	Built-up PA (%)	Built-up UA (%)	Vegetation PA (%)	Vegetation UA (%)	Others PA (%)	Others UA (%)	OA (%)	K
1989	80.3	81.4	85.9	84.1	82.3	81.0	81.5	0.67
1999	81.4	79.6	86.7	85.2	84.1	83.0	83.9	0.72
2009	85.2	83.9	87.4	86.0	86.0	84.7	86.3	0.79
2019	88.7	87.2	89.3	88.1	87.5	86.0	88.4	0.83

The accuracy assessment results in Table 1 revealed a steady improvement in classification accuracy of the LULC maps from 1989 to the year 2019. In 1989, the overall accuracy (81.5%) and Kappa coefficient (0.67) indicates a substantial level of agreement, suggesting that the classification was generally reliable though affected by moderate commission and omission errors. Both Producer's and User's Accuracies for built-up, vegetation, and other classes were above 75%, reflecting satisfactory class separability despite sensor and mapping limitations. By 1999, marginal increases were observed across all accuracy indices, with OA rising to 83.9% and Kappa to 0.72, implying improved classification consistency and reduced misclassification, particularly within built-up and vegetated areas. The 2009 and 2019 maps show significant enhancements, with

OA values of 86.3% and 88.4% and corresponding Kappa values of 0.79 and 0.83, denoting high reliability and near-perfect agreement. This progression illustrates technological advancements in image processing, classification algorithms, and availability of higher-resolution data. The consistent rise in both Producer's and User's accuracies across the years signifies a gradual reduction in confusion among land cover classes, enhancing confidence in temporal LULC change detection and spatial pattern analysis.

RESULTS AND DISCUSSION

3.1 Demographic Characteristics of the Respondents

The study noted a nearly equal representation of men and women in Embu municipality (51.3%) males and (49.7%) females. The study observed both males and females interacted with the ecosystem. Nevertheless, more males, who frequently controlled activities like fishing, vegetation clearing, and swimming, may have a directly influenced the Rupingazi riverine ecosystem degrading its quality. On the other hand, women may have an influence on the ecosystem through, domestic water collection and small-scale urban farming. They were also involved in washing clothes in the river that could have significantly degraded the Rupingazi water quality.

The study sought information on age distribution in Embu, the findings were presented on Table 2

Table 2. Age Distribution of Respondents

Age Bracket	Percentage (%)
20-30	44.75
31-40	28.45
41-50	13.50
Above 50	13.3
Total	100.0

The study noted that the age group of 20 to 30 years old, which accounted for the biggest percentage of the population (44.75%), represented a group of people who were more actively involved in urban development, looking for housing, infrastructure development, and economic prospects. This group (20-30) may have been involved in recreation activities such as swimming contributing to degradation of water quality in River Rupingazi. They were also found to build shanty structures along the riverine ecosystem since they could not afford the high-cost houses within the municipality residential zone. The age group of 31 to 40 (28.45%) came in second, perhaps carrying on same developmental trends but with more obligations, such as family and work. This group also may have contributed much on negative influence on the riverine ecosystem, since it constituted most of the developers along the Rupingazi riverine ecosystem. Those over 50 (13.3%) and those in the 41–50 age range (13.5%) comprised lesser percentages. The study noted that the aforementioned age groups (41–50 & over 50) were keener in mitigating the negative influence of urban sprawl on Rupingazi riverine ecosystem by embracing sustainable measures such as riverine tree planting.

The study further sought information on duration of stay of respondents in Embu municipality. The findings were presented on Table

Table 3. Duration of Stay of Respondents

Duration of Stay	Percentage (%)
0-5 years	31.0

6-10 years	50.75
Above 10 years	18.25

According to the study, the majority of respondents (50.75%) had been residents of the municipality for 6–10 years, followed by those who had been residents for 0–5 years (31.0%) and those who had been residents for more than 10 years (18.25%). It was noted that, because of their extended exposure, longer-term residents had a better awareness of the ecosystem's past difficulties and changes overtime, making it possible for them to notice changes in vegetation cover, land use patterns, and water quality degradation. Newer residents, on the other hand, might not be as conscious of these changes and might be more concerned with the short-term advantages or difficulties than the long-term effects thus influencing negatively the Rupingazi Riverine ecosystem.

Further, the study sought information on level of education of respondents in Embu municipality and its influence on Rupingazi Riverine ecosystem. The findings were presented on Table 4

Table 4. level of Education of Respondents

Level of Education of Respondents	Percentage (%)
Informal	4.5
Primary	28.5
Secondary	43.25
Tertiary	23.75

The study found out that the respondents in Embu Municipality had a wide range of educational backgrounds; the majority (43.25%) had completed secondary school, followed by primary (28.5%), tertiary (23.75%), and informal (4.5%) education. The study concluded that, given the importance of basic literacy in comprehending environmental issues, this distribution indicated that a sizable fraction of the population possessed knowledge on importance of conserving riverine ecosystems. It was noted that higher education was associated with more specialized knowledge and awareness of ecological protection, which may have impacted on beneficial behaviours like pollution control, riverine tree planting and sustainable urban farming. Notably, the study noted that majority of those involved in *juakali* industries lacked formal education, making them to engage in riverine ecosystem. However, it was noted that the large portion of the population with only primary and informal education was not well aware of their influence on the ecosystem of the River Rupingazi thus contributing to its degradation.

3.2 Ordinal Logistic Regression Analysis of Perceived Drivers of Urban Sprawl on Rupingazi Riverine Ecosystem

The study sought information on perceptions of Embu urban residents on drivers of urban sprawl along Rupingazi riverine ecosystem. A Likert questionnaire was administered to Embu municipality residents. The data was fed in SPSS to compute the ordinal logistic regression and the findings were presented on Table 5

Table 5. Ordinal Logistic Regression Analysis for Drivers of Urban Sprawl on Rupingazi Riverine Ecosystem:

Predictor Statement	Coefficient(β)	Sig.	Agree %
Proximity of River Rupingazi to Embu municipality	0.710	0.000	70.85
Lack of strict zoning regulations	0.680	0.000	68.84

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Housing shortages within Embu municipality	0.546	0.000	65.58
Population growth pressure in Embu municipality	0.502	0.000	63.82
Informal settlements driven by amenities within Embu municipality	0.409	0.001	62.56
Juakali industrial development along riverine ecosystem	0.319	0.013	59.30
Increased infrastructure projects near riverine ecosystem	0.299	0.019	58.54
Urban farming along riverine ecosystem	0.283	0.014	54.77
Search for cloth washing water in River Rupingazi	0.272	0.033	54.77
Search for riverine resources	0.150	0.238	51.51
Cheaper land prices along riverine ecosystem	0.047	0.713	50.50
Search for waste dumping sites along riverine ecosystem	-0.278	0.029	45.98
Search for recreational places along riverine ecosystem	-0.154	0.225	42.96

Based on the information presented on Table 5, the study constructed an ordinal logistic regression model to predict the probability of urban sprawl's drivers influence on the Rupingazi Riverine Ecosystem. β1to β13 represented predictor values; where higher coefficient values meant more influence by urban sprawl predictor and lesser coefficient value implied lesser influence by urban sprawl drivers on Rupingazi riverine ecosystem. The percentage agreement on the model represents the x values. Higher percentage shown higher values of x. Therefore, the predictor coefficient values were directly proportional to values of x. The ordinal logistic regression model was represented by the equation below:

$Log((p/(1-P)) =$

$- \beta_0 - (\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + \beta_{12} x_{12} + \beta_{13} x_{13})$

Where various urban sprawl predictors were represented by x_1 to x_{13} as shown below:

x_1: Proximity of River Rupingazi to Embu municipality (70.85%)

x_2: Lack of strict zoning regulations (68.84%)

x_3: Housing shortages within Embu municipality (65.58%)

x_4: Population growth pressure in Embu municipality (63.82%)

x_5: Informal settlements driven by amenities within Embu municipality (62.56%)

x_6: *Juakali* industrial development along riverine ecosystem (59.30%)

x_7: Increased infrastructure projects near riverine ecosystem (58.54%)

x_8: Urban farming along riverine ecosystem (54.77%)

x_9: Search for cloth washing water in River Rupingazi (54.77%)

x_{10}: Search for riverine resources (51.51%)

x_{11}: Cheaper land prices along riverine ecosystem (50.50%)

x_{12}: Search for waste dumping sites along riverine ecosystem (45.98%)

x_{13}: Search for recreational places along riverine ecosystem (42.96%)

Where: P: represented the probability of observing a negative influence on the Rupingazi Riverine Ecosystem. Positive β coefficients indicated increasing likelihood of urban sprawl predictor causing a negative influence along Rupingazi riverine ecosystem. Negative β: coefficients indicated decreasing likelihood of the urban sprawl predictor causing negative influence along Rupingazi riverine ecosystem. After computation, the ordinal regression equation gave a probability of one implying that the thirteen predictors had almost certain negative influence on Rupingazi riverine ecosystem. x_1- x_{13}: represented the agreement percentage by urban residents on various urban sprawl predictor statements. Therefore, from findings the study came up with the equation to model the influence of various drivers of urban sprawl on Rupingazi riverine ecosystem as follows:

$$\text{Log}\left((1-P/P)\right) = -316.175 - (0.710x_1 + 0.680x_2 + 0.546x_3$$

$$+ 0.502x_4 + 0.409x_5 + 0.319x_6 + 0.299x_7 + 0.283x_8 + 0.272x_9$$

$$+ 0.150x_{10} + 0.047x_{11} - 0.278x_{12} - 0.154x_{13})$$

$$P \approx 1$$

The ordinal logistic regression statistical analysis of drivers of urban sprawl along the River Rupingazi within Embu municipality revealed significant findings. Ten out of thirteen predictors' variables had p-values less of than 0.05. This indicated a statistically significant influence, leading to the rejection of the null hypothesis. Notably, the proximity of the river to Embu municipality (β = 0.710, p = 0.000) and lack of strict zoning regulations (β = 0.680, p = 0.000) emerged as the strongest predictors, suggesting that they were key drivers of urban sprawl along the river. Other significant factors included housing shortages (β = 0.546), population pressure (β = 0.502), and the presence of informal settlements attracted by local amenities (β = 0.409). Similarly, economic and subsistence activities such as *juakali* industry (β = 0.319), infrastructure expansion (β = 0.299), urban farming (β = 0.283), and the search for cloth-washing water (β = 0.272) were also statistically significant. Three variables that included search for riverine resources (β = 0.150, p = 0.238), cheaper land prices (β = 0.047, p = 0.713), and search for recreational places (β = -0.154, p = 0.225) revealed no significant relationship and thus led to the acceptance of the null hypothesis

The strong influence of proximity to the river (*β = 0.710, p = 0.000*) suggested that the river's location relative to Embu municipality played a major role in attracting settlement and development. Being close to the central business district, the riverine zones offered residents and developers convenient access to town amenities. At the same time, the lack of strict zoning regulations (*β = 0.680, p = 0.000*) allowed unregulated development, creating an enabling environment for the spread of informal and formal settlements into ecologically sensitive area.

The statistical significance of housing shortages (β = 0.546) and population pressure (β = 0.502) reflected the increasing demand for affordable shelter in the face of urban sprawl. The study noted that with limited available land in planned zones, residents were pushed to occupy marginal lands along the river, leading to urban sprawl. Additionally, the presence of informal settlements attracted by riverine resources (β = 0.409) encouraged people to settle near the river despite potential riverine ecosystem risks the significance of the *juakali* industry (β = 0.319), infrastructure expansion (β = 0.299), urban farming (*β = 0.283*), and search for cloth-washing water (β = 0.272), can be attributed to availability of free spaces along the riverine ecosystem. This made the riverbanks ideal locations for such activities.

The ordinal logistic regression analysis revealed that variables such as the search for riverine resources (β = 0.150, p = 0.238), cheaper land prices (β = 0.047, p = 0.713), and search for recreational places (β = -0.154, p = 0.225) were statistically insignificant. This suggested that while these factors may exist, they had no strong influence along the riverine ecosystem compared to socio-economic drivers. For instance, land prices varied significantly across the Embu municipality land use zones; hence people could have settled elsewhere rather than along Rupingazi riverine ecosystem. The study findings revealed that urban sprawl along the riverine ecosystem was shaped primarily by functional and economic needs rather than price of land, search for riverine resources and leisure-oriented motivations such as recreational activities.

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The ordinal logistic regression findings have profound implications for urban planning, environmental management, and policy formulation within Embu municipality. The statistical significance of ten out of thirteen predictors revealed the urban sprawl influence along the River Rupingazi. In particular, the strong influence of proximity to the river and the absence of strict zoning regulations suggested an urgent need for comprehensive spatial plan implementation, monitoring and land-use controls measures. The role of socio-economic drivers such as housing shortages, population pressure, and informal settlements further indicated gaps in Embu municipality governance and resource allocation, to mitigate the urban challenges. Moreover, the significance of economic and subsistence activities like the *juakali* industry, urban farming and cloth washing in the river highlighted the dependence of urban residents on the riverine ecosystem. These findings call for integrated strategies that balance urban sprawl with riverine ecosystem sustainability.

The current study's findings align closely with previous research that has examined the underlying causes of urban sprawl and riverine ecosystem degradation. The strong influence of river proximity and weak zoning enforcement as key predictor of encroachment agrees with findings by Kyeni (2020) and Omollo (2023**)**, who revealed that poor implementation of zoning regulations and weak planning control were major contributors to riparian encroachment in Nairobi and Kisii towns, respectively. Similarly, Rotich (2022**)** and Nyongesa et al (2022) found that the expansion of urban built-up areas toward river ecosystem in Eldoret and Voi was largely driven by accessibility, availability of cheaper land, and limited institutional monitoring. The current results also mirror with; Omasire et al (2020**)**, who identified rapid population growth and housing shortages as key factors promoting unregulated expansion into agricultural and riparian lands in Wote Town. Furthermore, informal settlements and *Juakali* industries observed in the present study reflected the findings of Maina and Waiganjo (2024**)** and Ogude et al (2024), who linked informal sector activities to environmental pressure and unplanned settlement growth in small urban centers. The influence of urban farming and domestic activities along the riverine zone concurs with Mwangi (2015**)**, who noted that limited access to urban resources encourages residents to utilize riparian areas for food production and water collection.

3.3 Influence of Urban Sprawl on LULC Changes along River Rupingazi Ecosystem

During the processing of Landsat 4 satellite images, cloud masking was first conducted to eliminate cloud cover, haze, and shadow effects that could compromise classification accuracy. This was achieved using the quality assessment (QA) bands and the flask algorithm within ArcGIS to ensure only clear sky pixels were retained. Subsequently, training samples representing key land cover classes; built-up areas, vegetation, and others were selected through supervised classification using the maximum likelihood classifier (MLC) method. These training samples were carefully digitized based on spectral signatures and field verification points to enhance classification accuracy. Additional pre-processing steps, including radiometric and geometric corrections, were applied to ensure that the images were spatially and spectrally consistent for multi-temporal analysis from 1989 to 2019.

The data was analysed using Arc GIS and findings presented on Table 6.

Table 6: Influence of Embu Urban Sprawl on LULC Change over the Years (1989–2019) Along River Rupingazi

LULC Category	1989		1999		2009 (Km²)		2019	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Vegetation	4.61	69.11	4.46	56.74	3.74	44.95	2.82	31.58
Built-up Areas	1.97	29.54	3.38	43.00	4.58	55.05	6.04	67.64
Others	0.09	1.35	0.02	0.26	0.04	0.00	0.07	0.78

Source: Field Data, 2025

In 1989, vegetation dominated the landscape with 4.61 km² (69.11%), indicating a largely natural environment with limited human interference. Built-up areas covered 1.97 km² (29.54%), showing a modest level of urban development, while the "others" category occupied only 0.09 km² (1.35%). By 1999, vegetation declined to 4.46 km² (56.74%) as built-up areas expanded to 3.38 km² (43%), reflecting the beginning of significant urban growth. This pattern continued through 2009, where built-up areas (4.58 km²; 55.05%) overtook vegetation (3.74 km²; 44.95%) for the first time. In 2019, urban surfaces further increased to 6.04 km² (67.64%), while vegetation dropped to 2.82 km² (31.58%).

These patterns can be attributed to several interrelated factors over the study period. Between 1989 and 1999, Embu experienced steady population growth and infrastructural expansion (population and census, 1999) driven by urban migration and economic development. This led to the conversion of vegetated land for housing and commercial activities. From 1999 to 2009, urbanization accelerated as the town expanded outward. This may have been driven by improved transport networks and government investment in public institutions, resulting in a significant reduction in vegetation cover. By 2019, rapid urban sprawl and the establishment of residential estates, and business centers had drastically transformed the landscape. The projected 2029 figures suggest continued urban expansion fueled by population pressure, modernization, and limited enforcement of land use regulations. Consequently, the steady decline in vegetation cover and the minimal "others" category highlight the environmental cost of uncontrolled urban growth, posing risks such as increased runoff, reduced infiltration, biodiversity loss, and degradation of the River Rupingazi ecosystem.

The findings of the current study on LULC changes along the River Rupingazi ecosystem closely mirrored with several related studies across Kenya and other parts of the world. Consistent with the observed decline in vegetation cover and expansion of built-up areas between 1989 and 2029, similar patterns of riparian vegetation loss and urban encroachment had been documented along the River Lumi in Taita Taveta County, where deforestation and settlement expansion significantly altered the riparian ecosystem (Ndalilo *et al*., 2021). Comparable urbanization-driven vegetation degradation was also noted by Cao and Natuhara (2020) in Japan, emphasizing that riparian zones within urban settings experienced marked ecological transformation due to anthropogenic pressure. Nasare et al. (2023) and Soita et al. (2024) linked human- induced land uses such as sand mining and settlement growth to riparian degradation and increased bare land, corresponding to the "others" category expansion observed in the present study. Similarly, Ruto et al. (2023) and Kayitesi et al. (2022), highlighted that urban sprawl was the dominant driver of vegetation decline and ecosystem alteration in River Hydro-Morphology in the Tropics. Overall, the study findings illustrated a clear trend of declining vegetative and other land uses in favour of increasing urban sprawl. The study used the data presented on Table 10 to come up with LULC maps for 1989, 1999, 2009, 2019.

3.5 Policy implications

The results indicate several areas requiring planning attention: strengthening development control and enforcement of zoning provisions may help manage settlement expansion toward environmentally sensitive areas, improving access to affordable and appropriately located housing may reduce pressure for settlement in marginal areas, continued monitoring of infrastructure and economic activities near the riverine zone is important and Embu municipality planning agencies should integrate community perceptions with spatial and ecological evidence when making decisions concerning riverine land management.

3.6 Recommendations

The County Government of Embu should strengthen land-use planning and development control policies by addressing key drivers of urban sprawl such as population pressure, informal settlements, and unregulated infrastructure expansion. This can be achieved through enforcement of zoning regulations, promotion of compact urban development, and provision of affordable housing to reduce uncontrolled outward expansion. There is a need to establish a continuous geospatial monitoring system using GIS and remote sensing to track spatial and temporal patterns of urban expansion. This will enable planners to detect rapid land-use changes, predict future sprawl trends, and implement timely interventions to minimize unplanned growth and its environmental impacts.

Limitations of the study

The study relied on residents' perceptions gathered through questionnaires and interviews, which may have introduced subjective biases as respondents' views might not fully represent objective urban development patterns. This was delimited by supplementing the findings with google satellite images analysis to capture the riverine spatial temporal changes.

CONCLUSIONS

The study assessed residents' perceptions and statistically analyzed the key drivers of urban sprawl and their contribution to Rupingazi riverine ecosystem degradation in Embu municipality. The findings revealed that proximity to River Rupingazi, weak zoning regulations, housing shortages, and population growth were the main contributors to urban expansion toward the riverine zones, with proximity to the river and poor enforcement of zoning laws exerting the strongest influence. These results underscore the urgent need for effective policy interventions that strengthen urban land-use planning, enforce zoning regulations, and promote sustainable development practices to safeguard sensitive ecosystems. Future research should adopt integrated spatial-temporal and socio-economic modeling approaches to predict and manage urban sprawl more effectively in rapidly urbanizing areas.

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Author contributions

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The authors declare no conflict of interest

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Data availability statement

The data used in this study are available upon reasonable request to the corresponding author.

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