Available on: https://jsshrs.ep-journals.org/ E-ISSN: 3051-3561, P-ISSN: 3051-3553

Journal of Social Science and Human Research Studies

Volume: 02 Issue: 04 April-2026

Land Use Dynamics and Sustainability of Economic Activities in the Voi River Riparian Ecosystem

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Published Date: April 30, 2026 **Article DOI: 10.65150/EP-jsshrs/V2E4/2026-24**

ABSTRACT: This study examined land use dynamics and the sustainability of economic activities within the Voi River Riparian Ecosystem in the Tsavo landscape of Kenya. The study aimed to map major land use activities, analyze spatial and temporal changes in land use patterns, determine the effects of land use dynamics on the sustainability of key economic activities, and assess the influence of government land use policies on environmental and economic sustainability. The research was guided by Land Use Change Theory, Sustainable Livelihoods Framework, Political Ecology Theory, and Institutional Theory. A positivist research philosophy and descriptive research design were adopted. The target population consisted of 2,000 households and 20 key informants from relevant stakeholder institutions. A sample of 80 households was selected using Yamane's (1967) formula, alongside 20 key informants. Primary data were collected using structured questionnaires and interview guides, while a pilot study involving 8 households and 2 key informants was conducted to improve validity and reliability. Data were analyzed using descriptive and inferential statistics, including multiple regression analysis and diagnostic tests. The findings revealed that major land use activities, changing land use patterns, and supportive government policies significantly influenced the sustainability of economic activities in the ecosystem. The study emphasized the importance of balanced land use, stronger policy enforcement, sustainable practices, community participation, and alternative livelihoods in promoting long-term ecological conservation and household income stability within the Voi River riparian ecosystem.

KEYWORDS: Land Use Dynamics, Riparian Ecosystem, Economic Sustainability, Government Land Use Policies, Livelihood Activities

INTRODUCTION

Background of the Study

Riparian ecosystems are important landscapes that support both environmental sustainability and human livelihoods through activities such as agriculture, fisheries, tourism, and small-scale enterprises (Allan et al., 2021). Their productivity depends on healthy water systems, fertile soils, vegetation cover, and habitat connectivity that sustain ecological functions and ecosystem services (Foley et al., 2021). These ecosystems provide irrigation support, flood regulation, biodiversity conservation, and habitats for fish and wildlife, all of which contribute directly to household incomes and local economic stability (Vörösmarty et al., 2022). However, increasing human activities such as agricultural expansion, settlement growth, sand harvesting, deforestation, and industrial development have significantly altered riparian environments, reducing their ability to provide these essential services (Lambin & Geist, 2021).

Land use refers to the human modification of natural environments for farming, settlement, industry, and other economic purposes (Lambin & Geist, 2021). In riparian zones, land use dynamics result from the interaction between human activities and natural ecological processes. Activities such as farming near riverbanks, settlement expansion, sand extraction, and vegetation clearing transform land cover, reduce soil stability, disrupt nutrient flows, and alter hydrological patterns (Pahl-Wostl et al., 2022). These changes affect water availability, biodiversity, and ecosystem resilience, which in turn influence the sustainability of livelihoods that depend on riparian resources (Foley et al., 2021). Studies show that land degradation reduces the capacity of riparian zones to support irrigation, regulate floods, and maintain productive agricultural and fisheries systems (Allan et al., 2021). Maintaining a balance between land use and ecosystem health is therefore necessary for long-term economic sustainability.

Globally, evidence from temperate and semi-arid regions shows that land-use pressures have major impacts on economic productivity and ecosystem health (Vörösmarty et al., 2022). Expanding agriculture and urban development along rivers have caused habitat loss, declining soil fertility, increased sedimentation, and weakened water regulation systems (Foley et al., 2021). These effects threaten crop production, fisheries,

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and tourism while increasing risks of flooding and drought (Allan et al., 2021). Intensified land use also contributes to biodiversity loss and reduced ecological connectivity, limiting opportunities for sustainable tourism and wildlife conservation (Vörösmarty et al., 2022). These findings highlight the need to understand land-use patterns and their consequences to ensure that economic activities in riparian zones remain productive and resilient.
In Africa, riparian landscapes face increasing pressure from population growth, agricultural expansion, deforestation, mining, and poor land management practices (Turpie et al., 2021). Unsustainable land use along rivers causes soil erosion, declining water quality, biodiversity loss, and disruption of ecosystem services that support agriculture, fisheries, and small-scale businesses (Mwangi et al., 2022). Weak governance structures, poor policy enforcement, and limited community participation often worsen these problems by allowing continued encroachment into sensitive riparian areas (Turpie et al., 2021). Research across African river systems shows that integrated land-use planning and adaptive management approaches that combine ecological conservation with livelihood support can improve both environmental sustainability and economic outcomes (Mwangi et al., 2022).
In Kenya, rivers and riparian zones remain central to agriculture, water supply, fisheries, tourism, and other small-scale economic activities (Kairu et al., 2023). However, rapid settlement expansion, deforestation, sand extraction, and farming along river corridors have caused habitat destruction, reduced water availability, riverbank instability, and weakened ecosystem services (NEMA, 2022). Although national and county governments have introduced policies aimed at promoting sustainable land management and protecting riparian reserves, implementation remains inconsistent (NEMA, 2022). Poor coordination in land-use planning and weak enforcement of environmental regulations continue to undermine the ecological functionality of many rivers (Mwangi et al., 2022). As a result, crop production, fisheries, tourism, and local enterprises are increasingly threatened by environmental degradation.
The Voi River riparian ecosystem is an important ecological and economic corridor within the Tsavo landscape of Taita Taveta County. It supports key livelihoods such as agriculture, tourism, sand harvesting, brickmaking, and small-scale trade while also serving as a wildlife movement corridor between Tsavo East and Tsavo West National Parks (Koskey et al., 2021). Riparian vegetation and stable riverbanks are essential for maintaining agricultural productivity, water regulation, and ecological connectivity in this semi-arid environment (Njue et al., 2016). However, unregulated human activities such as intensive farming, settlement expansion, sand extraction, and brickmaking have increasingly degraded the ecosystem (Omollo & Ogendi, 2023). These activities have caused soil erosion, vegetation loss, riverbank instability, and disrupted water flows, weakening the ecological functions of the river corridor.
The Voi River also plays a major role in supporting wildlife habitats and tourism within the Tsavo ecosystem. Declining water availability, habitat degradation, and disruption of wildlife corridors threaten both biodiversity conservation and tourism performance (Tsavo Trust, 2023). Unsustainable land-use practices have reduced agricultural productivity, weakened tourism income, and undermined the resilience of households that depend on the river for livelihoods (Wildlife Conservation Society Kenya, 2024). Despite these growing concerns, there is limited empirical evidence on how land-use dynamics in the Voi River simultaneously affect ecological integrity and the sustainability of key economic activities in this semi-arid context.
Most previous studies have focused on other Kenyan rivers with different climatic and hydrological conditions, leaving the Voi River relatively underexplored (Mwangi et al., 2022). This creates a knowledge gap regarding how land use changes influence environmental health and livelihood sustainability in this fragile ecosystem. There is therefore a need for focused research that examines the interactions between land use, ecosystem integrity, and economic activities. Such evidence is important for informing sustainable land-use planning, conservation strategies, and policy interventions that can protect both livelihoods and the long-term ecological stability of the Tsavo landscape.

Statement of the Problem

Riparian ecosystems in semi-arid landscapes are increasingly under pressure from human activities, threatening both ecological integrity and livelihood sustainability. Rivers and their riparian zones provide essential resources such as water, food, and fertile land, yet many have experienced severe degradation due to unsustainable land-use practices (Vörösmarty et al., 2022). In sub-Saharan Africa, over 70% of rivers have been affected by agricultural expansion, urban development, and resource extraction, resulting in soil erosion, vegetation loss, declining water quality, and weakened ecosystem services that support farming, fisheries, and small-scale businesses (Turpie et al., 2021). In Kenya, more than 65% of riparian zones have been degraded by unsustainable farming, settlement growth, and sand harvesting, causing riverbank instability and reduced environmental productivity (NEMA, 2022; Kairu et al., 2023).
Although successful examples such as the Okavango Delta in Botswana and the Mekong River Basin show that integrated land-use planning and regulated resource use can balance ecological conservation with economic productivity (McCarthy et al., 2021; Smajgl et al., 2015), the Voi River riparian ecosystem continues to face serious ecological and economic challenges. Unregulated sand harvesting, brickmaking, unsustainable farming, and settlement expansion have accelerated soil erosion, reduced vegetation cover, disrupted water flows, and weakened wildlife corridors within the Tsavo East and West ecosystems (Tsavo Trust, 2023; Wildlife Conservation Society Kenya, 2024). These pressures have reduced agricultural productivity, weakened tourism performance, and threatened the resilience of households that depend on the river for livelihoods (Mwangi et al., 2022).
Despite these challenges, there is limited empirical evidence on how land-use dynamics in the Voi River simultaneously affect ecological integrity and the sustainability of key economic activities in this semi-arid riparian system. Most previous studies have focused on other river systems with different climatic and ecological conditions, leaving the Voi River underexplored. This study therefore seeks to examine the relationship between land use, ecosystem integrity, and resource-based economic activities to provide evidence for sustainable management and policy interventions within the Tsavo ecosystem.

Objective of the Study

The study was guided by four objectives:

i). To map and describe major land use activities within the Voi River riparian ecosystem.
ii). To examine spatial and temporal changes in land use patterns in the Voi River riparian ecosystem.

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iii). To determine the effects of land use dynamics on the sustainability of key economic activities in the Voi River riparian ecosystem.
iv). To determine the effect of government land use policies on national economic and environmental sustainability.

Research Questions

The study sought to answer the following research questions:

i). **H_{01}:** There is no significant variation in major land use activities within the Voi River riparian ecosystem between 2022 and 2026.
ii). **H_{02}:** There is no significant change in land use patterns in the Voi River riparian ecosystem between 2022 and 2026.
iii). **H_{03}:** Land use dynamics have no significant effect on the sustainability of key economic activities in the Voi River riparian ecosystem between 2022 and 2026.
iv). **H_{04}:** Government land use policies have no significant effect on land use patterns and national economic and environmental sustainability between 2022 and 2026.

REVIEW OF LITERATURE

This study was guided by four theories: Land-Use Change Theory, Sustainable Livelihoods Framework (SLF), Political Ecology Theory, and Institutional Theory. These theories provide a strong foundation for understanding how land-use dynamics influence the sustainability of economic activities within the Voi River riparian ecosystem.

Land-Use Change Theory, advanced by Turner et al. (1994) and further developed by Lambin and Geist (2001), explains how human activities such as farming, settlement expansion, and sand harvesting drive changes in land cover. The theory distinguishes between direct causes like deforestation and indirect drivers such as population pressure and economic demand (Geist & Lambin, 2002). In this study, it helps explain how agricultural expansion, settlements, and extractive activities transform the Voi River ecosystem and affect ecological stability (Mwangi et al., 2022; Tsavo Trust, 2023).

The Sustainable Livelihoods Framework (DFID, 1999) emphasizes how households depend on natural, financial, social, human, and physical capital to sustain livelihoods (Chambers & Conway, 1992; Scoones, 2009). It explains how communities adapt their livelihood strategies in response to environmental and economic pressures. In the Voi River context, the framework helps assess how households respond to land-use changes through activities such as farming, sand harvesting, and brickmaking, and how these affect livelihood sustainability (Kairu et al., 2023; Tsavo Trust, 2023).

Political Ecology Theory, developed by Blaikie and Brookfield (1987), focuses on how political, social, and economic power relations shape environmental outcomes. It explains how land-use conflicts, unequal access to resources, and weak governance influence environmental degradation (Robbins, 2004; Bryant & Bailey, 1997). In this study, the theory helps analyze how policy enforcement, land rights, and institutional power affect sustainable use of riparian resources and the distribution of benefits and burdens among communities (Mwangi et al., 2022; Kairu et al., 2023).

Institutional Theory, introduced by North (1990) and expanded by Scott (2001), explains how formal and informal institutions such as laws, regulations, and social norms influence resource management. It emphasizes the importance of policy enforcement, institutional coordination, and governance systems in sustaining common resources (Ostrom, 1990; North, 2005). In this study, the theory helps evaluate how government land-use policies, regulatory frameworks, and institutional coordination shape environmental sustainability and economic activities along the Voi River (Tsavo Trust, 2023; Kairu et al., 2023).

The conceptual framework shows the relationship between land-use dynamics, government land-use policies, and the sustainability of economic activities. Independent variables include agricultural expansion, settlement growth, industrial development, and natural resource extraction (Nguyen & Tran, 2022; Mensah & Owusu, 2022). Government land-use policies act as moderating variables, while sustainability of economic activities is the dependent variable. Effective policies promote balanced land use, environmental conservation, and livelihood sustainability (Bekele & Tesfaye, 2023; López & Santos, 2022).

Empirical studies show that land-use dynamics significantly influence ecological integrity and economic sustainability in riparian ecosystems. International studies by Li et al. (2022) and García et al. (2021) found that urban expansion and agricultural intensification increased economic output but reduced wetlands, biodiversity, and water quality. African studies such as Alemayehu et al. (2023) and Mensah and Owusu (2022) revealed that agricultural expansion, mining, and irrigation improved short-term incomes but caused soil erosion, reduced water availability, and weakened long-term livelihood resilience. In Kenya, studies by Mwangi et al. (2023), Kiplagat et al. (2022), and Omondi and Otieno (2022) showed that farming, settlement growth, and sand harvesting supported livelihoods but increased environmental degradation and policy compliance challenges. However, most studies focused on single sectors and lacked integrated analysis of land use, policy, and sustainability, creating a gap addressed by this study.

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Conceptual Framework

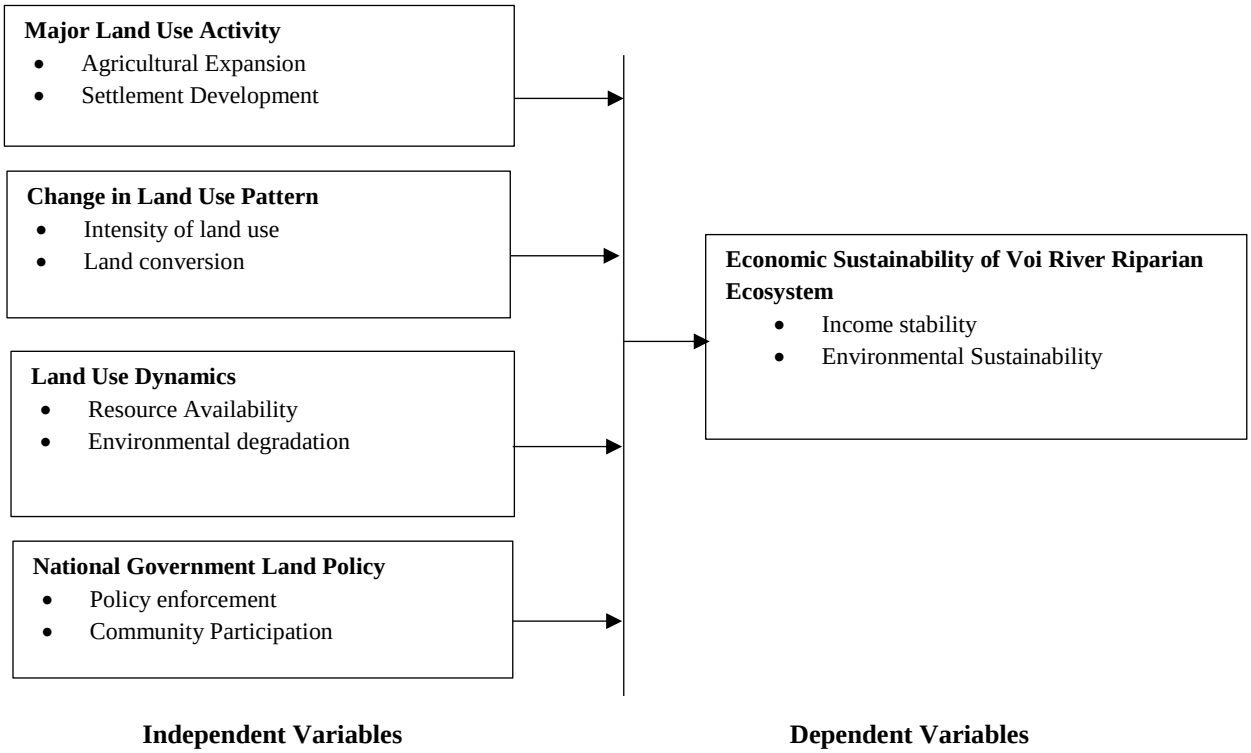


Figure 2.1: Conceptual Framework

MATERIALS AND METHODS

Research Design

The study adopted a positivist research philosophy and a descriptive research design to enable objective measurement and systematic analysis of the relationship between land use dynamics and the sustainability of economic activities within the Voi River riparian ecosystem (Saunders et al., 2020; Creswell & Creswell, 2018). The descriptive design was appropriate because it allowed the researcher to collect quantitative and qualitative data on existing land-use practices, policy interventions, and livelihood outcomes without manipulating the study environment (Kothari, 2021). This design supported the examination of cause-effect relationships among study variables and facilitated the use of statistical analysis for hypothesis testing (Mugenda & Mugenda, 2019).

Target Population and Sampling Technique

The target population comprised 2,000 households residing around the Voi River riparian ecosystem and 20 key informants drawn from relevant stakeholder institutions, including county government officials, conservation agencies, and local administrative leaders. The household sample size of 80 respondents was determined using Yamane's (1967) formula to ensure statistical representativeness (Yamane, 1967). In addition, all 20 key informants were purposively selected because of their specialized knowledge and direct involvement in land-use management and ecosystem conservation (Patton, 2015). Simple random sampling was used to select household respondents to ensure equal representation and minimize bias, while purposive sampling was applied for key informants to obtain in-depth qualitative insights (Saunders et al., 2020; Kombo & Tromp, 2016).

Instrumentation and Data Collection Procedure

Primary data were collected using structured questionnaires administered to household respondents through the drop-and-pick-later method, while interview guides were used to collect qualitative information from key informants (Kothari, 2021). The questionnaires captured information on land use activities, spatial and temporal land-use changes, policy effectiveness, and sustainability of economic activities. Interviews provided deeper understanding of institutional and governance issues affecting the riparian ecosystem (Creswell & Creswell, 2018). A pilot study involving 8 households and 2 key informants was conducted to refine the research instruments. Validity, being the degree to which results obtained from the analysis of the data that actually represent the phenomenon under study (Kimaku, 2021), was assessed using the Content Validity Index (CVI), while reliability was tested using the test–retest method to ensure consistency and accuracy of the instruments (Mugenda & Mugenda, 2019; Orodho, 2020). Reliability, which refers to the degree to which a research instrument consistently produces stable and dependable results when applied repeatedly under similar conditions (Asenahabi, 2019), was also tested. It measures the internal consistency and dependability of the instrument in capturing the intended data. Cronbach's alpha is commonly used to assess reliability, where values above 0.9 indicate excellent reliability, values around 0.8 reflect very good reliability, and values of 0.7 are considered good and acceptable for research purposes (Mwakima, Kimaku, & Mwithiga, 2025).

Data analysis

Data were analyzed using both descriptive and inferential statistics with the support of Statistical Package for the Social Sciences (SPSS). Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize demographic characteristics and

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study variables (Pallant, 2020). Inferential statistics included Pearson correlation analysis and multiple regression analysis to determine the relationship between land use dynamics, government land-use policies, and the sustainability of economic activities (Field, 2018). A multiple regression model was estimated to test the study hypotheses and assess the significance of predictor variables. Diagnostic tests including normality, multicollinearity, heteroscedasticity, autocorrelation, and linearity were also conducted to ensure the validity and robustness of the regression model (Gujarati & Porter, 2021; Hair et al., 2020).

Ethical Considerations

Ethical approval for the study was obtained from the Ethics Review Committee of Taita Taveta University. Participation was purely voluntary, and all respondents provided informed consent before taking part in the research. Confidentiality and anonymity were maintained through the use of unique identification codes, and all collected data were securely stored with limited access. Furthermore, enumerators upheld professionalism, integrity, and respect in all interactions with respondents during the data collection process.

RESULTS

A total of 400 questionnaires were issued to respondents, with 288 filled and returned while 19 were voided and 93 were unreturned. The returned questionnaires formed a response rate of 72.0% as shown in Table 1.

Table 1: Response Rate

Questionnaire	Frequency	Percent
Returned	288	72.0
Voided	19	4.75
Non returned	93	23.25
Total	**400**	**100.0**

Demographic Information Analysis

Table 2: Demographic Data

Demographic Variable	Category	Frequency	Percentage (%)
Gender	Male	167	58.0
	Female	121	42.0
Age	18–30	73	25.3
	31–40	95	33.0
	41–50	69	24.0
	50+	51	17.7
Education Level	No Formal Education	37	12.8
	Primary Education	119	41.3
	Secondary Education	83	28.8
	Tertiary Education	49	17.0
Economic Activity	Farming	121	42.0
	Sand Harvesting	57	19.8
	Business	63	21.9
	Employment	47	16.3
Years in Organization	Less than 5 Years	41	14.2
	6–10 Years	67	23.3
	11–20 Years	95	33.0
	Above 20 Years	85	29.5
Total		**288**	**100.0**

Key Findings

The descriptive analysis of study variables showed that major land use activities within the Voi River riparian ecosystem include farming, settlement expansion, sand harvesting, and brickmaking, which are the main sources of household income and livelihood support (Babbie, 2013). Most respondents indicated that agricultural expansion and settlement growth have increased significantly over time, especially between 2022 and 2026, leading to encroachment into riparian buffer zones and increased pressure on natural resources (Mwangi et al., 2022; Tsavo Trust, 2023).

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Sand harvesting and brickmaking were also identified as common economic activities, although they were associated with riverbank degradation, soil erosion, and vegetation loss (Omollo & Ogendi, 2023).

The analysis further revealed notable spatial and temporal changes in land use patterns, including reduced vegetation cover, increased built-up areas, and expansion of cultivated land. These changes were largely driven by population growth, demand for income-generating activities, and weak enforcement of riparian land-use regulations (Kairu et al., 2023; NEMA, 2022). Respondents agreed that such changes have negatively affected water availability, soil fertility, and biodiversity, thereby threatening the sustainability of farming, tourism, and other river-dependent activities (Foley et al., 2021; Vörösmarty et al., 2022).

Findings also showed that land use dynamics significantly influence the sustainability of key economic activities by affecting access to fertile land, water resources, and ecological services (Pahl-Wostl et al., 2022). While some households adopted adaptive strategies such as crop diversification, embankments, and soil conservation, many remained vulnerable to environmental degradation (Scoones, 2009). Government land use policies were found to play a moderate but important role in promoting sustainability. However, weak implementation, inadequate monitoring, and low public awareness limited policy effectiveness (North, 2005; Mwangi & Wekesa, 2022). Overall, the descriptive analysis confirmed that balanced land use, stronger regulation, and community participation are essential for sustaining livelihoods and protecting the Voi River riparian ecosystem.

Table 3: Major Land Use Activities results

Statement on Major Land Use Activities	SD	D	N	A	SA	D	Mean	SD
Agricultural activities along the river have increased in recent years	7	12	10	39	28	12	3.82	0.97
Farming activities are expanding closer to the riverbanks	10	15	9	36	25	14	3.68	1.02
Residential settlements along the river have increased significantly	8	15	15	34	22	15	3.56	1.05
New structures are being developed within the riparian zone	6	17	19	32	20	17	3.48	1.09
Sand harvesting activities along the river are common	9	14	9	33	30	14	3.69	0.98
Brick-making activities are increasing within the ecosystem	10	16	11	31	26	16	3.57	1.01
AVERAGE	**8**	**15**	**12**	**34**	**25**	**15**	**3.63**	**1.020**

Table 4: Spatial and Temporal Changes Results

Statement on Spatial and Temporal Changes	SD	D	N	A	SA	Mean	SD
Natural vegetation along the river has reduced over time	8	11	8	38	32	4	0.95
Agricultural land has replaced natural riparian vegetation	3	10	18	36	29	3.9	0.99
Land use patterns have changed significantly in the past ten years	7	9	16	34	31	3.9	1.02
The frequency of land use change has increased in recent years	4	10	21	35	27	3.8	1.04
Economic activities along the river are more intensive than before	10	13	10	33	30	3.8	1.01
Land along the river is being utilized more extensively than in the past	5	11	19	34	28	3.7	1.03
AVERAGE	**6**	**11**	**15**	**35**	**30**	**3.9**	**1.007**

Table 5: Land Use Dynamics results

Statement on Land Use Dynamics	SD	D	N	A	SA	Mean	SD
Changes in land use have affected household income levels	7	14	10	36	33	3.95	0.980
Economic returns from river-based activities fluctuate due to land use changes	8	16	11	35	30	3.81	1.050
Land use changes have reduced access to water resources	9	15	14	34	28	3.74	1.070
The availability of fertile land has declined due to land use practices	6	14	17	32	31	3.77	1.040
Environmental degradation affects the productivity of economic activities	9	11	14	34	32	3.86	1.020
Soil erosion and riverbank degradation affect household livelihoods	7	13	17	33	30	3.78	1.030
AVERAGE	**8**	**14**	**14**	**34**	**31**	**3.82**	**1.032**

Table 6: Government Land Use Policies results

Statement on Government Land Use Policies	SD	D	N	A	SA	Mean	SD
I am aware of government regulations governing riparian land use	5	14	14	38	29	3.8	0.990
Government policies on land use are clearly communicated to residents	8	14	17	35	26	3.6	1.070
Enforcement of riparian land use regulations is effective	6	20	20	31	23	3.4	1.150
Authorities regularly monitor activities along the river	8	18	16	33	25	3.5	1.090

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Community members are involved in land use decision-making processes	9	15	16	32	28	3.6	1.060
Public participation influences land use management outcomes	11	12	17	33	27	3.6	1.050
AVERAGE	**8**	**16**	**17**	**34**	**26**	**3.57**	**1.068**

Table 7: Sustainability of KEA results

Statement on the Sustainability of KEA	SD	D	N	A	SA	Mean	SD
Income from river-based activities is stable over time	6	11	20	35	28	3.66	1.04
River-based activities provide a reliable long-term income	11	17	9	33	30	3.69	1.05
Current economic activities can be sustained for many years	9	11	19	34	27	3.61	1.03
Future generations can benefit from current land use practices	12	16	14	32	26	3.54	1.06
Environmental conservation supports economic sustainability	11	16	9	33	31	3.70	1.02
Unsustainable land use threatens future economic activities	10	13	14	34	29	3.67	1.03
AVERAGE	**10**	**14**	**14**	**34**	**29**	**3.65**	**1.038**

Correlation Analysis

Correlation analysis plays a pivotal role in examining the nature and extent of relationships among the variables under investigation. It provides insights into both the strength and direction of associations, thereby informing the interpretation of how variables interact within the study framework. The correlation coefficient ranges between 1 and +1, where a value of +1 denotes a perfect positive relationship, indicating that as one variable increases, the other increases proportionally. Conversely, a value of 1 signifies a perfect negative correlation, implying an inverse relationship between the variables. A value of 0.000 shows the absence of any relationship. Correlation coefficients ranging from 0.001–0.250 reflect a weak association, 0.251–0.500 indicate a moderately strong relationship, 0.501–0.750 denote a strong correlation, and 0.751–1.000 represent a robust correlation.

Table 8: Correlation Matrix for Study Variables

Variable	Y	X1	X2	X3	X4
Y	1	0.612**	0.578**	0.491**	0.536**
X1	0.612**	1	0.558**	0.492**	0.507**
X2	0.578**	0.558**	1	0.427**	0.459**
X3	0.491**	0.492**	0.427**	1	0.444**
X4	0.536**	0.507**	0.459**	0.444**	1

Where: Y = Sustainability of key economic activities, X1 = Major land use activities along the Voi River riparian ecosystem, X2 = Spatial and temporal changes in land use patterns, X3 = Effects of land use dynamics on key economic activities, X4 = Government land use policies on environmental sustainability.

The correlation analysis demonstrates that all independent variables have statistically significant positive relationships with the sustainability of economic activities. Major land use activities along the river exhibited the strongest association ($r = 0.612$, $p < 0.01$), indicating that increased farming, settlement expansion, sand harvesting, and brick-making are closely linked to household income stability and the long-term viability of economic livelihoods. Spatial and temporal changes in land use patterns were positively correlated with sustainability ($r = 0.578$, $p < 0.01$), suggesting that ongoing shifts in how land is allocated and utilized over time influence the ability of households to maintain stable economic outcomes. The effects of land use dynamics on key economic activities showed a moderate positive correlation ($r = 0.491$, $p < 0.01$), reflecting that alterations in land accessibility, soil fertility, and water resources can impact productivity, though adaptive practices mitigate some negative consequences. Government land use policies on environmental sustainability were moderately correlated with economic sustainability ($r = 0.536$, $p < 0.01$), highlighting the importance of regulatory enforcement, policy awareness, and community participation in securing stable livelihoods. The intercorrelations among independent variables are moderate, indicating that while land use intensity, temporal changes, and policy enforcement are related, they each provide distinct contributions to explaining sustainability outcomes. Qualitative insights from key informants confirmed these patterns, showing that households that diversified activities and followed environmental guidelines experienced more predictable incomes and resilience against seasonal fluctuations. These results are consistent with the literature emphasizing that integrated land use planning, adaptive natural resource management, and effective policy implementation are critical for sustaining economic activities in riparian ecosystems (Mwangi & Wekesa, 2022). Overall, the analysis establishes that major land use, temporal land use changes, land use impacts, and government policies significantly influence the long-term sustainability of river-based livelihoods.

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Regression Analysis

Regression analysis was performed to assess how major land use activities, spatial and temporal land use changes, the effects of land use dynamics on key economic activities, and government land use policies affect the sustainability of economic activities in the Voi River riparian ecosystem. The multiple correlation coefficient (R) is 0.754, which suggests a strong linear relationship between the predictors and the dependent variable. The regression results indicate that land use activities, land use changes, land use dynamics, and government land-use policies jointly explain 56.9% of the variation in the sustainability of key economic activities in the Voi River riparian ecosystem, as shown by the R^2 value of 0.569 (Field, 2018; Pallant, 2020). The adjusted R^2 of 0.552 confirms that the model maintains strong explanatory power even after accounting for the number of predictors, demonstrating the reliability of the selected variables in explaining sustainability outcomes (Gujarati & Porter, 2021). The standard error of 0.312 indicates minimal deviation between observed and predicted values, suggesting a precise and well-fitting model (Hair et al., 2020). These findings imply that the combined effect of land use practices and policy interventions significantly influences household livelihood sustainability and long-term economic resilience. Qualitative evidence from key informants further supports this conclusion, showing that households practicing diversified land use strategies and complying with environmental regulations experienced more stable income streams and improved resilience. Overall, the results confirm that effective land management and supportive policy frameworks are critical determinants of sustainable economic activities along the Voi River riparian ecosystem. The model summary results are presented in Table 9.

Table 9: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.754a	0.569	0.552	0.312

Table 4.3: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.462	4	4.616	28.67	0.001
	Residual	13.989	87	0.161		
	Total	32.451	91			

The ANOVA results show that the regression model is statistically significant ($F = 28.67$, $p = 0.001$), indicating that the independent variables collectively predict the sustainability of key economic activities. The large F-value suggests that the variance explained by the model is substantially greater than the unexplained variance. The low p-value ($p < 0.01$) supports rejecting the null hypothesis, confirming that at least one of the predictors significantly contributes to explaining sustainability outcomes. These results are consistent with observations from key informants, who reported that households combining diversified land use and adherence to policies experienced higher and more stable incomes. Therefore, the ANOVA confirms that the regression model is appropriate for testing the study hypotheses. These findings align with existing research highlighting the importance of integrated land use planning and policy enforcement in enhancing economic sustainability in riparian areas (Mwangi & Wekesa, 2022). The significant model validates the framework and sets the stage for analyzing individual predictor contributions in the next subsection.

Table 10: Regression Coefficient Results

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.872	0.312		2.80	0.007
Major Land Use Activities	0.421	0.098	0.412	4.29	0.001
Spatial & Temporal Land Use Changes	0.378	0.111	0.351	3.40	0.001
Effects of Land Use Dynamics	0.295	0.104	0.283	2.84	0.006
Government Land Use Policies	0.337	0.102	0.316	3.30	0.002

The regression results show that all four independent variables significantly influence the sustainability of key economic activities in the Voi River riparian ecosystem. Major land use activities had the strongest effect ($\beta = 0.412$, $p = 0.001$), indicating that farming, settlement expansion, sand harvesting, and brickmaking are the most influential factors in improving household income stability and long-term livelihood sustainability (Field, 2018; Pallant, 2020). A one-unit increase in major land use activities leads to a 0.421-unit increase in sustainability, highlighting the importance of productive and well-managed land use practices.

Spatial and temporal land use changes also had a strong positive effect ($\beta = 0.351$, $p = 0.001$), showing that changes in land allocation and use patterns significantly affect access to fertile land, water resources, and productivity (Gujarati & Porter, 2021). The effects of land use dynamics, such as soil erosion, riverbank degradation, and environmental stress, had a moderate positive influence ($\beta = 0.283$, $p = 0.006$), suggesting that households using adaptive strategies like crop rotation and embankments maintain better economic sustainability (Hair et al., 2020).

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Government land use policies also contributed significantly ($\beta = 0.316$, $p = 0.002$), confirming that policy enforcement, public awareness, and community participation are important for sustaining river-based livelihoods (North, 2005; Ostrom, 1990). The model explains 56.9% of the variation in sustainability ($R^2 = 0.569$), while the significant ANOVA results confirm the model's reliability. Overall, the findings demonstrate that sustainable land use, adaptive management, and effective policy implementation are key drivers of economic resilience in the Voi River riparian ecosystem (Mwangi & Wekesa, 2022).

The overall model becomes:

$$\mathbf{Y = 0.872 + 0.421X_1 + 0.378X_2 + 0.295X_3 + 0.337X_4}$$

Interpretation of Findings

The study findings reveal that land use dynamics significantly influence the sustainability of economic activities within the Voi River riparian ecosystem. Major land use activities such as farming, settlement expansion, sand harvesting, and brickmaking were the strongest predictors of livelihood sustainability, showing that households rely heavily on riparian resources for income, food security, and survival. When these activities are sustainably managed, they improve household income stability and resilience; however, poor management accelerates environmental degradation and threatens future productivity (Mwangi et al., 2022; Tsavo Trust, 2023). Spatial and temporal land use changes, including shifts in cultivation patterns and settlement growth, affect access to fertile land, water resources, and ecological services. While farming near riverbanks increases short-term productivity, it also increases risks such as soil erosion and biodiversity loss (Kairu et al., 2023; Foley et al., 2021). Environmental degradation was found to reduce agricultural productivity and other livelihoods, though adaptive practices improved resilience. Government land use policies also significantly shaped sustainability outcomes, emphasizing the importance of policy enforcement, institutional coordination, and community participation for long-term environmental conservation and sustainable livelihoods.

Practical Implications

The study shows that sustainable management of farming, settlement expansion, sand harvesting, and brickmaking is essential for protecting the Voi River riparian ecosystem and sustaining local livelihoods. Stronger land-use planning, effective enforcement of environmental policies, improved institutional coordination, and community participation are necessary to reduce environmental degradation, protect biodiversity, and enhance long-term household income stability. Conservation agencies and local communities should promote restoration programs, sustainable farming, and alternative livelihoods to support ecological and economic sustainability.

Theoretical Implications

The study strengthens Land-Use Change Theory, Sustainable Livelihoods Framework, Political Ecology Theory, and Institutional Theory by showing that land use activities, governance systems, and household adaptation jointly influence ecological and economic sustainability. It confirms that sustainable livelihoods depend on balanced resource use, adaptive capacity, policy enforcement, and institutional support. The study also provides an integrated theoretical perspective for understanding riparian ecosystem management in semi-arid regions such as the Voi River ecosystem.

Limitations of the Descriptive Analysis

The descriptive analysis faced several limitations. One limitation was its reliance on self-reported data from households and key informants, which may have been affected by recall bias, exaggeration, or reluctance to disclose sensitive land use practices. Another challenge was that the study focused only on the Voi River riparian ecosystem, limiting generalization to other regions. Additionally, descriptive statistics such as means and percentages summarized trends but could not establish cause-and-effect relationships. Further, secondary data from institutions like Kenya Wildlife Service and Kenya Forest Service may have contained gaps or inconsistencies. Lastly, rapid environmental changes after data collection may reduce the long-term relevance of the findings.

CONCLUSIONS AND RECOMMENDATIONS

The study concluded that land use dynamics significantly influence the sustainability of economic activities within the Voi River riparian ecosystem. Major land use activities such as farming, settlement expansion, sand harvesting, and brickmaking were found to be the strongest determinants of livelihood sustainability, as households heavily depend on these activities for income generation, food security, and survival. When managed sustainably, these activities improve household resilience and long-term economic stability; however, unsustainable practices accelerate soil erosion, vegetation loss, riverbank degradation, and declining water quality, which threaten future productivity and ecological balance.

The study further concluded that spatial and temporal changes in land use patterns directly affect access to fertile land, water resources, and ecosystem services. Increased cultivation near riverbanks and unplanned settlement growth may provide short-term economic benefits but often undermine long-term environmental sustainability by increasing flood risks, biodiversity loss, and habitat destruction. The findings also showed that land use degradation negatively affects agriculture, tourism, and other livelihood activities, although households adopting adaptive strategies such as crop diversification, soil conservation, and protective embankments demonstrated greater resilience.

Government land use policies were also found to significantly influence environmental and economic sustainability. Effective policy enforcement, institutional coordination, and community participation were essential in regulating riparian land use and reducing unsustainable practices. However, weak implementation, low public awareness, and fragmented institutional responsibilities reduced policy effectiveness and allowed continued encroachment into riparian zones.

The study recommended stronger enforcement of land use regulations and riparian buffer zone protection by county and national governments to control farming encroachment, illegal sand harvesting, and settlement expansion. Integrated land use planning involving government agencies, conservation institutions, and local communities should be strengthened to balance economic development with environmental conservation. Conservation agencies such as Kenya Wildlife Service and Kenya Forest Service should enhance restoration programs, habitat protection, and

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ecosystem monitoring. Local communities should be supported through environmental awareness programs, sustainable farming practices, and promotion of alternative livelihoods such as eco-tourism and small enterprises to reduce overdependence on riparian resources. Finally, institutional collaboration and policy harmonization should be improved to ensure effective governance, long-term ecological sustainability, and stable household livelihoods within the Voi River ecosystem.

Future Research Directions

Future research should examine additional socio-economic and environmental factors influencing livelihood sustainability, including climate change, population growth, land tenure systems, market access, and technology adoption. Comparative studies across other semi-arid riparian ecosystems in Kenya, such as the Tana and Athi River systems, would help determine whether similar land use patterns and sustainability challenges exist. Longitudinal studies are also recommended to track land use changes and livelihood outcomes over time and establish stronger causal relationships. The use of advanced GIS, remote sensing, and spatial modelling techniques would improve land use mapping accuracy and prediction of future ecological risks. Further studies should evaluate the effectiveness of specific policy interventions such as riparian buffer zone enforcement, community-based conservation, and alternative livelihood programs like eco-tourism and sustainable agribusiness. Interdisciplinary research combining ecology, economics, governance, and social behavior would provide deeper insights for sustainable riparian ecosystem management.

Acknowledgments

I would like to express my sincere gratitude to all individuals and institutions who contributed to the successful completion of this research project. I also wish to acknowledge the residents and households within the Voi River riparian ecosystem, local administrative leaders, and staff from relevant institutions including Kenya Wildlife Service, Kenya Forest Service, the National Land Commission, and Taita Taveta County Government who generously participated in this research by providing the necessary information and responding to the questionnaires and interviews. Their cooperation, support, and willingness to share their experiences made this study possible.

ETHICAL DECLARATIONS

Funding Information: No external funding was received for this manuscript.

Conflict of Interest: The authors declare that they have no conflict of interest.

Data Availability Statement: The data supporting this study are available from the corresponding author upon reasonable request.

Research Ethics: Ethical approval for the study was granted by Taita Taveta University, and informed consent was obtained from all participants prior to data collection.

RECOGNITIONS OF THE AUTHOR CONTRIBUTION

Geoffrey Sawe Nyambeche - Conceptualization, methodology, data collection, data analysis, writing.

Monica Wanjiru Kinyanjui - Supervision, refining methodology, reviewing and editing.

Fredrick Lala- Supervision, validation, editing and reviewing.

DATA AVAILABILITY

Owing to confidentiality requirements, the complete dataset is not publicly accessible. However, anonymized data and related supporting materials can be obtained from the corresponding author upon reasonable request.

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