

Article

Fostering Neighbourhood Social–Ecological Resilience Through Land Readjustment in Rapidly Urbanising Cities in Sub-Saharan Africa: The Case of Nunga in Kigali, Rwanda

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Abstract: Rapid urbanisation in Sub-Saharan Africa demands innovative land management strategies that promote sustainable, inclusive, and resilient urban development. This study investigates the potential of land readjustment (LR) to foster neighbourhood-scale social–ecological urban resilience (SEUR) through a case study of the Nunga LR project in Kigali, Rwanda. Grounded in the social–ecological system (SES) theory and operationalised through the social–ecological land readjustment model for resilient neighbourhoods, the research evaluates LR practices against an integrated benchmark framework combining LR aspects, neighbourhood design standards, and resilience attributes. The study uses secondary data, project shapefiles, and key informant interviews to assess how Rwanda’s emerging LR model contributes to resilient neighbourhood development. Findings demonstrate strong community mobilisation and adaptive governance capacity. However, critical resilience dimensions—including modularity, green infrastructure integration, land-use diversity, and adaptive feedback mechanisms—were only partially operationalised. Consequently, while LR improved spatial formalisation and basic infrastructure provision, it fell short of creating a truly resilient, multifunctional neighbourhood ecosystem. These findings highlight the need to reframe LR from a purely technical land management tool into a systemic resilience-building mechanism. Policy recommendations include mandating green/blue infrastructure in LR plans, establishing innovative financing mechanisms, institutionalising adaptive monitoring, strengthening affordability safeguards, and promoting multifunctional spatial layouts. The study contributes to urban resilience and land governance scholarship by offering a context-sensitive, empirically tested model for integrating SEUR principles into LR practice in rapidly urbanising African cities. Future research should pursue longitudinal analyses and dynamics modelling of land readjustment impacts to deepen understanding of urban resilience pathways in the Global South.

Keywords: urban resilience; green infrastructure; land-use planning tools; land-based financing; sustainable neighbourhood; climate change



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1. Introduction

Rapid urbanisation in Sub-Saharan Africa presents significant challenges to sustainable development and social–ecological resilience, particularly in fast-growing cities where planning systems struggle to keep pace with demographic and spatial change. These

challenges include resource depletion, inadequate infrastructure, informal settlements, climate vulnerability, and rising social inequalities [1]. Urban expansion in many African countries has outpaced population growth, resulting in sprawling, inefficient land use and growing pressure on natural ecosystems and urban services [2–4]. As urban land is transformed, driven by both rural–urban migration and natural population growth, there is a critical need for spatial planning approaches that align land-use change with social and ecological resilience imperatives.

Neighbourhood-scale planning has emerged as a promising approach to address these urbanisation challenges more locally and inclusively. Unlike city-wide master planning, which often lacks sensitivity to local needs and complexities, neighbourhood-based planning enables context-specific solutions and greater stakeholder engagement [5,6]. However, in many developing countries, including Rwanda, urban development continues to be guided predominantly by top-down master plans with limited integration of resilience thinking, ecological infrastructure, or community input at the neighbourhood level [3]. This results in neighbourhoods that lack the social cohesion, green and blue infrastructure, and adaptive capacity essential for long-term urban resilience.

Urban resilience, originally rooted in ecological systems theory [7], has increasingly gained traction in planning research and practice as cities face mounting stressors [8]. Conceptualised within a non-equilibrium framework, resilience in urban contexts involves the ability of urban systems—viewed as dynamic social–ecological systems—to maintain identity, function, and structure in the face of disturbance [9,10]. Global frameworks such as the New Urban Agenda and the Sustainable Development Goals underscore the importance of resilience in addressing urban risk and uncertainty [11,12]. Resilience, particularly in its non-equilibrium framing, is increasingly seen as critical to understanding and managing urban systems as adaptive, complex, and evolving entities.

Despite its conceptual evolution, urban resilience remains inadequately embedded in planning tools and development strategies. Most frameworks for modelling or measuring resilience remain theoretical and are seldom operationalised at the neighbourhood scale [13,14]. There is a significant gap in integrating resilience principles into land-use planning tools such as land readjustment, especially in fast-growing urban contexts where land scarcity, informality, and climate risks intersect. In the context of developing countries, Sub-Saharan Africa inclusive, integrating resilience principles into urban development projects is still in its infancy, with several critical gaps limiting its effectiveness in fostering long-term urban sustainability and adaptability [15]. Urban and climate resilience planning often lacks consideration of a systems approach, adequate community participation, focus on environmental resilience, and institutional and policy integration [16–19].

Land readjustment (LR) offers a promising, underutilised tool for fostering neighbourhood-level resilience in rapidly urbanising contexts. As a participatory and often self-financing land management approach, LR involves land pooling, infrastructure investment, and the redistribution of serviced plots, aiming to improve urban form and service delivery while maintaining landowner rights [15,20]. While LR has been widely used to deliver grey infrastructure and housing, especially in Asia and more recently in parts of Africa [21], its potential to incorporate green infrastructure and landscape-based resilience strategies remains largely unrealised [22,23]. The limited integration of green infrastructure, social inclusion, and environmental equity undermines the transformative potential of LR in contributing to sustainable urban development.

Green infrastructure refers to the strategically planned network of natural and semi-natural areas—such as parks, green roofs, wetlands, urban forests, and permeable surfaces—that provide ecosystem services and support environmental, economic, and social sustainability in urban areas [24]. Green infrastructure can enhance urban resilience

by regulating microclimates, controlling runoff, reducing pollution, and supporting biodiversity and human well-being [24,25]. However, integrating these ecological functions into LR remains limited by financial, spatial, and policy constraints, particularly in low-income settings [26,27]. LR offers a strategic opportunity to overcome these barriers by embedding resilience into neighbourhood design and land-use change processes.

This paper explores how LR can be designed and implemented to foster neighbourhood social–ecological resilience in the context of rapidly urbanising cities in Sub-Saharan Africa. Using the case of the Nunga LR project in Kigali, Rwanda, the study develops a conceptual model that integrates LR with neighbourhood design and social–ecological resilience principles. While recent approaches, such as the participatory and inclusive land readjustment [18], claim to overcome the challenges of the conventional LR model by promoting participation in the process and inclusiveness in the outcomes, the resilience aspect is less emphasised. Our proposed model advances the UN-Habitat approach to incorporate neighboured planning standards and social–ecological resilience principles into LR design and implementation. The model was adapted to Rwanda’s urban planning policy, and references were made to the neighbourhood design standards developed by UN-Habitat. The aim was to assess the extent to which the Rwandan LR model, particularly the Nunga project, integrates neighbourhood planning and social–ecological resilience for sustainable and resilient urban development. The study seeks to address two central research questions:

- (1) How can land readjustment be designed to foster neighbourhood social–ecological resilience?
- (2) To what extent do land readjustment models in developing countries integrate neighbourhood design and social–ecological resilience principles?

By addressing these questions, the study aims to contribute to the theoretical development of resilience-integrated land-use planning and provide practical insights for policy and planning reforms in rapidly urbanising contexts.

The paper is organised as follows: Section 2 presents the theoretical and conceptual framework linking LR, neighbourhood planning, and social–ecological resilience. Section 3 outlines the research design and case study research materials and methods. Section 4 presents empirical findings from the Nunga LR project. Section 5 discusses implications for planning practice and policy, and Section 6 concludes with key insights and future research directions.

2. Theoretical Framework

This section conceptualises urban areas as social–ecological systems and elaborates the notion of social–ecological urban resilience (SEUR) at the neighbourhood scale. It critically reviews various LR models applied globally and integrates their common elements with resilience-focused urban design principles. The resulting conceptual model seeks to connect LR processes with social–ecological resilience to guide neighbourhood planning in rapidly urbanising contexts, especially in Sub-Saharan Africa.

2.1. Urban Areas as Social–Ecological Systems

Urban environments are complex adaptive systems characterised by interconnected subsystems that include infrastructure, institutions, ecosystems, and human networks, whose dynamic interactions shape urban form and function [28,29]. These systems self-organise in response to internal and external disturbances, with feedback mechanisms that influence their stability, transformation, and adaptability [30,31].

Framing cities as social–ecological systems (SEs) emphasises the mutual dependence between human and ecological subsystems [9,32]. Adaptive governance, which facilitates

learning and coordination across institutions and actors, is central to maintaining this co-dependence in times of stress or change [33]. Urban SES models deconstruct cities into key elements—people, institutions, physical infrastructure, and ecosystems—to evaluate how spatial planning interventions can bolster resilience to disturbances [34–36]. Complex adaptive systems theory [37] further strengthens this view by highlighting the role of decentralised rules, multi-scalar interactions, and emergent behaviours in shaping urban evolution. Urban SESs consist of biophysical units, social agents, and governing institutions within defined spatial and functional boundaries [36].

Figure 1 illustrates the interaction between urban social and ecological subsystems, the role of institutions, and the impacts of external stressors. Spatial interventions—such as plans, programmes, or projects—can influence resilience by strengthening or weakening feedback mechanisms and institutional adaptability [14]. This process, termed adaptive governance, ensures that institutions remain responsive and flexible under changing conditions [33]. The social subsystem comprises human populations and their activities, while the ecological subsystem includes physical resources and processes. The ecological systems support social systems' well-being and economic development by providing ecosystem services and interconnections (through networked systems such as roads). Building social–ecological urban resilience involves interventions, such as plans, programmes or projects [14], that enhance the adaptive capacity of social agents and the resilience of natural and built-up environments. Here, the resilience of the natural and built environments refers to maintaining the identity and functioning of the system components during and post-disturbance [30]. Institutions (localised formal and informal rules) influence the constant interactions between the social agents and the natural and built systems. Institutions may also need to adapt to changes to allow the building of social capacity and resilience of natural and built systems. The adaptability of institutions to facilitate the transformative resilience of urban systems is known as adaptive governance [33]. Adaptive governance connects social agents and institutions at multiple organisational levels.

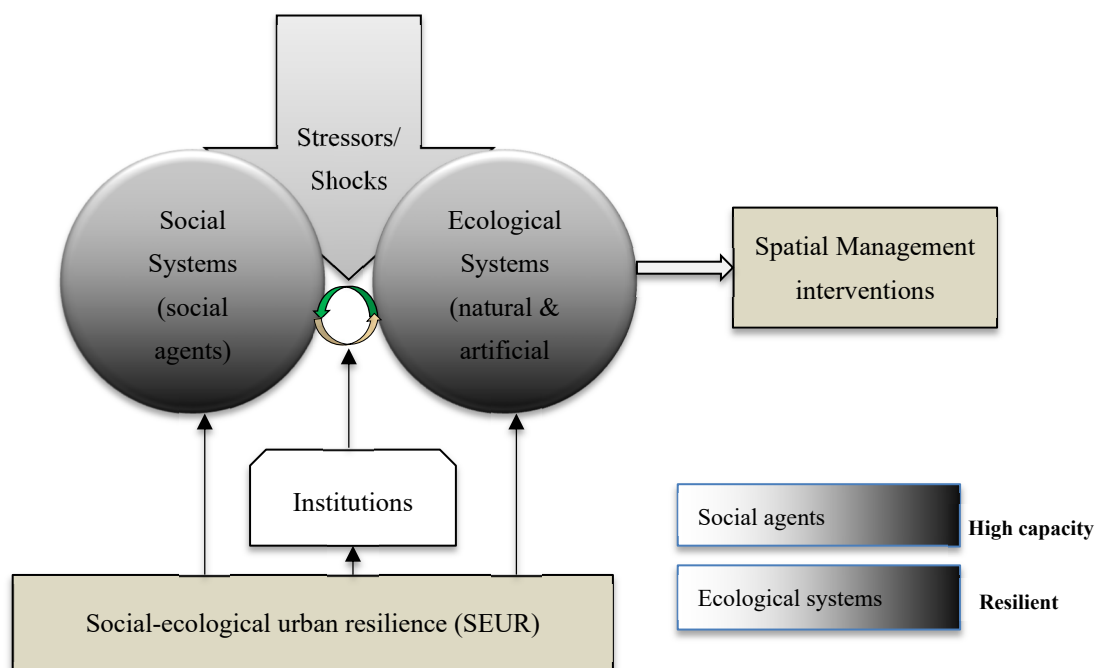


Figure 1. Simplified model of an urban social–ecological system. Source: Adapted from Tyler and Moench, 2012 [35].

2.2. Social–Ecological Urban Resilience at the Neighbourhood Scale

The resilience concept, originally rooted in ecology [7], has evolved into a guiding principle in urban planning. It refers to the capacity of urban systems to absorb, adapt, or transform in response to shocks and stresses while maintaining critical functions and identity [30,38]. A neighbourhood-level focus enables more context-sensitive resilience-building strategies, given its manageable spatial scale and the potential for participatory planning [5,13].

The resilience concept emerged in urban studies in the 1990s as an attractive perspective for cities [8,39]. Urban resilience has become essential due to the increasing threats associated with rapid urbanisation, such as disaster risk and land degradation, which lead to resource depletion and social inequalities and impact climate change [1]. Rapid urbanisation, especially in the Global South, is associated with challenges that include inefficient land use and poor urban design that manifest in the form of informal urban settlements and sprawl, as well as inadequate water and sanitation systems, that together threaten the future well-being of urban dwellers [40]. Urban resilience has emerged as a way of rethinking urban planning practices to build capacity to deal with uncertain future changes [8,34,41]. Nevertheless, the focus has been mainly on assessing the recovery process with limited exploration of the planning and absorption stage [42]. There are limited studies on bottom-up participatory approaches to land-use planning and management in urban resilience. In this regard, local governments and landowners are supposedly vital actors. However, sometimes higher government levels restrict their actions and face a lack of adequate financing to implement local land-use plans [43]. It is also noted that the definition of urban resilience is not associated with urban planning tools, and a gap exists between resilience approach and resilient actions within urban governance [44]. There is a need for a pragmatic approach to building resilient cities that innovates urban planning by integrating resilience into a flexible tool to manage and govern spatial complexity at the neighbourhood scale.

A neighbourhood is a collection of people who share services and some level of cohesion in a geographically bounded place that offers more advantages to urban planning, as its size helps engage the participation of landowners and stakeholders [5]. The issue is how a neighbourhood should be designed and what tools could effectively be used to foster urban resilience. It is thus crucial to specify the perspective of resilience that needs to be achieved and the neighbourhood design principles. Due to its dynamic and evolutionary nature, the non-equilibrium view of resilience is considered more beneficial to urban planning and design [38]. This resilience perspective is also known as evolutionary or social–ecological resilience [13,38]. The focus is on system function rather than states or structures, and resilience requires connecting structure with its processes [38]. Social–ecological urban resilience is thus the capacity of urban systems to maintain their identity and function when undergoing change [45]. It is argued that focusing on social–ecological resilience offers the advantage of exploring gaps in urban planning studies by integrating ecological factors with urban systems at various spatial scales [13]. Integrating social–ecological resilience principles into neighbourhood design allows for a multifunctional, inclusive, and adaptive urban form. Key principles include diversity, modularity, tightness of feedback, social cohesion, and innovation [9,10]. These can be operationalised through design standards such as compact layouts, mixed land use, and equitable distribution of services [46], as summarised in Table 1.

Table 1. Neighbourhood design and social–ecological resilience principles.

Neighbourhood Planning Principle	UN-Habitat Design Standards	Social–Ecological Resilience Principle	Social–Ecological Characteristics/Factors	Reference
Adequate space for streets and an efficient network	Street network should occupy at least 30% of the land and at least 18 km of street length per km ²	Diversity	Organised citizen groups; various institutional actors; diversity of participants; various land uses	[9,10,14,30,35,41,46]
High density	At least 15,000 people per km ²	Modularity	Self-sufficiency; diverse citizen groups, businesses, and institutions	[9,35,41,46–48]
Mixed land use	At least 40% of floor space for economic use	Tightness of feedbacks	Self-sufficiency; diverse institutions; social networks	[9,30,35,41,46]
Social mix	20–50% of the residential area for low-cost housing	Social cohesion and equity	Social cohesion and equity	[35,46,47,49]
Limited land-use specialisation	Single-function blocks < 10%	Learning and innovation	Citizen groups; participatory spaces	[9,30,35,41,46]

Table 1 shows the principles that should guide the design of urban neighbourhoods and the social–ecological resilience principles that need to be considered during the development process for a resilient neighbourhood. UN-Habitat proposes five principles that future cities should consider when building urban structures and spaces where urban life thrives and address various urbanisation challenges, such as urban sprawl, low density, and social segregation of land use, among others [46].

The principles support the three critical features of sustainable neighbourhoods and cities: compact, integrated, and connected. One of the objectives of the neighbourhood design principles is to promote high-density urban growth, alleviate urban sprawl, and maximise land-use efficiency. Other objectives include encouraging walkability, providing an interconnected network of streets, fostering local production and consumption, and providing housing typologies that cater for various housing needs [46].

Planners can integrate neighbourhood design with urban resilience principles to ensure that new settlements and, consequently, new cities have the potential to thrive despite various environmental and social changes from both within and outside. For instance, in designing adequate space for streets and other uses, citizens, institutional actors, and other stakeholders should be engaged to ensure that their various needs are considered in the design and implementation of the neighbourhood land-use plan. The involvement of multiple actors ensures that the designed land uses are diverse enough to cater for various needs, leading to social cohesion and equity. High density, mixed land use, and limiting land-use specialisation slow down urban sprawl, provide social equity, support better public open space, support a range of compatible activities, and allow land uses to be close together in appropriate locations and flexible to adapt over time [46]. On the other hand, modularity (the capacity to accommodate unexpected service demand or extreme pressures) should be incorporated into neighbourhood design by allowing redundant land uses (open spaces and streets) to provide multiple options for service delivery during a crisis or disaster. Likewise, tightness of feedback (ecosystem control mechanisms) and social cohesion (which includes trust, social networks, and leadership) are necessary to allow services to respond quickly and appropriately to shocks and enhance social agents' capacity to respond collectively to change. Including various ecosystems,

such as open and green spaces, in neighbourhood design tightens feedback lengths and promotes the social cohesion necessary for social–ecological resilience [24].

2.3. Land Readjustment as a Tool for Social–Ecological Resilience

Land readjustment (LR) is an inclusive and flexible urban land management approach whereby fragmented land parcels are pooled, planned, serviced, and redistributed to original owners, with portions allocated for public infrastructure [15,20]. LR has demonstrated success across diverse contexts, such as Germany, Japan, South Korea, and Colombia, in delivering serviced plots and basic infrastructure. However, models vary by legal frameworks, public participation levels, and financing mechanisms (Table 2).

Table 2. Key aspects and features of various LR models.

LR Model	LR Aspects				Reference
	Social	Legal	Technical	Outcomes	
German	Landowners' participation Equitable redistribution	German Building Code, compulsory	Cost sharing	Serviced plots Higher land value	[50–52]
Japanese	Landowners contribute 10–30% of their land to public spaces	Land Readjustment Act of 1954	Public–private partnership	Higher land value Improved infrastructure	[52,53]
Korean	Stakeholder involvement, 30–40% land contribution	Urban Development Act (2000), which integrates LR and other urban development tools	Public agency-led	Higher land value Improved infrastructure	[54,55]
Taiwanese	Participation of landowners and local government	Land Readjustment Act	Equitable redistribution	Public facilities Regular parcels	[21,56,57]
Turkish	Up to 45% land contribution	Regulation on Land and Plot Readjustment (2018)	Voluntary and compulsory	Utilities, roads, and public spaces	[58–60]
Indian	Collaborative planning	State-level Town Planning Schemes (TPS) laws	Public–private cooperation	Infrastructure development	[61–63]
Spanish	Public participation	Urban Management Regulations (1978)	Cost sharing	Serviced plots Social housing	[20,64]
Colombian	Social equity and inclusion	Law 1753 (2015)	LR is government-led	Infrastructure Social housing	[65,66]

While LR in developed countries often integrates community needs and infrastructure provision, models in developing countries remain narrowly focused on grey infrastructure and often exclude equity considerations [20,22]. This gap limits the potential of LR to foster social–ecological urban resilience, particularly in low-income urban settings. Green infrastructure—parks, wetlands, and vegetated spaces—enhances climate adaptation, ecosystem services, and social well-being [24,25], and its equitable distribution is critical for resilience and social justice [26].

LR, when properly designed, can serve as a participatory and self-financing tool that integrates landscape ecology, neighbourhood design, and resilience principles into a single planning mechanism. It enables the transformation of fragmented and informal urban landscapes into cohesive, adaptive, and multifunctional neighbourhoods.

Table 2 presents the main LR models along with their respective characteristics from various countries. These models indicate that LR primarily transforms existing land parcels into well-defined urban plots with essential public infrastructure. This process is regulated either through specific LR legislation or is generally addressed within the urban development laws. However, it is observed that the areas designated for public spaces predominantly consist of grey infrastructure, such as roads and concrete public facilities, especially in developing countries with limited green infrastructure [22,23]. This pattern is particularly prevalent in Sub-Saharan African nations that are currently exploring LR practices [20,67–69].

While most models advocate for community participation in the LR process, the results often fall short regarding social equity and inclusion [15]. Promoting green infrastructure, equity, and social inclusion is crucial for enhancing social–ecological resilience. Green infrastructure is defined as a ‘strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services’ [70]. This concept is occasionally referred to as nature-based solutions (NbSs) [40,71] or urban green structures (UGSs) [72].

Urban green spaces represent the most accessible forms of green infrastructure, capable of fostering social cohesion, improving health, and alleviating stress for individuals [73]. These green spaces vary in size, ownership, and function and are generally classified into three spatial forms: urban parks, neighbourhood open spaces, and private gardens [73]. Green neighbourhood spaces encompass parks and playgrounds intended for public use within a specific community. In contrast, urban parks are larger green areas designed for recreational purposes, accessible to all urban residents and visitors, though they are limited in number within a city.

Green infrastructures are considered a vital mechanism for climate change adaptation in urban areas and are being integrated into city master plans as a mitigation strategy for the urban heat island effect [74]. As a tool for planning and managing land use through land contributions, LR can influence social–ecological urban resilience [75]. It is argued that well-designed and fairly distributed green infrastructure can enhance social cohesion and a sense of place, which fosters resilience [24]. Thus, integrating green infrastructure, social inclusion, and other resilience principles into the LR process can positively influence the social–ecological resilience of residential neighbourhoods and cities to various shocks and stresses.

2.4. Integrating LR with Neighbourhood Design and SEUR Principles

This study proposes a land readjustment model that integrates neighbourhood planning principles with social–ecological resilience factors. As shown in Figure 2, the model aligns LR’s social, legal, technical, and financial dimensions with key SEUR principles—diversity, modularity, feedback tightness, social cohesion, and innovation—within a compact, connected, and integrated neighbourhood structure. It is anchored in the national land-use and resilience mainstreaming policies, positioning LR as a practical vehicle for implementing sustainable and resilient urbanisation strategies in rapidly urbanising contexts like Kigali.

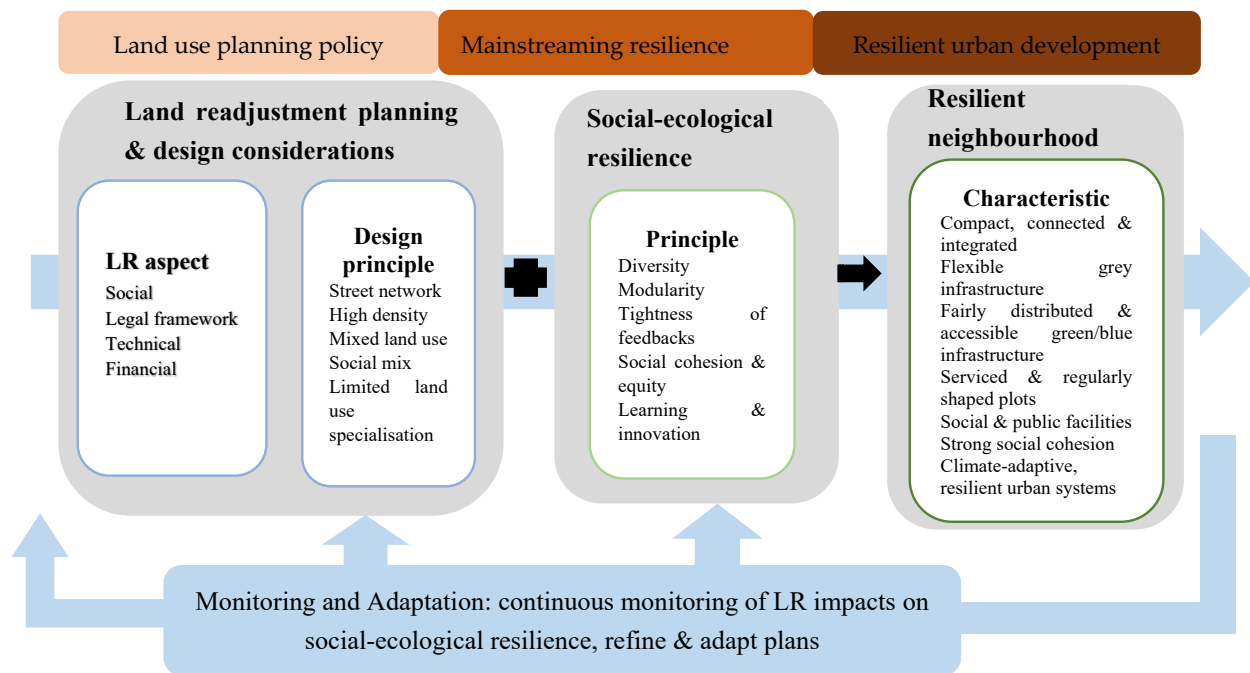


Figure 2. A social-ecological land readjustment model for resilient neighbourhoods. Source: Authors.

Legal provisions form the backbone of the model, enabling inclusive participation, setting spatial standards, and outlining mechanisms for cost recovery and conflict resolution. The technical design process, informed by multidisciplinary expertise, translates these provisions into physical outcomes. When social-ecological principles are embedded throughout the LR process, outcomes include accessible green infrastructure, robust public services, equitable land distribution, and socially cohesive communities.

The integrative model not only defines the utility of LR in urban development but also establishes it as a critical tool for operationalising urban resilience at the neighbourhood level. The model serves as an analytical foundation for the empirical assessment of LR's contribution to SEUR in Kigali's Nunga project, as detailed in subsequent sections.

3. Materials and Methods

3.1. Research Design and Case Study Approach

This study employed a qualitative case study approach grounded in the social-ecological system (SES) perspective. The case study method was chosen for its ability to investigate complex, context-specific phenomena such as land readjustment and its integration with neighbourhood resilience. Specifically, we assessed the extent to which LR projects in Kigali incorporate principles of social-ecological urban resilience (SEUR), based on the social-ecological land readjustment model for resilient neighbourhoods developed for this research.

3.2. Case Study Justification

The selected case study is the Nunga LR project in Kigali, Rwanda. This choice was driven by several strategic and theoretical considerations aligned with the aims of the study.

First, Kigali, the capital and largest city in Rwanda, provides a highly relevant context for examining LR as a resilience-building mechanism in rapidly urbanising Sub-Saharan African cities. Rwanda's policy environment is uniquely conducive to innovative land management practices: the country has achieved full land registration through its national Land Tenure Regularisation Programme (LTRP), establishing clear property rights that

form a prerequisite for successful LR implementation. Furthermore, Rwanda's National Urbanisation Policy (2025) and the Kigali City Master Plan 2020–2050 explicitly promote sustainable urban expansion, compact development, and the use of LR as a tool for planned urbanisation. This regulatory foundation supports the empirical exploration of how LR can operationalise social–ecological urban resilience principles. The choice of Kigali was also influenced by the fact that LR application is more advanced in Kigali and the project's spatial data are more available and accessible compared to other cities that are still in the early stages of applying LR.

Second, the Nunga project represents a first-mover example of participatory land readjustment in Kigali. It was selected by the City of Kigali as a pilot project to demonstrate how fragmented, peri-urban agricultural land can be reconfigured into serviced, residential neighbourhoods. Its pilot status means the lessons learned can be used to scale up LR practices across Kigali and potentially in other Rwandan cities. Studying Nunga thus allows the research to capture insights at the intersection of policy experimentation, institutional learning, and community adaptation.

Third, Nunga offers a critical case for examining the practical challenges and opportunities of embedding SEUR principles into land readjustment. The project area faces typical peri-urban pressures, such as informal subdivisions, environmental vulnerability (e.g., slope instability, flooding), and socio-economic diversity, which test the applicability of resilience-based land management models. The case thus provides an ideal setting to assess how LR processes integrate (or fail to integrate) modularity, feedback sensitivity, diversity, and social cohesion—key attributes identified in the theoretical framework.

Fourth, the selection of Nunga is informed by pragmatic research considerations. As the most advanced LR project at the time of data collection, Nunga had relatively sufficient publicly available documentation, accessible planning data (e.g., zoning plan, plot redistribution plan, digital spatial data for easy analysis), and engaged local stakeholders willing to participate in interviews. This accessibility enabled a richer, multi-layered analysis linking planning intentions to on-the-ground outcomes.

In summary, the Nunga LR project embodies both theoretical relevance and empirical feasibility for this research. Its analysis offers important insights into how land readjustment can contribute to fostering resilient, sustainable, and inclusive neighbourhoods in the face of rapid urban change.

3.3. Policy Context and Benchmark Framework

Understanding the policy and regulatory framework environment is critical for evaluating the extent to which land readjustment can serve as a vehicle for fostering social–ecological urban resilience. In Rwanda, and in Kigali in particular, several key policy instruments directly influence land use, urban planning, resilience-building, and community participation—each providing an essential backdrop for this study.

First, the National Strategy for Climate Change and Low-Carbon Development (2022) [76] articulates Rwanda's ambition to build climate-resilient cities by promoting sustainable land management, green infrastructure, and inclusive urban development. This strategy emphasises adaptation, ecosystem restoration, and low-carbon growth, all of which are relevant for embedding resilience principles into LR projects.

Second, the National Urbanisation Policy (2025) [77] prioritises compact, connected, and inclusive urban development. It explicitly endorses land readjustment as a strategic tool for structuring orderly urban expansion while minimising environmental degradation and promoting equitable access to services. The policy envisions urbanisation as a driver of socio-economic transformation but warns against unplanned sprawl and infrastructure deficits—challenges that LR seeks to mitigate.

Third, the Kigali City Master Plan 2020–2050 [78] operationalises the national policy goals at the city scale. It provides detailed land-use designations, different guidelines, and urban design standards for different neighbourhood typologies. Importantly, it stresses the need for mixed-use development, high-density living, and affordable housing—all spatial principles closely aligned with SEUR attributes.

Fourth, the Participatory Land Readjustment Guidelines (2021), issued by the Rwanda Land Management and Use Authority (National Land Authority) [79], establish a procedural framework for implementing LR in a participatory and transparent manner. They specify steps such as stakeholder mapping, plot reallocation, infrastructure design standards, and dispute resolution mechanisms. These guidelines offer an opportunity to assess whether adaptive governance principles, such as inclusiveness, flexibility, and responsiveness, are integrated into practical LR implementation.

Based on these key documents and the theoretical insights from the social–ecological system (SES) approach, a benchmark framework was developed for this study. The benchmark functions as a diagnostic tool that integrates three essential dimensions:

- Land readjustment domain: Legal, social, technical, and financial components of LR processes (adapted from global LR best practices).
- Neighbourhood design standards: Derived from UN-Habitat and the Kigali City Master Plan, including compactness, connectivity, mixed-use diversity, social inclusion, and ecological integration.
- Social–ecological urban resilience attributes: Diversity, modularity, feedback sensitivity, social cohesion, and learning/adaptation, informed by SES and resilience planning literature.

The benchmark framework enables a structured evaluation of the Nunga LR project by posing key analytical questions, such as the following:

- To what extent are green and blue infrastructure incorporated into neighbourhood layouts?
- How are social equity and inclusion addressed during plot redistribution and reallocation?
- Are participatory mechanisms present, adaptive, and genuinely influencing outcomes?
- Is modularity or spatial flexibility designed into the layout to accommodate future shocks and stresses?

Each aspect of the benchmark is linked to specific measurable or observable indicators (Table 3). This integrative approach ensures that the evaluation systematically addresses the alignment between LR practice and SEUR principles, going beyond conventional planning metrics like plot count or cost recovery to assess broader sustainability and resilience outcomes.

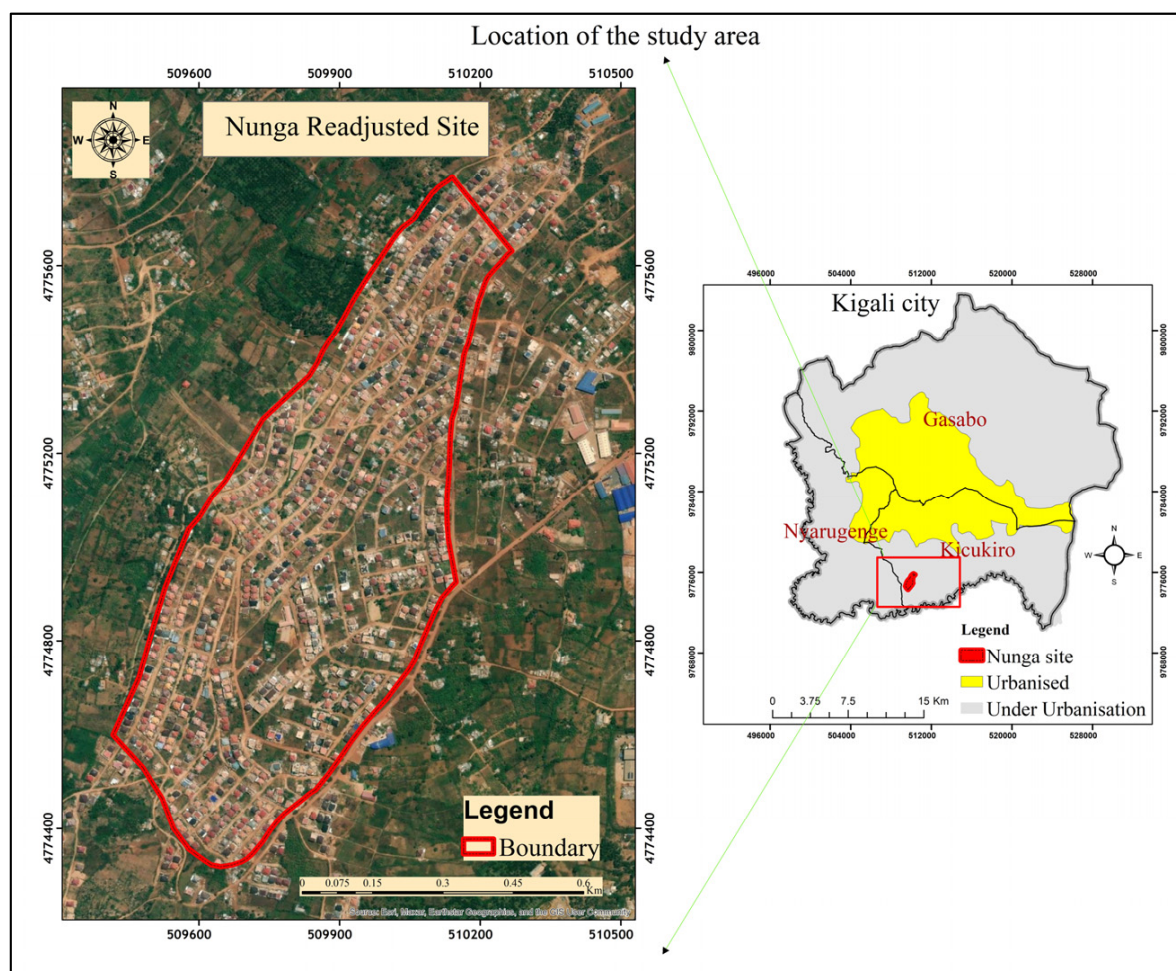
3.4. Study Area: The Nunga Land Readjustment Project

The Nunga Land Readjustment project (Figure 3), located in the Nunga Cell, Gahanga Sector of Kicukiro District, Kigali City, is the first LR pilot implemented in Rwanda, launched in 2014. This project was selected by the City of Kigali and the Ministry of Infrastructure as a demonstration of participatory land readjustment as a scalable and sustainable approach to managing urban growth and restructuring peri-urban areas.

The site encompasses approximately 62 hectares of formerly fragmented agricultural and semi-informal land. Prior to the project, the area exhibited typical peri-urban characteristics: irregular land subdivisions, inadequate infrastructure, environmental vulnerabilities, and absence of coherent public space allocation. Its selection reflects a strategic intention to transform underutilised urban fringe land into a planned, serviced residential neighbourhood aligned with Kigali's long-term urban development vision.

Table 3. Benchmark framework for evaluating resilience-oriented land readjustment.

LR Domain	Neighbourhood Design Principle	SEUR Attribute	Benchmark Indicators
Social	Social mix, inclusion	Social cohesion	-Diversity of plot allocation by income level -Stakeholder participation mechanisms -Gender and youth inclusion rates
Legal	Security of tenure	Adaptive governance	-Presence of legal frameworks for LR -Dispute resolution procedures -Institutional role clarity
Technical	Green/blue infrastructure Compactness Connectivity	Modularity and feedbacks	-Percentage of project area dedicated to public green/blue spaces -Street network density -Mixed-use zoning provisions
Financial	Affordability Cost sharing	Learning and innovation	-Cost-sharing formulas used -Budget allocation to green infrastructure -Financial sustainability provisions
Cross-cutting	Climate-sensitive planning	Diversity, adaptability	-Integration of climate risk assessments -Flexible land-use provisions -Nature-based solutions (NbSs) embedded in plans

**Figure 3.** Location of Nunga LR project.

The LR process involved approximately 400 original landowners (based on the number of land parcels before LR), and the project has resulted in the reconfiguration of plots into over 1170 serviced residential parcels, including space allocated for mixed land use, public amenities, and road infrastructure.

3.5. Data Sources and Collection

A robust and triangulated data collection strategy was essential to systematically assess the extent to which the Nunga Land Readjustment project integrates social–ecological urban resilience principles, as framed in the integrative land readjustment model for resilient neighbourhoods.

The study employed a combination of secondary and primary data sources, structured around the analytical dimensions of the social–ecological land readjustment model for resilient neighbourhoods: land readjustment domains (social, legal, technical, financial), neighbourhood planning standards, and SEUR attributes (diversity, modularity, feedback sensitivity, social cohesion, learning).

3.5.1. Secondary Data Collection

Secondary data formed the backbone for understanding the policy, planning, and spatial context of the Nunga LR project. These included the following:

- Urban planning and land policy documents that included key national- and city-level strategies, such as the Kigali City Master Plan 2020–2050, National Urbanisation Policy (2025), and Rwanda’s National Strategy for Climate Change and Low-Carbon Development (2022), were reviewed. Particular attention was given to how these policies frame LR, participatory planning, resilience, and green infrastructure integration.
- Technical project documentation that included planning reports, LR plans, plot reallocation maps, infrastructure layout drawings, and official project assessments (where available) provided insights into the design and operationalisation of the Nunga LR project.
- GIS spatial data: These included base maps, zoning maps, and parcel shapefiles obtained from the National Land Authority, the City of Kigali’s One-Stop Centre, and Kicukiro District. These datasets were essential for conducting spatial analysis of land-use changes, green space allocation, and street network configurations.
- Google Earth satellite imagery: This is an image that was obtained from the online application and was used to visualise land-use patterns and physical changes pre- and post-LR intervention.

3.5.2. Primary Data Collection

Primary data were collected to supplement and validate secondary data sources and to gain in-depth understanding of the governance and social dynamics of the LR process. These included the following:

- Key informant interviews: Semi-structured interviews were conducted with planners, project managers, local government officials, and the coordinator of the Nunga LR implementation committee. Interview questions were designed around the core domains of the framework, focusing on topics such as participatory practices, dispute resolution, integration of green infrastructure, social inclusivity, and learning mechanisms during project implementation.
- Focus group discussions: Two group discussions were conducted in two sessions that involved various stakeholders. The first session was held with members of the project implementing community while the second one brought together officials of Kicukiro District land management unit. The discussions focused on the planning and

reallocation phases to assess the quality and inclusiveness of participatory processes. Recordings were made and transcribed later for analysis.

- Field visits and visual documentation: Site visits were conducted to observe physical infrastructure, public spaces, and ecological features (e.g., drainage channels, preserved green spaces), and to document physical outcomes through photography and field notes. Observations focused on the materialisation of planning standards and the visible presence of SEUR elements.

3.6. Data Triangulation

Triangulation across multiple sources—official documentation, interviews, spatial data, and direct observations—were used to cross-verify findings and enhance the validity of interpretations. Particular emphasis was placed on identifying consistencies and discrepancies between planning intentions (as expressed in policy and project plans) and implementation outcomes (as observed on the ground).

In sum, the multi-source, multi-method data collection strategy was purposefully designed to comprehensively evaluate the Nunga LR project through the lenses of social, legal, technical, and financial resilience integration, as structured in the benchmark framework. This approach also allowed for capturing both the procedural and substantive dimensions of resilience-building through land readjustment.

3.7. Data Analysis

The data analysis process was structured around the integrative land readjustment model, ensuring alignment with the study's conceptual and theoretical underpinnings. The objective was to evaluate the extent to which the Nunga LR project integrated the key domains of land readjustment, neighbourhood planning standards, and social–ecological resilience principles.

A mixed qualitative–quantitative approach was adopted, combining content analysis, spatial analysis, and triangulated evaluation using the developed benchmark tool (Table 3).

3.7.1. Content Analysis

A systematic qualitative content analysis was conducted on planning documents, project reports, legal guidelines, policy frameworks, interview transcripts, and focus group discussion records.

Thematic coding was based on a deductive–inductive strategy. Themes were predefined according to the framework categories (social, legal, technical, and financial domains; SEUR attributes; and neighbourhood standards). Inductive themes emerged from the data themselves, such as challenges in financing mechanisms for green infrastructure or informal negotiation practices.

Coding was carried out manually by clustering themes and cross-referencing between textual sources. Special attention was given to identifying instances where policy intentions translated (or failed to translate) into implementation realities.

3.7.2. Spatial Analysis

Geospatial data (e.g., parcel layouts, road networks, zoning layers) were analysed using ArcGIS 10.2 software. Spatial analysis focused on assessing land-use distribution by evaluating the proportion of land allocated to residential plots, mixed uses, green infrastructure, and public amenities. It also focused on green/blue infrastructure integration by mapping the presence, continuity, and connectivity of natural spaces. Furthermore, street network density and connectivity were analysed by measuring street network efficiency to assess urban form compactness and accessibility. Finally, spatial analysis

was carried out to assess the range and distribution of plot sizes to infer social mix and affordability outcomes.

Spatial indicators were quantitatively compared against planning standards outlined in the Kigali City Master Plan and resilience-oriented urban design benchmarks.

Due to limitations in the availability of required digital datasets, we were unable to employ system dynamics modelling software like Vensim 10.3.0 to simulate feedback loops or dynamic interactions. Data limitations also affected the comprehensiveness of the analysis regarding certain aspects of land readjustment and social–ecological resilience. Consequently, this study relies on available secondary data to examine the initiation, legal instruments, and implementation processes of the Nunga LR project.

4. Results

This section presents the findings from the review of Rwanda’s urban planning documents and the case study evaluation of the Nunga LR project in Kigali. Results are organised according to the benchmark framework (Table 3), combining analysis of Rwanda’s model, neighbourhood planning standards, and social–ecological resilience factors.

4.1. Land Readjustment Model in Rwanda

Land readjustment in Rwanda has evolved as a strategic tool to guide urban transformation and manage the challenges of rapid urbanisation. It was formally adopted following the development of the Kigali City Master Plan 2020–2050 and supported by the Land Readjustment Guidelines (2021) issued by the National Land Authority (formerly the Rwanda Land Management and Use Authority). A review of key policy documents reveals that Rwanda’s LR model is designed to achieve three interlinked objectives:

1. Implementation of the master plan to facilitate the reorganisation of fragmented peri-urban and agricultural land into planned urban neighbourhoods, enabling the operationalisation of zoning and density targets set forth in the master plan.
2. Provision of cost-efficient infrastructure by requiring landowners to contribute land for roads and public services and cash for street construction. LR reduces the financial burden on the public sector while ensuring basic urban infrastructure development.
3. Increase urban land supply and formalisation through the increased availability of titled, serviced residential plots, thus absorbing urban population growth and supporting the government’s vision of orderly urbanisation.

The procedural model of LR in Rwanda, summarised in Figure 4, emphasises a community-led and participatory approach. A project can proceed only when at least 90% of landowners consent to participate. Once approved, a landowner committee is elected to oversee implementation, working with private consultants and government authorities. The process requires the following:

1. Landowner mobilisation and sensitisation.
2. Consent agreement documentation.
3. Preparation of the LR plan by technical experts.
4. Plot reallocation and infrastructure design.
5. Infrastructure construction (typically street network).
6. Handover of serviced plots to landowners.

However, analysis of the guidelines and policy texts reveals several critical gaps when assessed through the integrative land readjustment model for resilient neighbourhoods. The first gap is the narrow definition of public space. The LR model in Rwanda narrowly defines public spaces as roads, small community halls, and playgrounds, without embedding green infrastructure (like parks, buffers, and storm water management systems) as essential

resilience elements. Secondly, despite Rwanda’s broader national climate strategies, LR processes lack explicit requirements to address climate resilience risks such as flooding, urban heat, or ecosystem loss. Thirdly, although community participation is required at the outset, there is no institutionalised feedback loop post-implementation for adaptive learning, evaluation, or adjustment based on outcomes.

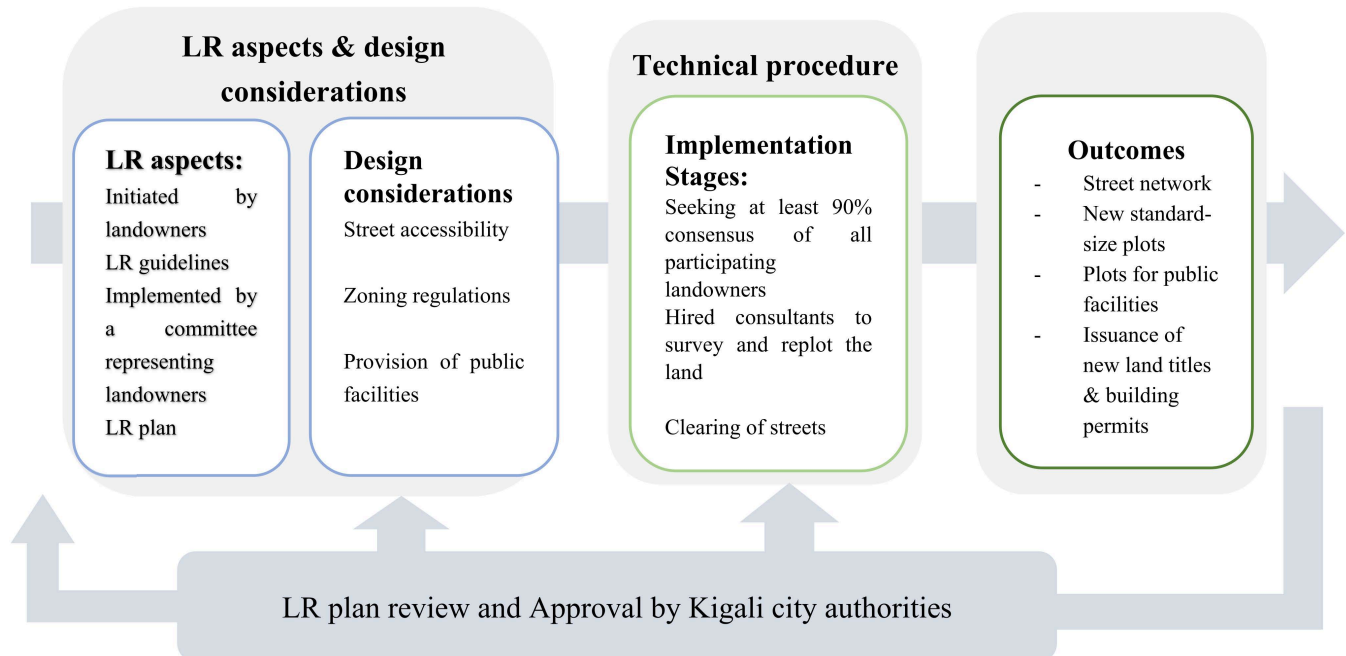


Figure 4. Land readjustment model in Rwanda. Source: Authors.

Thus, while Rwanda’s LR model creates a strong procedural foundation for participatory urban land management, it exhibits structural weaknesses in embedding resilience principles. Specifically, ecological modularity, system feedback sensitivity, and spatial adaptability—critical social–ecological resilience attributes—are insufficiently institutionalised within the LR process.

These limitations have direct implications for the implementation and sustainability of land readjustment projects, as seen in the empirical evaluation of the Nunga case study.

4.2. Evaluation of Neighbourhood Planning Standards in the Nunga LR Project

This sub-section evaluates the extent to which the Nunga LR project adhered to the neighbourhood planning standards outlined in the Kigali City Master Plan 2020–2050 and embedded key attributes of social–ecological urban resilience (SEUR). Analysis focused on land-use diversity, spatial organisation, green infrastructure, public space provision, and access to basic services.

Table 4 summarises the key planning benchmarks compared to the observed outcomes after implementation.

4.2.1. Infrastructure and Accessibility

The project achieved significant improvements in basic accessibility. A formal street network was laid out according to local national planning standards, enhancing block connectivity and access to individual plots. Electricity and water services were extended to most plots, addressing a major gap prevalent in informal settlements. However, critical deficits were identified. Drainage infrastructure was absent, making streets vulnerable to erosion and undermining long-term infrastructure resilience. In addition, street construc-

tion quality was inconsistent as roads remained unfinished, undermining the modularity and redundancy required for resilient mobility networks.

Table 4. Neighbourhood design standards vis a vis the LR plan and the outcome.

Neighbourhood Design Benchmark (Kigali City Master Plan 2020–2050)	Nunga LR Plan	Outcome on Site After LR
Appropriate roads, drainage system, water supply and electricity	All included in the plan	Roads are demarcated and cleared but not well constructed; there is no drainage system; water and electricity have been supplied
Community halls and playgrounds	None were planned	None were found on the site
Standard residential plot size (300 m ²)	The readjustment plan was based on this requirement	The standard plot size was respected to a large extent
One commercial facility (1.2 hectares) per neighbourhood	Thirty-one scattered parcels with sizes ranging from 140 m ² to 574 m ² ; the total surface area of parcels zoned for commercial is 0.87 hectares	Less than half have been developed while other parcels are still undeveloped
One educational facility (1.5 hectares) per neighbourhood One secondary school (2.4 hectares) per neighbourhood One combined primary and secondary school (2.8 hectare site) per neighbourhood	Five parcels of land zoned for schools, with surface areas ranging from 2803 m ² to 15,709 m ² ; the total area of parcels zoned for schools is 48,677 m ² (4.86 hectares)	One plot has been developed into a kindergarten; other plots have re-subdivided into residential plots
One community hall (0.5 hectare site) per neighbourhood	None was planned	None exists on the site
One religious facility (0.5 hectares) per neighbourhood	None was planned	None has been developed
One health facility (0.5 hectare site) per neighbourhood	None was planned	One private clinic has been developed on one of the parcels zoned as commercial
Green space to be 15 m ² per capita	Sixteen parcels with a total area of 9504 m ² (0.95 hectares) zoned for green spaces	Largely inaccessible; some are still used for farming

These shortcomings suggest that while technical planning standards were nominally addressed, practical implementation fell short of resilience-oriented neighbourhood design principles.

4.2.2. Public Facilities and Mixed Land Use

In line with the Kigali City Master Plan, the Nunga LR plan (Figure 5) envisioned a multifunctional neighbourhood combining residential, commercial, educational, and social facilities. However, on-the-ground outcomes reveal dominance of residential land use. Planned commercial and educational facilities were either delayed, vacant, or informally repurposed into residential plots. Absence of designated land for religious, health, and recreational facilities weakens the functionality and diversity of the neighbourhood. This erosion of mixed land use compromises the neighbourhood's self-sufficiency and functional diversity, which are key social–ecological attributes necessary for adaptive urban systems.

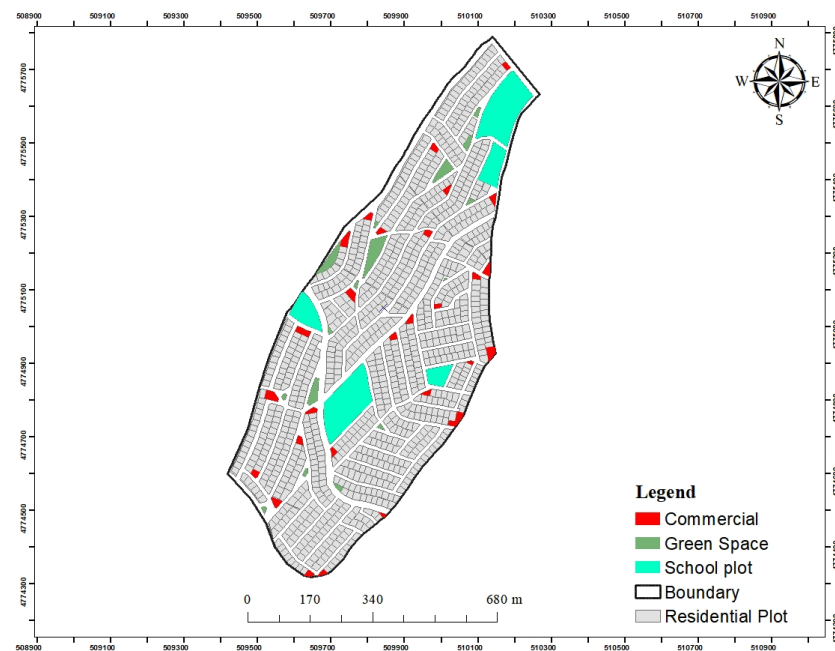


Figure 5. Approved Nunga LR plan.

Concerning social mix, 303 out of 1115 residential plots (27%) were planned for low-cost housing. This ratio is between 20% and 50% of the UN-Habitat standard [46]. In addition, there were no mechanisms to ensure that the low-cost plots were affordable to low-income households and prevent others with higher incomes from acquiring them. The owners of plots in the zone planned for low-cost housing had the right to sell to the highest bidder. Low cost was in the sense that owners were allowed to use low-cost building materials that would not be allowed in other zones. The sale of serviced plots to non-low-income buyers affected the inclusion principle as the poor households could not access the neighbourhood. Furthermore, land-use specialisation is high as most blocks accommodate mainly single-family residential units.

4.2.3. Residential Densification and Plot Design

The project successfully achieved standardised plot sizes (mostly 300 m²), facilitating orderly urban development. However, densification remained primarily horizontal, with minimal vertical building forms observed. The homogeneity of plot sizes and housing typologies limits adaptability to changing demographic or economic needs. Lack of spatial modularity and vertical densification opportunities reduces the neighbourhood's flexibility to sustainably absorb population growth or economic shifts.

4.3. Social–Ecological Urban Resilience in the Nunga LR Project

This sub-section evaluates how well the Nunga LR project operationalised key principles of social–ecological urban resilience based on the framework developed in this study. The assessment focuses on three critical social–ecological resilience dimensions, which include community organisation and social networks, land-use diversity and system modularity, and equitable cost and benefit distribution.

4.3.1. Landowners' Participation and Social Networks

The Nunga LR process displayed strong community mobilisation and participatory governance features, distinguishing it from many conventional top-down urban interventions. Landowners formed self-organised committees and informal WhatsApp groups to coordinate information sharing, decision-making, and collective bargaining with the

City of Kigali and technical consultants. Although constrained by procedural and regulatory limitations, landowners actively engaged in key LR phases including plan approval, plot reallocation negotiations, and infrastructure prioritisation. Informal platforms facilitated early conflict resolution over land contributions, plot sizes, and financial obligations, strengthening social cohesion and mutual trust.

These social dynamics represent critical assets for building adaptive governance capacity. Moreover, the persistence of these social networks beyond the project's completion suggests that the local community in Nunga has developed latent capacities for future collective action, innovation, and learning—essential for long-term neighbourhood resilience. However, these informal governance structures remain fragile in the absence of formal institutional support, leaving them vulnerable to erosion over time without strategic reinforcement by municipal authorities.

4.3.2. Limited Land-Use Diversity and Self-Sufficiency

Land-use diversity and spatial modularity are key determinants of a neighbourhood's ability to adapt to demographic, economic, and environmental changes. In Nunga, the initial LR plan proposed a functional mixture of residential, commercial, educational, and recreational land uses. However, the on-site observations reveal that residential plots overwhelmingly dominate the land-use structure. Some educational plots were informally converted to residential use (Figure 6).



Figure 6. Overlay of Nunga LR plan and the actual subdivisions as of 2021.

The resulting urban fabric exhibits low functional diversity and limited spatial modularity. Lack of mixed uses compels residents to travel to distant neighbourhoods for basic services such as shopping, education, and healthcare, increasing vulnerability to systemic shocks. Homogeneous plot sizes and monofunctional zoning restrict the neighbourhood's ability to flexibly adapt to population growth, ageing demographics, or changing economic patterns.

Thus, although land-use diversity was conceptually planned, weak regulatory enforcement, financial constraints, and limited resilience-focused planning standards contributed

to the erosion of modularity and adaptability in practice. For instance, designating sufficient spaces for recreation, education, and green infrastructure has implications on land contribution by landowners or the need for budget allocation by municipal government. This is a major challenge for implementing the proposed model in the contexts of developing countries, characterised by speculative land markets and limited local government budgets. LR has the potential to minimise the costs through land and cash contributions, but these may not meet all project costs and public space needs.

4.3.3. Equitable Sharing of Costs and Benefits

Social–ecological resilience requires equitable distribution of costs and benefits to sustain social cohesion and trust. All landowners contributed a portion of land for the public good (roads and public spaces), but the proportionality of contributions varied, creating perceptions of unfairness among some participants. In addition, although a cash contribution model was introduced to fund street construction and project management, enforcement was uneven. Wealthier landowners were more likely to fulfil their obligations, while lower-income participants struggled to comply, leading to delays and tensions. Regarding plot redistribution, market dynamics post-project saw low-cost plots increasingly purchased by middle-to-high-income buyers, undermining initial affordability goals.

The outcomes reflect partial success in achieving cost–benefit equity. The participatory mechanisms built early project legitimacy, but inconsistencies in land and financial burden-sharing risk long-term social fractures. Without post-project safeguards (e.g., resale restrictions or other affordability protection strategies), market dynamics can quickly erode the social diversity and inclusivity initially envisioned.

In resilience terms, while the Nunga LR process enhanced short-term social cohesion, its long-term ability to sustain equitable, inclusive urban development remains uncertain without stronger regulatory and governance interventions.

5. Discussion

5.1. Integration of Land Readjustment and Neighbourhood Planning Principles

Rapidly growing cities face multiple challenges, including fragmented urban expansion, lack of infrastructure, informal settlements, and socio-spatial inequalities. A key driver behind these issues is the reliance on urban development models that produce inefficient land-use patterns, undermining the resilience and well-being of urban dwellers [46]. As advocated by UN-Habitat, neighbourhood development offers a structured model to enhance liveability, sustainability, and land value. However, its practical application often requires substantial investment in street networks, public facilities, and recreational spaces—resources that many municipalities in developing countries lack.

Land readjustment (LR) has emerged globally as an innovative mechanism to address this gap, enabling self-financed urban servicing. However, the integration of LR with neighbourhood planning standards remains limited. In Rwanda, LR practice focuses predominantly on plot reconfiguration and basic accessibility without systematically incorporating neighbourhood-scale design standards such as mixed land use, vertical densification, or the provision of public spaces. This study's analysis of the Nunga LR project highlights these gaps: although the project achieved improved plot standardisation and accessibility, it failed to deliver integrated, compact, and multifunctional neighbourhood.

The lack of high-density, mixed-use planning, especially vertical development such as apartments, reflects both legal limitations and cultural preferences. However, given Rwanda's acute land scarcity and urbanisation pressures, densification and land-use diversity must become central strategies for sustainable urban development. The findings align with broader urban resilience literature, which emphasises the need for compact,

adaptive neighbourhoods to combat sprawl, ecological degradation, and infrastructure deficits [80,81].

5.2. *Fostering Neighbourhood Social–Ecological Resilience Through Land Readjustment*

Historically, LR studies have prioritised legal, financial, and administrative dimensions, with less emphasis on environmental and resilience aspects. This study addresses this gap by proposing a land readjustment model that integrates social–ecological resilience principles into LR design and implementation.

Results from the Nunga project demonstrate that participatory procedures, community-driven financial contributions, and collective organisation strengthened social cohesion, feedback sensitivity, and learning capacities—all critical for resilience [33]. Community mobilisation and procedural inclusiveness built social capital, positioning the neighbourhood for adaptive capacity in the face of future challenges, including climate change.

However, limited land-use diversity, inadequate green infrastructure, and minimal ecological integration critically weakened environmental resilience. As found in previous studies, green spaces—or broader green and blue infrastructure (GBI)—play a fundamental role in urban climate adaptation and mitigation [82,83]. For example, Marando et al. (2022) [82] demonstrated that urban green infrastructure can reduce urban temperatures by over 1 °C, with cooling effects scaling to 2.9 °C where tree cover exceeds 16%. These findings reinforce the urgent need for Rwanda’s LR models to establish per capita green space standards and integrate nature-based solutions directly into neighbourhood planning.

Thus, fostering neighbourhood resilience through LR requires moving beyond procedural participation to embed ecological multifunctionality, land-use modularity, and continuous institutional learning into the urban fabric.

5.3. *Contributions, Limitations, and Areas for Future Research*

This study contributes conceptually and practically to land management, urban sustainability, and resilience planning, particularly within the context of Sub-Saharan Africa. By applying a social–ecological system (SES) lens to land readjustment (LR), it offers a novel framework that bridges urban planning, neighbourhood design, and resilience thinking.

5.3.1. *Theoretical Contributions*

First, the study advances SES theory in urban land readjustment by conceptualising LR as a tool capable of enhancing sustainability and resilience at the neighbourhood scale. It identifies the potential of LR not only as a land management instrument but also as a means to integrate ecological and social considerations into urban redevelopment processes.

Second, the paper introduces an integrative conceptual model that links LR aspects—social, legal, technical, and financial—with neighbourhood design principles and social–ecological resilience attributes. This framework extends the current discourse on LR by incorporating resilience indicators into the assessment of LR outcomes.

5.3.2. *Practical and Policy Contributions*

From a policy perspective, the study provides actionable recommendations for aligning LR practices in Kigali with sustainability and resilience goals. It highlights the importance of strengthening the legal and institutional framework for LR, particularly the need for statutory guidance on public amenities, green infrastructure, and social equity considerations.

Moreover, the study underscores the value of community participation and the role of local knowledge in shaping successful and inclusive LR outcomes. These findings can inform the design of participatory planning processes and capacity-building strategies for planners, local authorities, and communities.

5.3.3. Limitations and Challenges

Despite its contributions, the study has several limitations. A critical limitation observed in the Nunga LR project—and more broadly in Rwanda's LR model—is the absence of dedicated funding for green infrastructure. Although green spaces and ecological buffers are essential components of resilient urban neighbourhoods, they remain marginal in LR planning and implementation due to limited financial resources. In the Nunga case, landowner cash contributions were prioritised for roads, with minimal green corridors or storm water system provisions. This reflects a broader institutional bias toward hard infrastructure, driven by budget constraints and the absence of earmarked funds for climate-responsive urban design. Without targeted financing mechanisms, such as resilience bonds, urban green funds, or climate adaptation grants, green infrastructure is likely to remain underfunded or excluded from LR projects. This underinvestment undermines LR's ecological and public health benefits and limits its capacity to deliver on the full promise of neighbourhood-scale social–ecological resilience. To overcome this barrier, future LR models must embed green infrastructure as a mandatory, funded component of planning, supported by enabling financial frameworks at national and municipal levels.

The absence of a specific LR law and the lack of explicit sustainability mandates in Rwanda's urban legislation constrain effective implementation. Additionally, while SES theory provides a valuable integrative lens, institutional fragmentation and resource constraints challenge its full operationalisation in practice.

Methodologically, this study focused on a single case study (Nunga), limiting generalisability. LR models vary across contexts and are influenced by land tenure patterns, governance capacities, and socio-cultural factors. Thus, while the proposed model is robust, it must be adapted flexibly to different settings.

5.3.4. Future Research

Future research should adopt a comparative case study approach across different cities or LR models in Sub-Saharan Africa to better understand context-specific dynamics and transferable lessons. Quantitative methods, including spatial metrics and dynamic modelling tools like Vensim, could also be employed to simulate feedback loops and assess system behaviours under different scenarios.

Further inquiry is also needed to evaluate the long-term impacts of LR projects on urban resilience at both neighbourhood and city scales. This includes exploring how multiple LR interventions can be integrated into broader urban systems to support adaptive governance, environmental justice, and equitable service provision.

6. Conclusions

This study evaluated the potential of land readjustment (LR) as a strategic tool for fostering neighbourhood-scale social–ecological urban resilience (SEUR) in rapidly urbanising Sub-Saharan African cities, using the Nunga LR project in Kigali, Rwanda, as a case study. Grounded in the social–ecological system (SES) approach and operationalised through the resilient land readjustment model, the research contributes both theoretically and empirically to the evolving discourse on sustainable urban transformation.

Findings from the Nunga case study reveal that LR can indeed serve as a platform for building social capital, participatory governance, and spatial formalisation—key pre-conditions for adaptive, resilient urban neighbourhoods. Strong collective action among landowners and establishing self-organised governance structures are notable successes that align with core SEUR attributes such as social cohesion and adaptive capacity.

However, the results also demonstrate significant gaps between planning aspirations and implementation outcomes. Critical resilience elements, such as green infrastructure,

spatial modularity, land-use diversity, and feedback-sensitive governance, were either weakly integrated or absent. Consequently, the Nunga LR project only partially operationalised the systematic integration of resilience principles. This partial success reflects broader structural tensions in urban planning across Sub-Saharan Africa, namely the challenge of translating progressive policies into ecologically and socially robust on-the-ground transformations amid rapid demographic growth, land market pressures, and institutional limitations.

In this sense, the study reinforces the insight that procedural participation, while necessary, is not sufficient. Achieving resilient urban futures requires deliberate integration of ecological, spatial, institutional, and equity-focused strategies into land governance mechanisms.

Practically, the research suggests that Rwanda's LR model, and by extension similar initiatives across the region, must evolve to mandate green/blue infrastructure (nature-based solutions) integration in LR projects, establish dedicated innovative financing mechanisms such as resilience bonds or urban green funds, institutionalise continuous learning and adaptive feedback mechanisms, strengthen safeguards for affordability and inclusivity post-implementation, and promote multifunctional, modular urban layouts to enhance resilience against future shocks and stresses.

The study theoretically advances the literature by offering an empirically tested, resilience-oriented land management framework tailored to the realities of rapidly urbanising African cities. The social–ecological land readjustment model for resilient neighbourhoods provides a transferable but context-sensitive tool for embedding SEUR principles into LR practices, offering pathways for more sustainable and equitable urban futures.

Future research should adopt comparative and longitudinal approaches to capture the dynamic impacts of LR projects across diverse urban contexts. Further application of system dynamics modelling and participatory methods can enrich our understanding of the feedback loops and trade-offs inherent in LR-resilience interactions. Additionally, deeper exploration of post-project adaptation and affordability can help refine LR strategies for long-term urban equity.

In sum, land readjustment holds considerable promise for shaping inclusive, adaptive, and sustainable cities in Sub-Saharan Africa. Realising this potential, however, requires a shift toward a more systemic and resilience-driven approach that fully embraces cities' complexity and dynamism as social–ecological systems.

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