



Article

Morphological Characteristics of Informal Settlements and Strategic Suggestions for Urban Sustainable Development in Tanzania: Dar es Salaam, Mwanza, and Kigoma

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Abstract: Rapid urbanization in developing countries has been accompanied by the spread of informal settlements, which is particularly prominent in sub-Saharan Africa. These settlements have become an important supplement to the inadequate formal housing supply in cities, and their spontaneously formed spatial patterns have important influences on sustainable development. In this study, qualitative and quantitative approaches were used to examine the morphological characteristics of informal settlements in Tanzania and the associated influences on urban development. Geographic spatial analyses, landscape pattern indices, and mathematical statistics, along with quick assessments, group discussions, and key informant interviews, were used to obtain detailed information on the spatial forms of informal settlements. The results indicate that the form of the settlements does not conform to the social, economic, or environmental characteristics of sustainable development. The disordered expansion of single-layered buildings with a single function, irregular road networks in poor condition, and a lack of consideration and protection of the ecological environment were found to negatively impact urban function and sustainable development. However, the structure and form of informal settlements could, in addition to formalization projects, be optimized to drive sustainable and socioeconomic development goals as well as environmental conservation.

Keywords: spatial form; informal settlements; socioeconomic development; environmental conservation; sustainable development; Tanzania

1. Introduction

Given rapid urbanization, traditional formal urban sectors in developing countries cannot meet the needs of growing urban populations, and the coexistence of formal and informal sectors has become a major paradigm of urban development [1]. Informal settlements have become an important component of the urban housing sectors of developing countries. ‘Informal settlement’ refers to a residential area that lacks basic services and infrastructure, where the housing stock may not comply

with current planning and building regulations and where inhabitants may have no security of tenure [2]. Specific and strategic interventions must urgently be developed for informal settlements to upscale the sustainable access and use of basic facilities [3]. Informal settlements are a result of many factors, which include the political economy, uncoordinated planning, invasion of land by land barons, and inappropriate planning ideologies [4]. They form spontaneously in the absence of planning; their rampant development can lead to the disorderly spread of cities and they are usually characterized by inefficient land use, environmental degradation, poor living conditions, unstable employment, and conflict over land use [5–7].

More than half (61.7%) of urban residents live in informal settlements in Africa [8]. The urban population in Africa is forecast to increase from 400 million in 2010 to 1.2 billion by 2050, with significant increases in the number and population of informal settlements [9]. How to effectively guide informal settlements into a sustainable development process has become a focus of governments and academia. Although conflicts have arisen between what are understood as modernist ideas of how cities should formally appear and a flexible mode of informal development [10], the ambivalence of government policy toward informal settlements has gradually shifted into a more positive approach [11]. Many African governments are becoming increasingly aware of the potentially positive contributions of informal settlements, and plans have gradually shifted from the forced removal and relocation model to the securing tenure model [12]. Land use planning plays a supporting role that enables the property formalization process to be effective [13], and empowering local government with planning competency is an important method to remove the barriers to planning transformation [14]. Informal settlements have been widely studied within political, sociological, and economic frameworks, yet the specifics of form are generally seen as contextual or irrelevant, even though their physical morphology may be closely integrated with social networks, domestic economics, and employment [15]. Accurate, localized, and standardized qualitative and quantitative data on the environmental, physical–spatial, and socioeconomic development characteristics of informal settlements are limited [16] but are critical for dealing with their problems [15,17].

Scholars are now focusing on the spatial forms of informal settlements as key to understanding this sector and developing appropriate management methods [18–21]. The development of remote sensing (RS) and geographic information system (GIS) technologies has assisted in this quest, and a growing number of studies are using high-resolution RS images [22–24]. Researchers have adopted different methods such as object-oriented extraction, space syntax, and spatial metrics, to extract and monitor spatial information for informal settlements and analyze their morphological characteristics [25–28]. Community-based mapping of the informal settlements has been proven useful for locally-based sustainability planning [29], and urban design could play an important role in addressing the complex challenges faced by informal settlements [30]. Studies showed that informal economic activities in downtown areas have multifaceted contributions to the spatial, social, economic, and environmental aspects of the areas, which is in line with the sustainable livelihood theory [31], but have an adverse effect on the quality of the built environment in residential areas with regard to aesthetic disorder, street trading, traffic jams, visual obstructions, indiscriminate disposal of waste, and land use conversion [32]. These findings are providing useful information for the recognition of informal settlements and the development of poverty elimination, settlement upgrading, and sprawl suppression strategies [33–36]. Informal settlements occur in both developed and developing cities and are associated with socio-economic, environmental, and administrative factors [37]. Most studies focused on morphological descriptions of informal settlements in a single city [38–40]; data regarding the relationship between morphological characteristics and specific socioeconomic functions have not yet been reported. We lack understanding of the impact of informal settlement morphological characteristics on urban development [41]. Comparative studies, combining morphological and functional perspectives, may provide a novel angle to better understand this relationship. Comparative urban studies are a widespread applied research approach across various disciplines that could be used for testing hypotheses against reality and contribute to an inductive discovery of new hypotheses and

theory-building [42]. However, such studies are challenged by the need to develop far reaching, useful, and accurate descriptions when applied to other contexts [43]. Although enlightening, the results from these studies may not be applicable everywhere; specific local context must be considered.

Tanzania has one of the highest proportions of urban population living in informal settlements in sub-Saharan Africa, at 50–80% [44]. The growth of informal settlements is an important form of urban expansion in most Tanzanian cities. Presently, many studies only focused on the growth and modeling of the informal settlements in Dar es Salaam [45–47], with most attention centered on social and economic development problems, regularization approaches, and the impacts of informal settlements [48,49]. Studies on informal settlement morphological characteristics in different cities and their influence on urban sustainable development are lacking, despite Tanzania’s secondary and tertiary cities absorbing increasing numbers of urban residents [50,51]. We selected the informal settlements of three cities in Tanzania in different development stages as case studies to analyze the morphological characteristics of informal settlements and their impact on urban sustainable development goals. The results provide useful structural data for the development of informal settlement renovation programs and offer a useful reference for urban planners, managers, and policymakers at regional and national levels.

2. Methodology

The main steps of the study were as follows: (1) Case area selection, (2) morphological analysis of the informal settlements, (3) functional development analysis of the informal settlements, and (4) evaluation of the influence of the informal settlements on sustainable development. The various input data sets used, methods, results, and the logical dependencies between them are detailed in Figure 1. Mean shape index (MSI), Shannon’s diversity index (SDI), Shannon’s evenness index (SEI), and the mean Euclidean nearest-neighbor (ENN) distance were used as indicators of building form [52,53]. Graph-theory-based concepts were used by employing α , β , and γ indices to determine the road network’s circuitry, complexity, and connectivity [54].

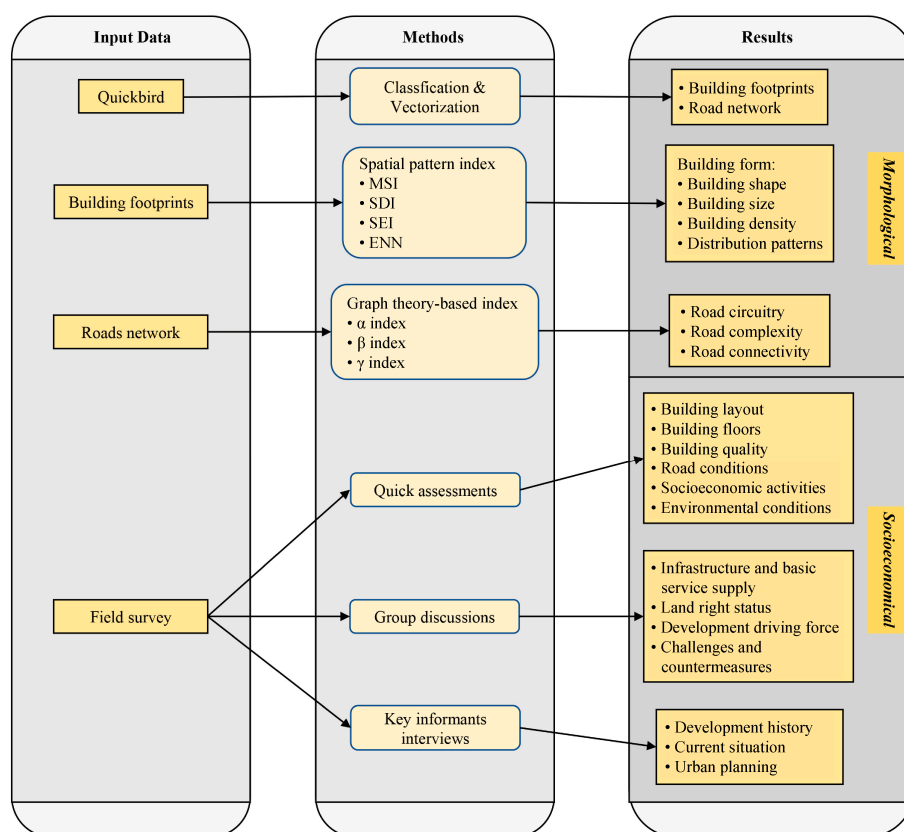


Figure 1. The workflow of the study, showing the input data, methods and results.

2.1. Tanzania's Informal Settlements

Tanzania's informal settlements have their own unique characteristics in terms of tenure security, structural quality of housing, and inhabitants [50,55]. First, anyone who erects a structure in the informal settlement has a perceived security of tenure emanating from three generations. Second, the use of modern building materials has increased tremendously since the early 1990s. Third, informal settlements in Tanzania consist of a wide range of socioeconomic groups [56].

2.2. Case Area Selection and Description

With a shortage of planned development areas, between 40% and 80% of all built up areas are informal in Tanzania [57,58], and most urban households in all major cities are in informal settlements [59]. Based on the development stage, population growth rate, availability of relevant data, and feasibility of field investigation, we selected Dar es Salaam, Mwanza, and Kigoma as case areas (Figure 2). Dar es Salaam has long been Tanzania's primary city, with the highest population growth in East African cities in recent years [9], but the city is simultaneously facing serious problems of informal settlement expansion. Mwanza is the second largest city in Tanzania with over 700,000 urban inhabitants in 2012 and a fast-growing population [60]. Mwanza is being challenged by a series of problems related to informal settlements expansion. Kigoma is a major town and transportation hub in Western Tanzania that has been experiencing rapid development in recent years and was selected as the representative of Tanzania's emerging small- and medium-sized cities. The development of informal settlements is causing problems to varying degrees in the three cities. Three case informal settlements were selected in each city based on the criteria that they (1) have shown notable expansion since 2000. Previous studies on urban expansion in Tanzania and Google Earth images (Google Inc., Mountain View, CA, USA) were used for this purpose; (2) should have a rapidly growing population in recent years, thus reflecting rapid urbanization in terms of population growth; and (3) should be representative in terms of urban development and morphological changes. The settlements were recommended by local experts and scholars. The three selected informal settlements were Chamazi (Dar es Salaam), Buhongwa (Mwanza), and Gungu (Kigoma).



Figure 2. Location map of Dar es Salaam, Mwanza, and Kigoma in Tanzania.

2.2.1. Chamazi

Chamazi belongs to the Temeke municipality in Dar es Salaam, with an area of 27 km² and an estimated 74,000 inhabitants in 2016. Due to its size, only part of it was selected as the research area. The population data were obtained from the ward executive officer of Chamazi. Two sub-wards, Mkondogwa and Vigoa, were selected to compare socioeconomic development differences in areas with differing building densities (Figure 3).

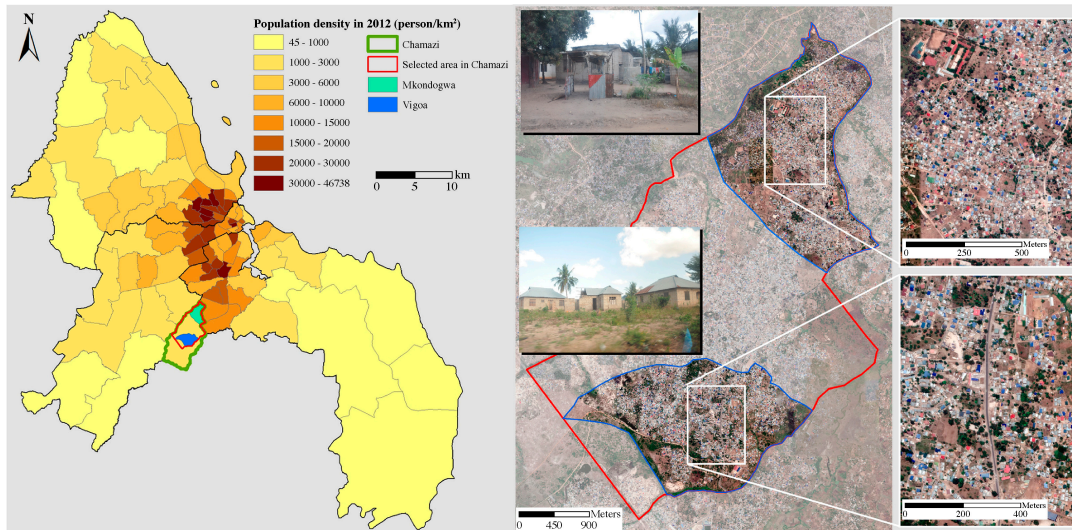


Figure 3. Location of Chamazi ward and Mkondogwa and Vigoa sub-wards in Dar es Salaam.

2.2.2. Buhongwa

Buhongwa is located in Nyamagana municipality, Mwanza. It has an area of 45 km² and an estimated 37,000 inhabitants based on 2016 data. The population data were obtained from the ward executive officer of Buhongwa. Due to its large size, part of the settlement was selected as the research area. With an average annual population growth rate of 8.3%, it is the fastest growing ward in Mwanza. Shibayi and Mitimilefu sub-wards, which have different building densities, were selected for study (Figure 4). According to the actual situation of the investigation, the Shibayi sub-ward was outside of the area we selected, but this should have no influence on our analysis.

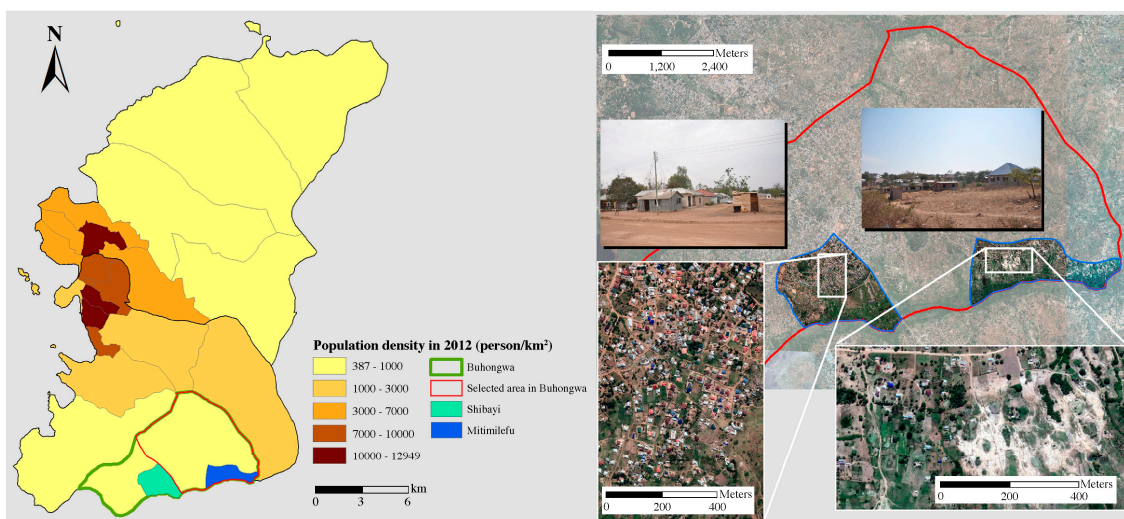


Figure 4. Location of Buhongwa ward and Shibayi and Mitimilefu sub-wards, Mwanza.

2.2.3. Gungu

Gungu belongs to Kigoma-Ujiji municipality, Kigoma. It has an area of 5.6 km² and an estimated 29,355 inhabitants according to data from 2016, with an average annual population growth rate of 6.8%. The population data were obtained from the Ward Executive Officer of Gungu. Two sub-wards with different building densities, Mwenge and Masanga, were selected for this study (Figure 5).

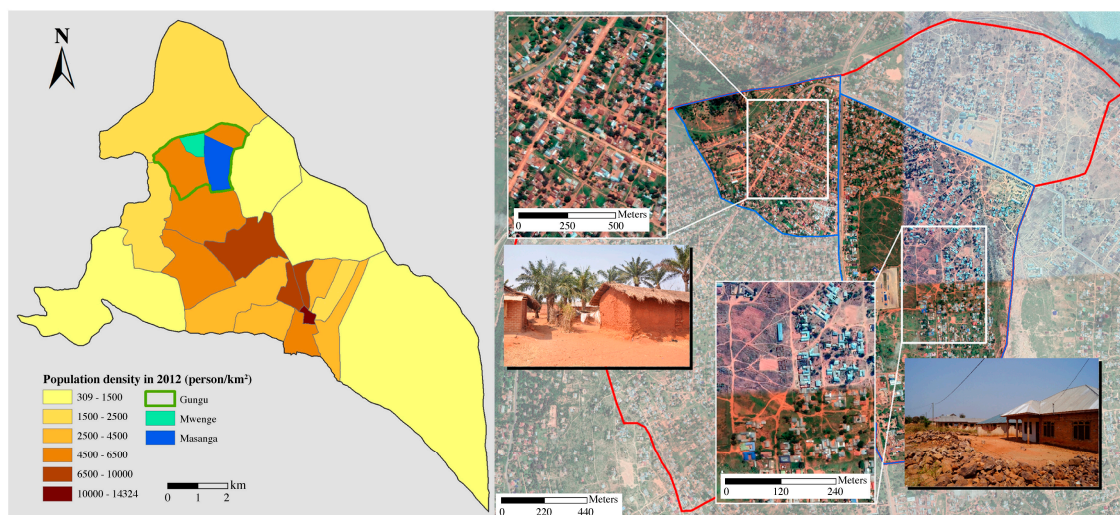


Figure 5. Location of Gungu ward and Mwenge and Masanga sub-wards, Kigoma.

2.3. Data Collection and Processing

2.3.1. Field Survey Data

In August 2017, the research team conducted field surveys involving quick assessments, group discussions, and key informant interviews. Quick assessments recorded the layout of buildings, number of building floors, road conditions, socioeconomic activities, and environmental conditions in each settlement. A scoring criterion that considered the courtyard situation, road conditions, number of building floors, degree of mixed land use, and roofing and wall materials was used to evaluate the quality of buildings (Table 1). Most of the previous studies considered wall materials, roof materials, and floor materials; other factors were considered here to judge the building quality more comprehensively. From the field survey, we found that the three settlements basically include one-storey buildings, with almost no access to paved roads. These two indicators were not included in the comprehensive score. Each settlement was divided into a grid. Chamazi was divided into 82,500 × 500 m grids, Buhongwa into 159,500 × 500 m grids, and Gungu into 100,250 × 250 m grids. Grids with different building densities were selected in each settlement, and 1–3 points (total 182 points) were assigned in each grid to produce a score of building quality.

A group discussion was organized in each of the six sub-wards, involving the ward executive officer, sub-ward leader, and four randomly selected local residents. In total, 33 local people participated in group discussions. Through pre-prepared questions, information about the infrastructure and basic service supply, land right status, development driving force, and main challenges and current countermeasures of each ward and sub-ward were obtained.

For each city, we interviewed one city planner, one ward executive officer, and two sub-ward leaders. In total, 12 key informants were selected for in-depth interviews to obtain detailed information about the development history, current situation, problems, and latest progress of urban planning efforts regarding the respective informal settlements. Limited by research time and resources, we were unable to interview the other sustainable-development-related professionals such as economists or social and environmental scientists.

Table 1. Building quality rating scale.

Evaluating Indicator	Observation	Score
Courtyard	30% and below have a courtyard	1
	30–70% have a courtyard	3
	70% and above have a courtyard	5
Roofing materials	30% and below are concrete, ceramic tile, or high quality iron sheet	1
	30–70% are concrete, ceramic tile, or high quality iron sheet	3
	70% and above are concrete, ceramic tile, or high quality iron sheet	5
Wall materials	30% and below are permanent materials such as bricks or cement	1
	30–70% are permanent materials such as bricks or cement	3
	70% and above are permanent materials such as bricks or cement	5
Degree of mixed land use	Mainly used for living	1
	Mix of residence and agriculture	3
	Mix of residence, industry, and commerce	5

2.3.2. GIS and Remote Sensing Data

GIS data, including administrative boundaries and road networks, were obtained from the Tanzania National Bureau of Statistics and OpenstreetMap (Geofabrik GmbH, Karlsruhe, Germany), respectively. Digital elevation model data were obtained from the United States Geological Survey and used to calculate the gradients of each settlement. High-resolution remote sensing images were used to extract the profiles of buildings using eCognition 8.7 software (Trimble Germany GmbH, Munich, Germany). The influence of the cloud amount in the remote sensing images can seriously impact interpretation results. According to the quality of the images in each year for each city, we finally chose remote sensing (RS) images in different years in the three informal settlements. Road layers were obtained by manual vectorization using road data in combination with RS images.

2.4. Morphological Analysis

2.4.1. Building Form

A set of spatial pattern indices (MSI, SDI, SEI, and ENN) were used to analyze the morphological characteristics of buildings: shape, size, density, and distribution patterns. The density of buildings is key to identifying informal settlements. A settlement can be characterized by both the building unit density (number of buildings per unit area) and building coverage (the ratio of the total area of buildings to the area of the corresponding administrative region).

2.4.2. Road Connectivity

The α index measures the circuitry of a network using the ratio of the number of circuits in the network to the maximum number of circuits possible (Equation (1)). The α index ranges between 0 to 1, with greater values indicative of a higher degree of network circuitry. The β index reflects the complexity and completeness of the road network and is expressed as the ratio of links to nodes (Equation (2)). The β index ranges from 0 to 3; $\beta < 1$ indicates a disconnected network, $\beta = 1$ indicates that the network is one single loop, and $\beta > 1$ means the network connectivity is rather complex. The γ index is used to measure the degree of node connection in a network, expressed as the ratio of links in a network to the maximum number of links between nodes (Equation (3)) [54].

$$\alpha = ((L - N) + 1)/(2N - 5), \quad (1)$$

$$B = L/N, \quad (2)$$

$$\gamma = L/(3(N - 2)), \quad (3)$$

where L is the number of links and N is the number of nodes.

3. Results

3.1. The Densification Process of Informal Settlements

3.1.1. Change in Building Area

Changes in the spatial distributions of buildings over time in Chamazi, Buhongwa, and Gungu are shown in Figures 6–8, respectively. The total building area of each settlement increased rapidly in recent years. The total building area in Chamazi increased by 70,426 m² from 2005 to 2010, and 180,107 m² annually from 2010 to 2013, which is a 2.6-fold increase in the rate of change per year. Buhongwa had a slightly lower annual total building area increase from 2004 to 2010 (15,054 m²); the increase almost quadrupled across the same time interval (63,336 m² annually from 2010 to 2016), which is equal to an increase of 4.2-fold. Similarly, the total building area in Gungu increased by 19,648 m² annually from 2003 to 2010, followed by an increase of 11.8 times from 2010 to 2013, when it grew by 231,215 m² annually.

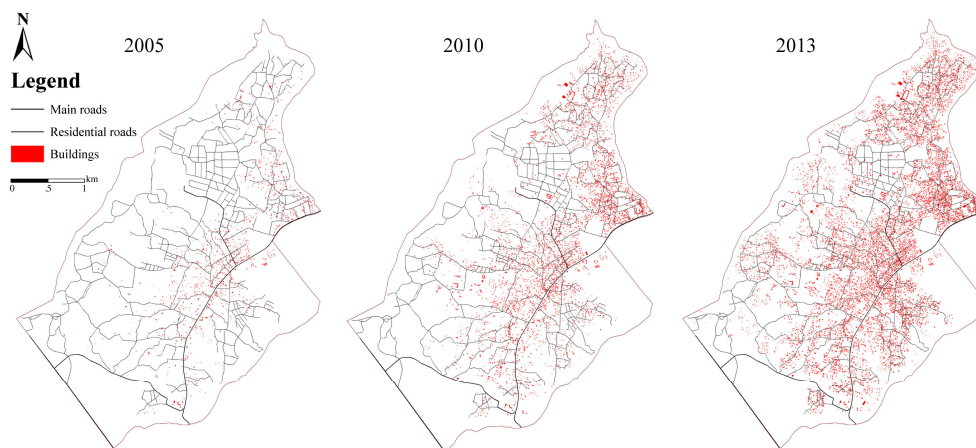


Figure 6. Spatial distribution of buildings in Chamazi from 2005 to 2013.

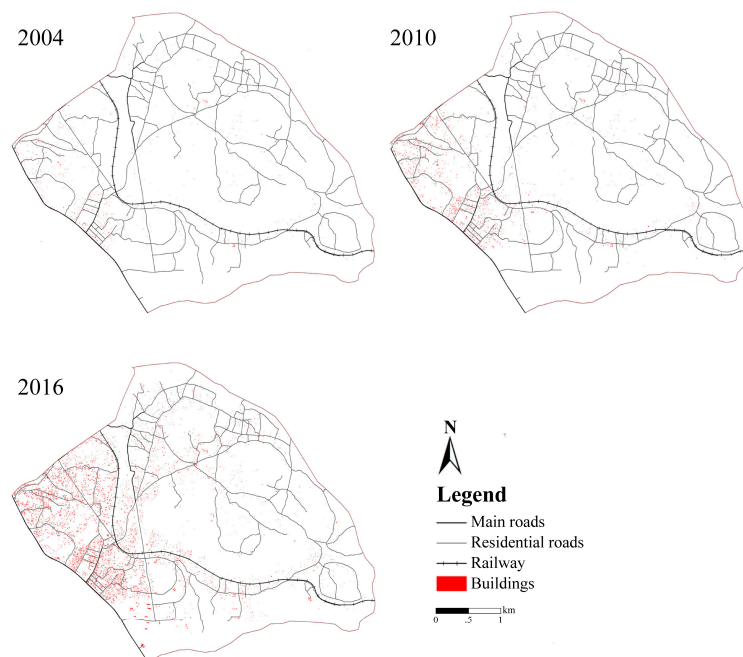


Figure 7. Spatial distribution of buildings in Buhongwa from 2004 to 2016.

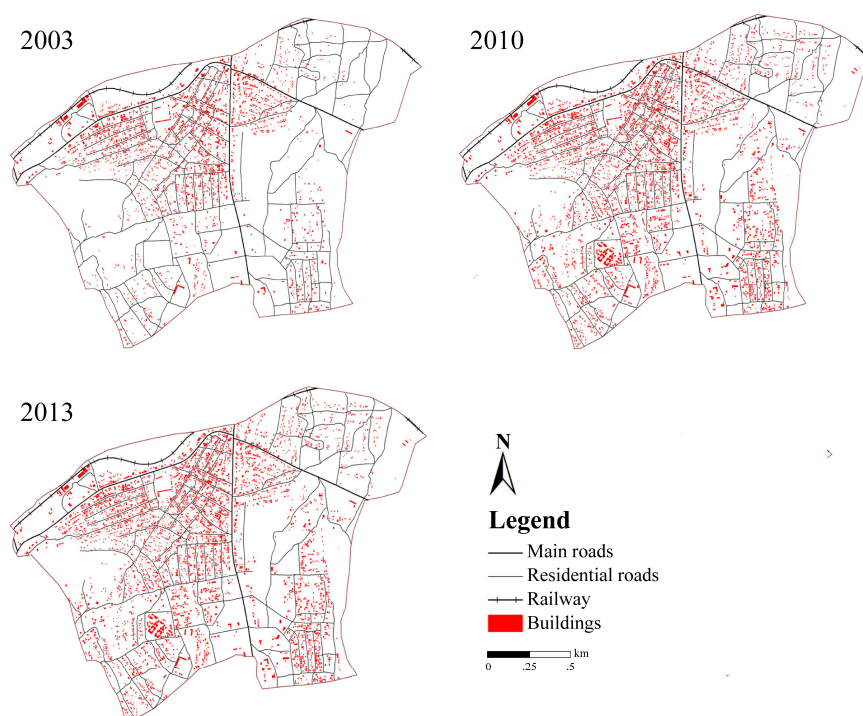


Figure 8. Spatial distribution of buildings in Gungu from 2003 to 2013.

The average building area was largest in Chamazi (85 m² in 2013), followed by Gungu (75 m² in 2013) and Buhongwa (76 m² in 2016). The average building area in Chamazi and Gungu was basically unchanged and tended to be stable; in Buhongwa, it increased gradually, suggesting an improvement in living conditions. The standard deviation (SD) of building size in each settlement was large, reflecting the lack of unified planning guidance for housing construction (Table 2).

Table 2. Statistical data concerning the buildings in Chamazi, Buhongwa, and Gungu.

Parameter	Chamazi			Buhongwa			Gungu		
	2005	2010	2013	2004	2010	2016	2003	2010	2013
Smallest building area (m ²)	8	7	4	8	7	6	8	6	5
Average building area (m ²)	87	86	85	53	63	76	74	75	75
Largest building area (m ²)	840	2151	2151	380	460	1630	1474	1474	1474
Total building area (m ²)	116,324	468,453	1,008,774	51,859	142,183	522,199	177,597	315,130	1,008,774
Standard deviation	63.067	75.726	68.649	43.513	50.000	69.032	66.768	67.676	67.203
Number of buildings (unit)	1334	5429	11844	977	2246	6871	2382	4225	4920
Building unit density (unit/ha)	0.9	3.6	7.9	0.3	0.7	2.1	5.0	8.9	10.4
Building coverage (%)	0.774	3.117	6.712	0.16	0.44	1.615	3.739	6.634	21.237

3.1.2. Differences in Building Unit Density

Building unit density was highest in Gungu (10.4 units/ha in 2013), followed by Chamazi (7.9 units/ha in 2013), and Buhongwa (2.1 units/ha in 2016). The low unit density in Buhongwa was probably a result of the rocky-hilly terrain. Similarly, Gungu had the highest building coverage (21.2% in 2013), followed by Chamazi (6.7% in 2013) and Buhongwa (1.6% in 2016; Table 2).

3.1.3. Change in Vegetation Coverage

Vegetation coverage in each settlement was found to decline over time. Chamazi had the largest decrease in vegetation cover from 6.5 km² in 2005 to 2.5 km² in 2013, indicating that the conversion

of green space (mainly woodland and cultivated land) was extensive during settlement expansion. The vegetated area in Buhongwa declined from 26% in 2004 to 19% in 2016, suggesting an increase in farmland encroachment. Vegetation coverage (mainly shrubs) in Gungu declined comparatively less than in the other two settlements, but nonetheless declined from 33% in 2000 to 25% in 2013 (Table 3).

Table 3. Changes in the vegetation area and coverage in Chamazi, Buhongwa, and Gungu.

	Chamazi			Buhongwa			Gungu		
	2005	2010	2013	2004	2010	2016	2003	2010	2013
Vegetation area (km ²)	6.492	4.538	2.482	8.366	7.664	6.259	1.557	1.264	1.195
Vegetation coverage (%)	43.2	30.2	16.5	25.9	23.7	19.4	32.8	26.6	25.2

3.1.4. Changes in Building Landscape

The average shape of buildings was simple and almost rectangular. The length and width ratio of buildings in Gungu was the largest, followed by Buhongwa, then Chamazi. Standard deviation values indicated the degree of variation in building shape, with the largest values found for Gungu, followed by Buhongwa and Chamazi.

Building diversity, as indicated by SDI, was found to increase gradually, with Chamazi having the largest values, followed by Buhongwa and Gungu. This increase was indicative of the coexistence of broad social groups in the informal settlements of Tanzania. SEI values indicate that the building distribution in Chamazi remained relatively even, whereas that of Buhongwa was relatively heterogeneous, perhaps due to its rocky-hilly terrain and large mining areas.

The ENN values suggested that the greatest changes in building landscape occurred in Chamazi. The change in value from 15.81 m in 2005 to 9.82 m in 2013 indicated that the buildings had a concentrated distribution pattern. Similarly, for Gungu, the ENN value gradually decreased from 11.29 m in 2003 to 10.28 m in 2013, with a slightly lower concentration of buildings than in Chamazi. Conversely, the ENN value for Buhongwa increased. New buildings may appear scattered because a large area of Buhongwa consists of farmland and rocky hills (Table 4).

Table 4. MSI, SDI, SEI, and ENN of buildings in Chamazi, Buhongwa, and Gungu.

Index	Chamazi			Buhongwa			Gungu		
	2005	2010	2013	2004	2010	2016	2003	2010	2013
SEI	0.9731	0.9724	0.9760	0.9646	0.9671	0.9673	0.9699	0.9703	0.9704
MSI	1.192	1.197	1.193	1.206	1.218	1.218	1.228	1.231	1.230
SD of MSI	0.0924	0.0898	0.0828	0.0810	0.1020	0.1021	0.1165	0.1152	0.1138
SDI	6.9951	8.3619	9.1538	6.6349	7.4603	8.5458	7.5388	8.1009	8.2484
ENN(m)	15.81	10.96	9.82	10.59	10.71	11.17	11.29	10.31	10.28

Notes: SEI, MSI, SDI, ENN means Shannon's evenness index, Mean shape index, Shannon's diversity index, and Euclidean nearest-neighbor distance, respectively.

3.2. Morphological Characteristics of Informal Settlements

3.2.1. Block Texture

Building density in Chamazi was mainly medium and high, composed mostly of single-storey detached buildings with few high-rise buildings. We found no clear textural features, the building sizes and building shapes varied widely, and the orientation was changeable; the blocks showed a twig-like distribution that followed the unplanned road network.

Building density in Buhongwa was mainly medium and low, containing mostly single-story detached houses except for some houses built on rocky-hilly terrain. With the exception of a large school in Southern Buhongwa, few other high-rise buildings were present. With the exception of the

relatively high building density along Kenyatta Road, most areas had low building density. The housing distribution was very complex, with varied sizes, orientations, and densities; the blocks showed an irregular twig-like distribution.

Building density in Gungu was mainly medium and high, with no multi-story buildings except for some churches and training schools. Buildings were dense and exhibited a certain texture overall. The orientations, sizes, and distributions of the houses were relatively regular compared to the other two settlements. The blocks showed a mixture of checkerboard and twig-like distributions.

3.2.2. Road Network Structure and Accessibility

The circuitry, complexity, connectivity, and density of the road network in Gungu were the highest, followed by that in Chamazi and Buhongwa (Table 5), which we suggest is related to proximity to the city center. Gungu is close to the city center and one of its two main roads runs through central Gungu. Chamazi and Buhongwa are located slightly farther from the city center. Except for its northwest corner, most of Gungu is rather flat and contains no river crossings. There is a seasonal river in the southwestern part of Chamazi, a large sand mining area and a small lake in the west, and large areas of woodland in the south and east. In Buhongwa, large areas of farmland are found in the south and north, and a mining area in the central part. In addition, the railway line has a certain impact on road connectivity.

Table 5. Road connectivity and road network density.

Ward	L	N	α	β	γ	Overall Road Network Density (km/km ²)	Main Road Network Density (km/km ²)
Chamazi	578	346	0.3392	1.6705	0.5601	6.5863	0.6811
Buhongwa	527	319	0.3302	1.6520	0.5542	3.1533	0.1765
Gungu	336	184	0.4215	1.8261	0.6154	8.6643	1.0499

Notes: The α index, β index, and γ index measures the circuitry, complexity, and connectivity of a network, respectively.

3.2.3. Distribution Characteristics of Building Density

- (1) With the increase in the road network density, building density tended to increase (Figure 9). Convenient transportation can promote economic development within settlements since the main economic activities are conducted along the main roads. Buildings were also found to be concentrated around the roads. In informal settlements, buildings tend to be established first, with roads formed around them. The road network was complex and irregular with poor road conditions, which reduce residents' quality of life and limit the economic development potential of the settlements.
- (2) The results showed that building density decreased with increases in slope (Figure 10). Many of the buildings in informal settlements were constructed ignoring slope conditions. The total area and average number of buildings with a slope of more than 15 degrees were largest in Chamazi, followed by Buhongwa and Gungu. Floods and landslides are significant environmental problems in these settlements. The demolition and reconstruction of residential areas have also caused difficulties.
- (3) With the increase in the ENN distance, building density tended to decrease (Figure 11). We found that the average distance between buildings was about 10 m, which gradually decreased over time. Many buildings are very close together and have a disordered orientation.
- (4) With an increase in the average building area, building density increased (Figure 12). The average building area was about 85 m² in Dar es Salaam, and about 75 m² in Mwanza and Kigoma. Most of the newly built houses have a large area, with more permanent building materials used. The newly built houses (mostly with courtyard walls) and old smaller houses (mostly semi-open) were both separated and intermixed. There was an obvious social gap between the residents of these two building types.

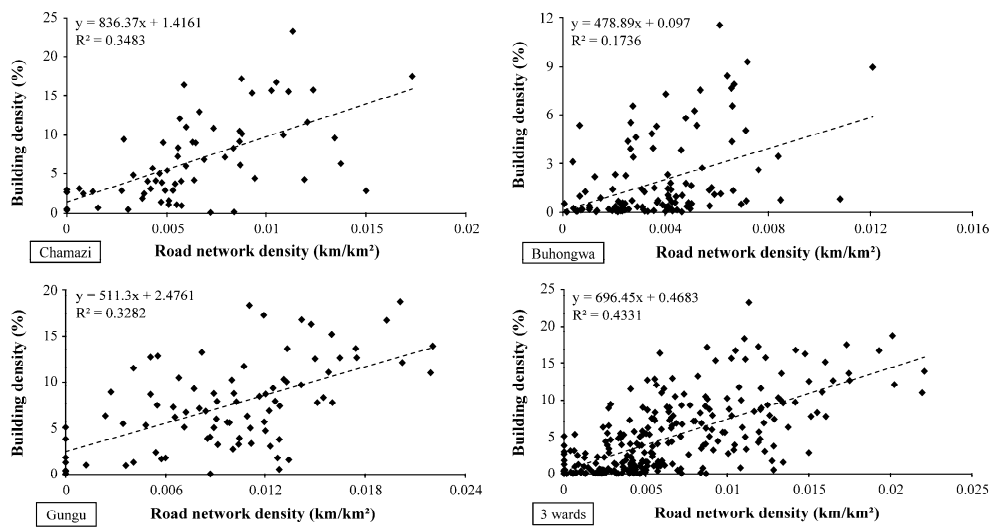


Figure 9. Scatter diagram of the relationship between building density and road network density.

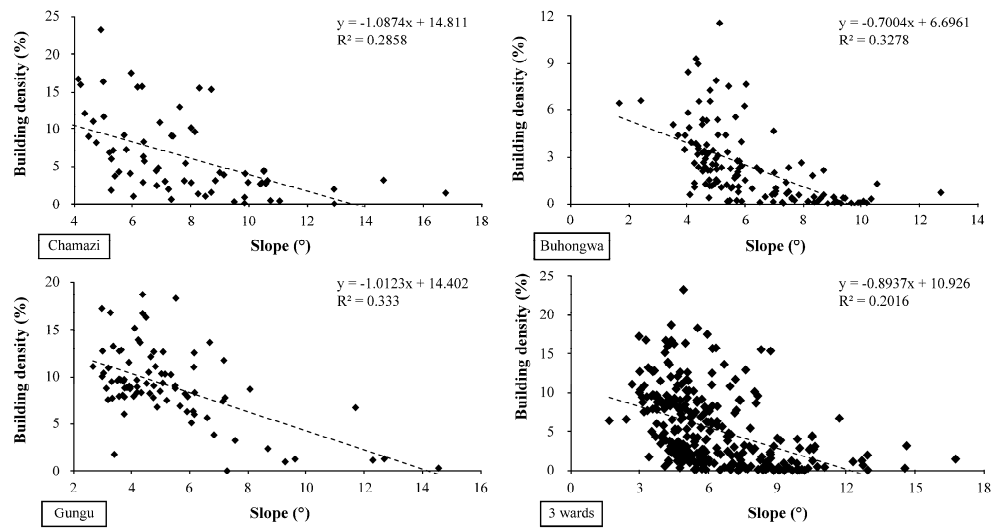


Figure 10. Scatter diagram of the relationship between building density and slope.

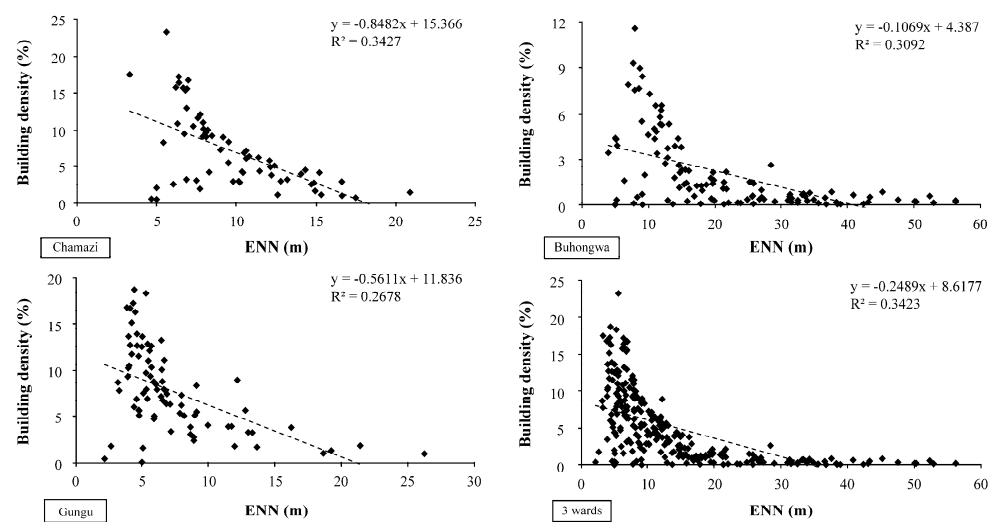


Figure 11. Scatter diagram of the relationship between building density and Euclidean nearest-neighbor (ENN).

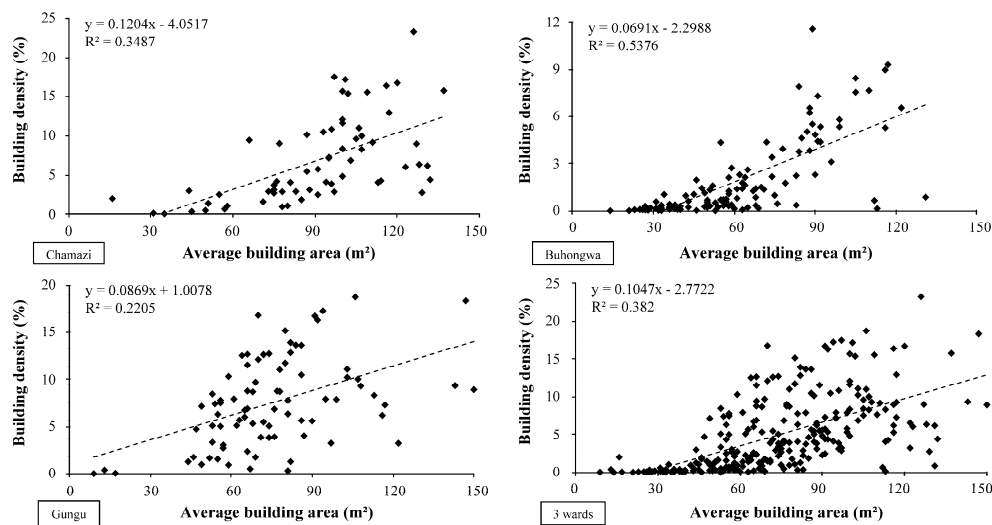


Figure 12. Scatter diagram of the relationship between building density and average building area.

- (5) With increasing building density, building quality tended to worsen (Figure 13). In 2013, the building densities of Chamazi and Gungu were 6.712% and 23.237%, respectively; in 2016, the building density of Buhongwa was only 1.615%. New, good quality housing in Chamazi and Gungu was mostly distributed in newly developed areas with a lower building density, low population, and poor infrastructure conditions. Settlements mainly expanded horizontally, with building quality and density showing a negative correlation. In most areas of Buhongwa, building density remained low over time, with newly added houses interspersed with old houses. Building construction was mainly in the process of densification. Therefore, the relationship between building quality and building density was not obvious.

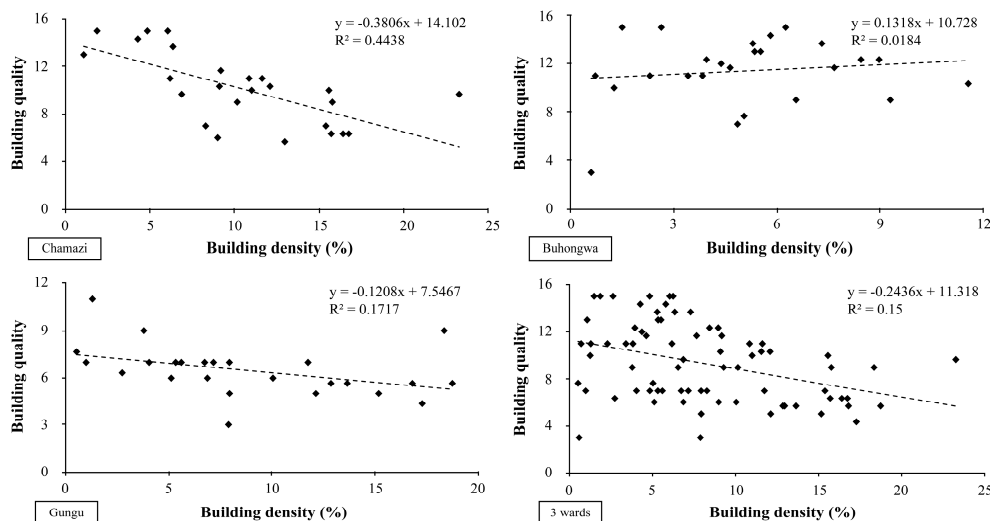


Figure 13. Scatter diagram of the relationship between building density and building quality.

3.3. Functional Development of Informal Settlements

3.3.1. Number and Composition of Residents

The three settlements were previously mainly composed of woodland, agricultural land, and open space. However, with the development of the national economy and market economy reforms, more land began to be sold to outsiders from around the year 2000 and onward. This led to the coexistence of different social groups within settlements, which are currently mainly of medium- and low-income

levels. Of the 24 residents interviewed, 15 relocated to the study area because the settlement was close to the main road, land was available at a low price, and the costs of living were low.

The increase in the number of migrants has driven rapid population growth in the settlements. The population density in the planned residential areas was much higher than that in the informal case settlements, indicating that settlements have much room for improvement in terms of population carrying capacity. The three settlements had an average of four to six people per household and an average of 5 to 10 people per building due to the existence of tenants. Chamazi has a large floating population (50%), mainly consisting of mobile vendors and workers from Illala and Kigoboni. The floating population of Buhongwa (22%) and Gungu (4%) are mainly students and mobile vendors from nearby wards. The residents of the three settlements are mainly engaged in small business activities (mostly informal), fisheries, animal husbandry, agriculture, and mining. The proportion of residents with a fixed occupation and income was 50% in Chamazi, 20% in Gungu, and 15% in Buhongwa. In all three settlements, the illiteracy rate was below 5%, with most residents having some level of primary or secondary education. These data were obtained through group discussions and key informants interviews.

3.3.2. Infrastructure Development

Despite the relatively adequate supply of electricity, the three settlements are far from meeting the needs of local residents in terms of the provision of public water, drainage, solid waste collection, education, and medical care. Chamazi has not been connected to the urban public water supply network, and only 20% of the residents of Buhongwa and Gungu have access to the public water supply. Most of the residents use pit latrines. There are no public drainage facilities. Groundwater and springs are easily contaminated by toilet waste, so diarrhea is a common problem. Solid waste is mainly collected by private contractors, but their services are very limited. Other wastes are mainly burned or thrown away. The prevalence of informal economic activities substitutes the shortage of commercial service facilities in the settlements to a large extent. Due to the lack of educational facilities, some primary school classrooms in Chamazi contain up to 600 students. Medical facilities in Buhongwa are especially inadequate.

3.3.3. Living Environment and Health

There are virtually no measures to protect the ecological environment in the informal settlements. With the wide use of dry toilets, and the lack of public drainage facilities and solid waste collection services, the living environment is often highly deteriorated, posing threats to residents' health. The three rivers of Chamazi often flood during the rainy season, and houses built along the river typically collapse during the rainy season. Much open-air waste near the Mzinga River (Figure 14) contributes to water pollution problems. Numerous sand mining activities occur around the seasonal river in the southwestern part of Chamazi. To prevent flooding during the rainy season, local residents have constructed a flood embankment using living garbage (Figure 15), which may be polluting the water.



Figure 14. Rubbish dumped by residents near the Mzinga River, Chamazi.



Figure 15. A flood embankment constructed using living garbage, Chamazi.

There are some industrial activities, a pharmaceutical factory, and a large garbage dump along the Nyashishi River in Southern Buhongwa (Figure 16). Nearly 85% of the garbage in Mwanza is processed at the Buhongwa dump, and this has negatively affected the surrounding environment. Gungu encounters light or heavy mountain torrents almost every year, causing serious waterlogging. The increased building activities have led to fewer trees and consequent soil erosion.



Figure 16. A Buhongwa dump site.

4. Discussion

Like many other developing countries, informal settlements are playing an increasingly important role in providing living and working spaces for the burgeoning urban population of Tanzania. The property and business formalization program launched in 2004 and implemented in 2008 is now the main method to cope with informal development in Tanzania, which proved to be helpful for regulating the real estate market, reducing land conflicts, and promoting economic development of informal settlements [61,62]. Many researchers reported that the morphological characteristics of informal settlements may have some important influence on sustainable development [15,37], but how to respond is still open for discussion, and little has been done to specifically tackle this problem. According to our findings, the spatial forms of informal settlements in Tanzania do not conform well to the principles of sustainable development in terms of economic, societal, and environmental protection. Through the optimization of the structure and form of the elements of informal settlements, their spatial development can better align with the sustainable development goals, which may further enhance the effectiveness of property and business regularization projects.

4.1. Building Density Control

Buildings in the informal settlements tend to have simple shapes and small areas; most are single-story detached buildings mainly used for living. The land use function is singular and there is a notable lack of markets, hospitals, schools, and other buildings for social service provision, resulting in high commuting costs and low life quality. The average distance between buildings is short, and many houses have no distinct boundary. They are intermingled, leading to poor privacy and poor living conditions. Building quality tended to worsen with increasing building density, with most of the low-quality buildings spreading horizontally. Building quality showed considerable disparity, the orientation of the buildings was highly variable, and high- and low-density building areas were mixed in a disorderly manner, failing to conform to the principles of compact communities. Areas of excessively high building density suffer from ventilation and lighting issues, and congested living conditions can easily cause land disputes and neighborhood conflicts. Areas of low building density reflect inefficient land use.

Building density is an important index that can be used to identify informal settlements since it is quite different from the planned area [16,63]. Building density needs to be controlled to improve the living conditions and land use efficiency. Areas with excessively high building densities (typically the areas with poor building quality) should be controlled to prevent further densification. Measures should be taken to transfer residents to low building density areas if necessary, thus creating space for the provision of roads and sanitation facilities. Areas with excessively low building densities should be merged and consolidated with each other to increase the population density, thus leading to improvements in land use efficiency and the provision of more economical infrastructure and social services. Two-story or multi-story buildings should be encouraged. The government, non-governmental organizations (NGOs), and community-based organizations should adopt a two-story or multi-story building scheme for the transformation of existing houses and the planning of new plots. Although the middle classes are increasingly entering informal settlements and are keen to invest in the building of single-layered luxurious houses, informal settlements continue to be mainly used to meet the housing needs of the urban low-income class. The development of multi-story housing is a possible method to deal with this demand and will help control the disordered low density horizontal expansion.

4.2. Environmental Protection

The layout of the buildings reflects the low amount of consideration of local environmental conditions, with many buildings constructed in or near environmentally risky areas, which jeopardizes the lives and properties of the residents. Safe drinking water is lacking, as rivers and groundwater sources are polluted by garbage and feces. Buildings have replaced much of the farmland and vegetated areas, the service functions of ecological space in informal settlements are declining continuously, and the landscape pattern is generally fragmented. The buildings scattered in the environmental risk area are difficult to centrally manage and providing infrastructure is inconvenient; thus, the living conditions are harsh and residents' health and property are at risk.

Measures should be implemented to improve residents' awareness of environmental risks and the need for environment protection to limit further expansion into environmentally risky areas and enhance the local capacity for mitigating environmental risks. Departments should gradually relocate residents from these areas when necessary. The characteristics and landscape value of the natural environment should be factored into local development plans, with protection given to ecological spaces. These places are not only important for entertainment activities, but also for economic opportunities.

4.3. Road Planning

Roads in informal settlements are short and narrow and have few regular sections. Accessibility is poor, with a high proportions of dead ends. Road networks are often irregular with changeable lengths, widths, and pavement types. Since unplanned roads are mixed amongst disorderly distributed

buildings, blocks have no clear textural features, instead having a semi-natural, loosely distributed, and branch-shaped pattern. This has not been conducive to the accumulation of economic activities and the effective provisioning of infrastructure and social services. Poor road conditions also restrict the development of public transport.

Road planning should be scheduled first. Tanzania Development Vision 2025 and National Growth and Reduction of Poverty II both point out that local road investment should be a high priority for inclusive growth and poverty eradication [64,65]. Since 2000, most of Tanzania's transportation budget has been devoted to the construction, maintenance, and upgrading of trunk roads, but local road conditions have rarely improved, especially in informal settlements [66]. Planned road networks can be used to regulate and control the layout of settlements, and create compact and orderly spatial forms, thus enhancing the accessibility and livability of settlements. This could also help to create activity centers, improve work and service conditions, and facilitate the transformation and upgrading of settlements in the future.

4.4. Local Autonomy

Overall, previous studies from Tanzania suggested that although local government units may not be able to deal with all land planning and administration matters, they stand a better chance of being able to do so than the central government due to their ability to respond quickly and affordably [67]. Therefore, planning rights could be moderately decentralized and encourage local autonomy. In an interview with the city planner of Kigoma, we learned that despite the efforts by the city planning department to formulate a detailed land use plan, the planning was difficult to implement due to the lack of funds for land surveys and related working personnel. Some sub-ward leaders in Gungu divided land boundaries by themselves to deal with the deficiency of government planning and to avoid land conflicts. This can promote orderly housing construction and layout and is also conducive to speeding up the process of land rights formalization. Sub-ward leaders have advantages in terms of the local residents' identity and land ownership authentication. Therefore, under the current constraints of the limited financial, management, and executive capacity of the governments at higher levels, planning rights could be decentralized to the ward level, making full use of local knowledge, and promoting the process of local autonomy.

5. Conclusions

The findings here provide three possible contributions. First, we obtained detailed information on the social and economic development of informal settlements in different cities of Tanzania using a field survey, group discussion, and interviews, which could provide useful basic information for formalization and upgrading for each informal settlement. Secondly, the temporal and morphological characteristics of informal settlements were analyzed, and the results showed that measures must be taken as soon as possible to prevent the further disordered spread of informal settlements. Most importantly, we discussed the possible relationship between the spatial form of informal settlements and their social economic development. We found that the spatial forms of informal settlements in Tanzania, basically the chaotic layout of single-layer dominated buildings and irregular road networks with poor accessibility, negatively impact the function and sustainable development of cities, and also weakened the development potential of informal settlements. The implementation of the Government of Tanzania's Property and Business Formalization program and other settlement upgrading strategies have generally emphasized policy and management issues related to land, housing, and social services. According to the results of this study, the government can promote the sustainable development of its society by optimizing the spatial forms of the informal settlements. First, building density should be controlled to improve living conditions and land use efficiency. Second, land for construction should be selected to avoid areas with high environmental risks, and ecological spaces should be protected. Third, land space can be maximized through the development of two- or multi-story buildings. In addition, by planning roads first, the layout of settlements could be regulated and controlled. Decentralization is

another possible method to encourage local residential planning. In general, land use planning should be better integrated for the formalization of property rights [13].

An additional contribution the extraction of informal settlements from remote sensing images. Building density, area, and height are the most commonly used indicators for delineating an informal settlement and describing its morphology [23–25]. However, due to size differences, locations, development stages, populations, economic capacities, and the variability in the research scale, defining and dividing informal settlements with the standard general form are difficult [68]. Concordant with our findings, Sirueri [39] found different spatial patterns for building density, average building area, average distance between buildings, and road connectivity in the informal settlements in Nairobi and Dar es Salaam, as did Kuffer [40] in the slums of three cities in Asia and Africa. However, commonalities exist in the average shape of the buildings, which tend to be simple and rectangular; the buildings are mostly one story, areas $\leq 90 \text{ m}^2$, an average distance between buildings of 10 m, and vegetation cover $< 25\%$. These indicators can be used for the identification and collection of basic knowledge of the current informal settlements in Tanzania, but data will need to be amended as informal settlements develop.

Urban sustainable development emphasizes people-orientation and capacity-building, as the three-dimensional coordinated development of society, economy, and ecology [69]. All three dimensions can be affected by the spatial organization of the city on different scales [70]. Determining how to guide a city to form a reasonable spatial form and promote the coordinated and healthy development of other elements is a hot issue in the study of urban sustainable development [71,72]. Compact city and smart growth theory embody this research. This study was also based on these theories and concepts, further indicating the important connection between spatial form and social economic development, attaching the importance of morphology in the theory of sustainable development. However, we mainly focused on the collection and processing of relevant data and the corresponding empirical analysis of the informal settlements; we did not conduct a theoretical analysis of local urban development and spatial form. More in-depth research is still needed to analyze the mechanism behind the relationship between the morphological elements of informal settlements and their functional development to propose more innovative suggestions to promote the sustainable development of the informal settlements.

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