# MODELLING INFORMAL SETTLEMENT GROWTH in Dar es Salaam, Tanzania

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March, 2011

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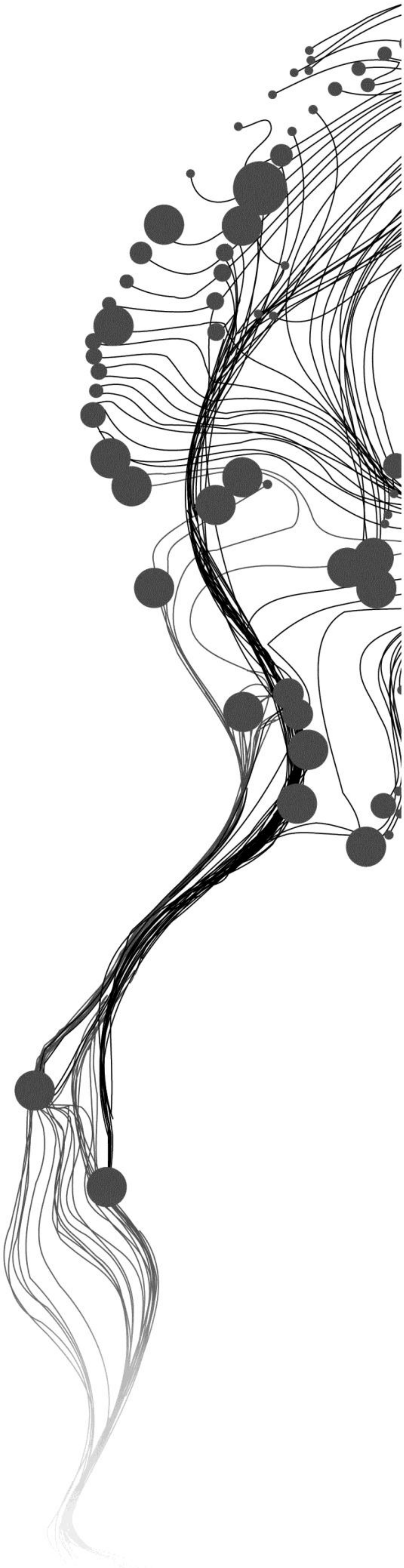

# MODELLING INFORMAL SETTLEMENT GROWTH in Dar es Salaam, Tanzania

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Enschede, The Netherlands, March, 2011

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning and Management

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# ABSTRACT

Dar es Salaam has witnessed rapid urbanization abreast many challenges that informal settlements have become inevitable manifestation of it. Although these settlements are known for relentless growth - leapfrogging into the unplanned periphery, very little is known about the driving forces for their sustained expansion and densification. Investigation of key driving forces of informal settlement growth in the city by coupling the potentials of Geo-Information Science with logistic regression modelling technique is made. A list of probable drivers is prepared in consultation with literature and experts' opinion, where in parallel spatio–temporal pattern of informal settlement expansion, 1982-2002, and densification, 1992-1998, was conducted. The probable driving forces then are set to binary and multinomial logistic regression modelling, to explain informal settlement expansion and densification, respectively. Distances to minor roads, existing informal settlements, other-urban land use and population density (all four with odds ratios <1); and proportion of informal settlements and undeveloped land in a surrounding area (both with odds ratios >1) are found to be the most influential predictors of informal settlement expansion during 1982-2002. Population density and distances to minor rivers, other-urban land use, central business district, major rivers and major roads are on the forefront in influencing the transformation of low density informal settlement to medium agglomeration. Moreover, emerging informal settlements' probable density class is found to be better explained by: population density, distances to other-urban land use and minor roads for low density class; distances to existing informal settlements, river valleys and major rivers for medium density class; and distances to minor roads, existing informal settlements and central business district for high density class. Evaluation and validation results indicate the models are valid, and trend extrapolation acquired future expansion and densification areas. Further comparison of predictions of informal settlements made by logistic regression and cellular automata modelling on the same study area achieved similar results; and beyond that it revealed the need to device a mechanism how policy makers can proceed with urban policies when different predictive models are at their disposal. The attained results and approaches stretched in this study can enhance the understanding towards the nature of informal settlement growth and help urban planners and policy makers for informed decision making.

***Key words***: informal settlement; logistic regression modelling; GIS; Dar es Salaam

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| | |
|---|---|
| ABM | Agent Based Model |
| ANN | Artificial Neutral Network |
| BAR | Building Area Ratio |
| CA | Cellular Automata |
| CBD | Central Business District |
| CBO | Community Based Organization |
| CI | Confidence Interval |
| CL | Confidence Level |
| DEM | Digital Elevation Model |
| DSM | Dar es Salaam |
| FAR | Floor Area Ratio |
| GIS | Geographic Information System |
| GWR | Geographically Weighted Regression |
| ILWIS | Integrated Land and Water Information System |
| IS | Informal Settlements |
| ISG | Informal Settlement Growth |
| ITC | International Training Centre, (currently, Faculty of Geo-Information Science and Earth Observation, University of Twente) |
| LR | Logistic Regression |
| LRM | Logistic Regression Model |
| NGO | Non-Governmental Organization |
| NIS | Non Informal Settlement |
| PASW | Predictive Analysis Software (originally SPSS) |
| PCP | Percentage of Correct Predictions |
| RIKS | Research Institute for Knowledge Syatems |
| RS | Remote Sensing |
| SE | Standard Error |
| SFAP | Small Format Aerial Photography |
| SPOT | Satellite Probatoire pour l'Observation de la Terre |
| SPSS | Statistical Package for the Social Sciences |
| SSA | Sub Saharan Africa |
| URT | United Republic of Tanzania |
| VIF | Variance Inflation Factor |

# 1. INTRODUCTION

The proliferation of informal settlement is usually counteracted by conventional reactive measures. These practices and strategies fall short to curb the ever increasing growth of informal settlements. This suggests new approaches and tools should be explored that urban planners and policy makers can use to improve the understanding and management of informal settlement growth (Sietchiping, 2004).

This research aims to model informal settlement growth, in Dar es Salaam, by coupling the potentials of GIS and logistic regression modelling techniques. The model is anticipated to explore the effects of various driving forces of informal settlement growth which are going to be thoroughly studied to generate predictive model. This will allow for much deeper understanding of the driving forces of informal settlement and enhance policies that are meant to deal with it.

## 1.1. Background and justification

**Informal settlements**

Urban development trends with regard to the built environment, the urban economy and the provision of services can be analysed with 'formal'/ 'informal' continuum. Formal urban developments are those that go along with the purview of a state land administration system and complies with its legal and regulatory requirements, while informal urban development does not comply with one or another requirement (UN-HABITAT, 2009a). With this regard, informal settlements[1] may bear attributes like, illegal occupation of land, non-adherence to building codes and infrastructure standards, or both illegality of land and non-conformity to building standards and codes (Fekade, 2000).

Already in 2008 over half of the world population lived in urban areas and it is expected to rise to 70 percent by 2050, whereby Africa and Asia would experience the fastest rate of urbanization and Africa's urban centres would host 61.8 percent of the continent's population at that point in time (UN-HABITAT, 2008, 2009a). This rate and scale of urban population growth, accompanied by climate change and resource depletion, would require a high level of concern and intervention from all stakeholders to avoid human and environmental calamity, particularly where 90 per cent of all upcoming urban population growth will take place in developing[2] countries (Blanco, et al., 2009). Here it should be noted that significant number of the urban population in developing countries highly depend on the informal sector (UN-HABITAT, 2009a), to which informal settlements are one form of its manifestation (Roy, 2005).

[1] In this study the term informal settlement is used interchangeably with terms self-planned, unplanned, squatter, unauthorized, illegal, irregular settlement and informal development.

[2] Although the term "developing countries" may have negative connotations, as indicated by Satterthwaite (2002), there is still no best word to describe the less developed countries accurately. Nearly all terminologies are highly contested and in this research the author opt to use the term as it appear in the referred material, that include, but not limited to: Third World, Global South, the South, non-industrialized, developing, underdeveloped and emerging economies.

**Urban growth and informal settlements in Sub-Saharan Africa (SSA)**

The Sub-Saharan Africa region has been experiencing unprecedented urbanization rate for so long as a result of inherent demographic processes (natural population growth and migration). Prolonged declining of economic performance, political instability and institutional decadence have exacerbated associated problems of rapid urbanization in the region (Kombe & Kreibich, 2000). This region is also known for unparalleled economic and urban growth, where economic advancements lagging way behind (Blanco, et al., 2009; Kombe & Kreibich, 2000; Sliuzas, et al., 2004). This has led the majority of urban population, especially the urban poor, to survive in a condition of informality (Blanco, et al., 2009). In Africa, in general, around 60 percent of the urban labour force relies on the informal economy, and further researches are indicating that this proportion is increasing over time (UN-HABITAT, 2009a). Housing is the main manifestation of informality in developing countries. Informal settlements are being the host to low and middle income citizens who no longer have access to affordable serviced land and formal housing. The situation further worsens as there are often mismatches between what is constructed and what is needed by the people. These and other factors add up to make 62 percent of the urban population of SSA to live in slums (UN-HABITAT, 2009a).

Sub-Saharan Africa region, or generally the global south, has long depended upon the developments of western urban planning practice. This has earned them nothing but a system incapable of dealing with the context at hand, which is poverty, inequality, informality, rapid urbanization, and spatial fragmentation (Kombe & Kreibich, 2000; Rakodi, 2001; Sliuzas, et al., 2004; Watson, 2009).

**Urban growth trend in Tanzania**

Tanzania is one of the countries in Sub-Saharan Africa within which the highest proportion of its urban population lives in informal settlements. The proportion ranges between 50 to 80 percent and the informal housing shares more than 50 percent of the whole urban housing stock. Informal settlements have covered most of the urban landscape, and have been proliferating both in terms of density and expansion. It can also be recalled that in Dar es Salaam, for instance, the number of informal settlements increased from 40 in 1985 to over 150 in 2003, which tripled while the population nearly doubled in the specified time span (Kombe, 2005).

The evolving organic urban forms and their associated land use structure of cities in Tanzania are not in compliance with normative urban land development concepts and standards. These irregularly evolved urban forms house a number of problems, for instance, inefficient land use distribution, development pattern and health threats as density of settlements increase over the landscape. This indicates planners and urban managers should understand the very role of social and economic factors, including other forces that underpin organic urban growth (Kombe, 2005).

**Dar es Salaam and informal settlements growth**

Informal sector is the prime option for land seekers in most developing countries where the public sector fails to manage urban growth according to its legal norms and the expectation of the citizens which fuel the rapid growth of informal settlement (Kironde 2006; Kombe, 2000). Dar es Salaam, the study site, in 2007 comprised 29 % of the urban population of Tanzania with 3.31 million inhabitants. The city is found in the highly urbanizing region of east Africa with projected population of 5.7 million for 2010 where Tanzania's urban population is expected to double in 2025, 25 years earlier than the global one, to be 21 million. This rapid urbanization has already started to generate social, economic and spatial problems which need urgent response (UN-HABITAT, 2008). Studies carried in 1995 showed that about 70% of the population of Dar es Salaam is accommodated in informal settlement (URT, 2000). Sliuzas, et al. (2004) noted high informal settlement growth rate as opposed to the planned residential land use class across time. Reviewing the two land use classes in two time ranges, i.e. 1982-92 and 1992-98, the annual growth rates for planned residential were 3.0 and 2.1, while it was 4.7 and 9.1 for informal settlements respectively. Sliuzas, et al. (2004) also claims densification of informal settlements via incremental housing construction as a major aspect of informal settlement development process apart from expansion.

Despite an increasing informal settlement growth in cities of the developing countries the availability of researches on forces responsible for their sustained existence is incomplete (Kombe & Kreibich, 2000). It is high time that new models should be explored, especially in the middle of scarce data sources, that aim to identify key driving forces liable to urban expansion and differential densification which can earn policy relevant outputs (Sliuzas, et al., 2004).

## 1.2. Research problem

There have been different policies, strategies and programs devised by third world governments to solve urban housing problem which is the main breeding platform for informal settlement. These approaches include, public housing programs, sites and services programs, slum and area upgrading, among others; but none of which could address the housing need with its huge scale. The response by the people to this malfunctioned interventions and ineffective land delivery system was establishing self-planned settlements or informal settlements (Fekade, 2000).

Informal settlements have long been treated in a reactive manner. Policies and practices which support this approach contributed less to the overall urban quality of life and also fail to stop further proliferation of informal settlements. This call for proactive and defining approaches that would mitigate losses encountered by informal settlements and put a halt on their sustained proliferation. To establish such a system driving forces and probable areas of future informal settlements should be detected and be well integrated in the urban planning and policy formulation practice. To this end, this research is necessitated to address the research problems that constitute the probable drivers of ISG in DSM which has not yet been well explored, significant driving forces of IS expansion and densification that needs to be thoroughly investigated, and also the undefined probable areas of further expansion and densification of IS in DSM. Moreover urban planning authorities are in need of approaches and tools like urban growth models to better understand the nature of informal urban growth and specifically ISG.

Dealing with informal settlements after their appearance would have societal, environmental and economical costs. To avoid such a huge loss and futile interventions so far entertained; modelling informal settlements by coupling GIS with logistic regression technique would unveil the main drivers of informal settlement and depict probable areas of future informal settlement growth, in terms of expansion and densification. This predictive model is believed to help planners and policy makers in understanding the intrinsic nature of informal settlements, and support them in making informed decisions and also devising proactive measures.

## 1.3. Research objectives and questions

### 1.3.1. Main objective

To investigate key driving forces of informal settlement growth (ISG) in Dar es Salaam by coupling GIS with logistic regression model.

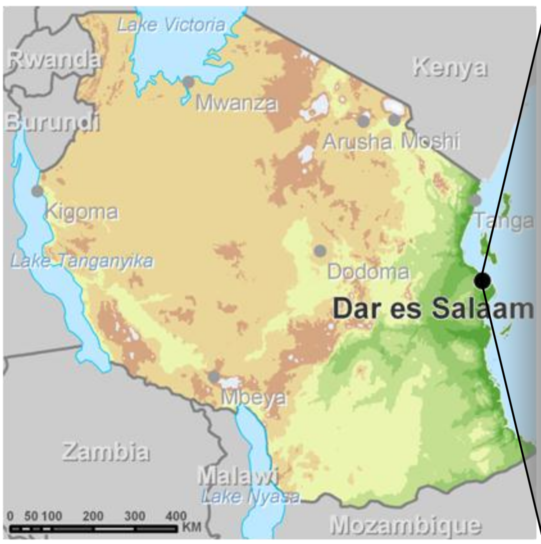
### 1.3.2. Sub-objectives and questions

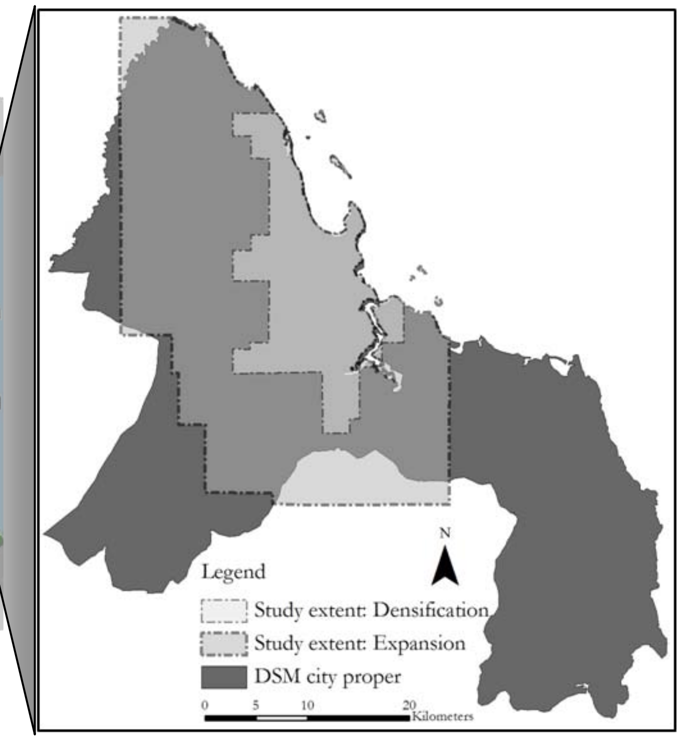
1. To build conceptual model of informal settlement growth in Dar es Salaam
   - What is the spatial pattern of ISG in the development of Dar es Salaam?
   - What are the potential drivers of IS expansion and densification across time in Dar es Salaam?
2. To build a logistic regression (LR) model of ISG in Dar es Salaam
   - What are the driving forces of IS expansion and densification in Dar es Salaam?
3. To determine future ISG pattern in Dar es Salaam
   - How robust is the proposed LR model?
   - Where are the probable areas of IS expansion and densification?
   - What is the implication of future ISG pattern for actual urban planning process?

## 1.4. Spatial extent of the research

The spatial extent of the research does not cover the whole administrative boundary of Dar es Salaam, but the main urban fabric of the city across time. For the purpose of investigating the driving forces of IS expansion the study area claims an area about 980 km² (small scale data, AP's 1: 54,000 and Maps 1: 50,000), within which most of the urban growth encounters of Dar es Salaam had been entertained. While for investigating the driving forces of IS densification a subset (large scale data, AP's 1:12,500 and Maps 1: 2,500) of the aforementioned geographical limit is taken. The research is delimited to these spatial extents after the rather rich data available within each spatial limit pertinent to the data requirements to address the objective set forth (cf.,Sliuzas, et al., 2004).

Figure 1: Extent of study area




Source: Hill & Lindner (2010)

## 1.5. Conceptual framework

### 1.5.1. Nature of informal settlements growth

Informal settlements manifest different urban features pertinent to their stage of growth. Fekade (2000), citing Zaghloul (1994), describes that informal settlements do not follow a linear development pattern but explode at a certain stage of their development lifetime. This leads to the three phases of informal settlement growth:

- Infancy / starting stage: the stage at which available land (e.g. agricultural land) is converted to residential use by low-income households. It is depicted by scattered layout of built forms which in time will proceed from scattered expansion to reach collective expansion stage where almost 50 per cent of the settlement area would be built-up.
- Booming / consolidation stage: this stage comes into being by the urban critical mass after collective expansion. At this stage the middle income group is also attracted and housing construction would be heightened till no more vacant land is available. When the booming stage reaches its peak, about 80 per cent of the land would be used for housing construction.
- Saturation stage: this is the stage whereby additional construction is primarily entertained through vertical densification[3].

These are the basis of analysis in this research with regard to informal settlements growth pattern.

### 1.5.2. Hierarchy theory and scale issue

Hierarchy relates to the partial ordering of entities and comprises interrelated subsystems, each of which are made of smaller subsystems until the lowest possible level is reached. From the perspective of hierarchy theory, any hierarchical entity can be structured in a three-tiered system in which levels corresponding to slower behaviour are at the top ( level +1), systems attributed to faster behaviour would claim successively the lower level in the hierarchy (level -1), while the level mid way in the hierarchy is the focal level (level 0) which is the level of interest (Hay, et al., 2002).

Scale plays an important role in the understanding of hierarchical systems (Hay, et al., 2002; Wu & David, 2002). Issues of scales are also inherent in studies examining the physical and human forces driving land use and land cover changes (Currit, 2000). The multi-scale issue in urban growth has its own distinguishing spatial, temporal, and decision making dimensions. These scale dimensions may further be elaborated as to depict their distinct character as: spatial scale relates with the concepts of resolution and extent, temporal scale with the terms of time step and duration while decision making scale is linked to agent and domain (Cheng, 2003). A change in land use is the aftermath of multiple processes that act over different scales. There are dominant processes for each specific scale and aggregation of detailed level processes does not earn the real picture of the higher-level process. To this end hierarchically structured data can be useful to analyse land use, and the driving forces at different scales (Verburg, et al., 2004).

### 1.5.3. Modelling informal settlements growth with regard to hierarchy theory

As has been described in the foregoing section, informal settlements (ISs) do have three tiers of development stage – infancy, booming/consolidation and saturation. These stages can be interpreted as stages of expansion, densification and intensification, respectively, of informal settlements growth per se. As the main objective of this study is to investigate the drivers of ISG, here it is acknowledged that the key drivers responsible for ISG are diversified and with different level of significance to each specific stage.

[3] It should be noted that due associated expenses of stable structure that would bear anticipated vertical growth, at the infancy stage there is nearly none that would be erected accordingly. So, mainly it is an emergent behaviour (Fekade, 2000).

The urban planning development tier at the top of the hierarchy can have different levels of administrative structure to deal with informal settlements, and can respond proactively to ISG as per the drivers responsible for the specific growth pattern.

Here, in modelling ISG the three aspects to be looked in IS developments are: where will IS be, where will high density of IS be, and where will intensified IS proliferation take place? From modelling perspective these phases can be conceptualized and take the form of definition beneath (cf., Cheng, 2003):

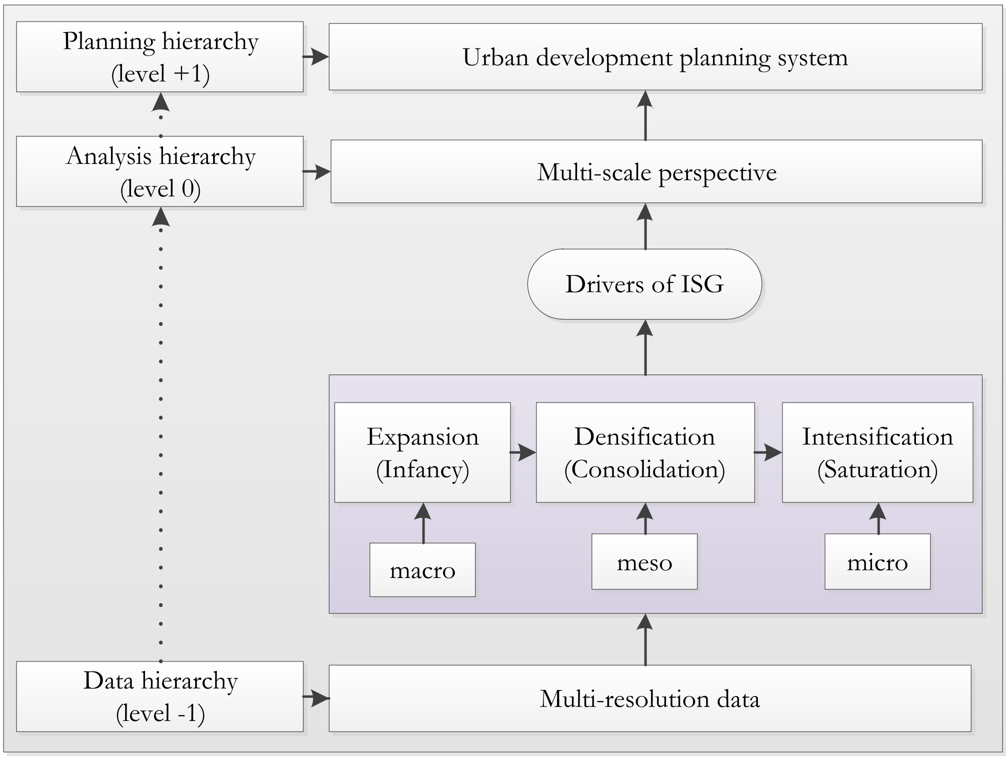
- Expansion: the possibility of any undeveloped land[4] to be transited to informal settlement in any pixel
- Density: the possibility of IS agglomerated in any pixel
- Intensity: the possibility of high density IS intensified in any pixel

In spatial extent, these concepts can also be hierarchically redefined as:

- Expansion (macro-scale): It covers the whole city proper of the study area, Dar es Salaam, and can be represented in the LR model as a binary spatial system E ($E_1$: change to IS, $E_0$: no-change to IS).
- Densification (meso-scale): It would have a spatial extent where there is a transition of undeveloped land to IS, i.e. $E_1$: change to IS. Densification, $D = E_1$, will have a binary system D ($D_1$: high density, $D_0$: low density)[5].
- Intensification (micro-scale): It is spatially limited to the extent whereby there is high density, $D_1$. Thus intensification, $I = D_1$, defines another binary system I ($I_1$: high intensity, $I_0$: low intensity).

This three-scale spatial extent of informal settlements growth is incorporated for analysis in a simple three-level hierarchy system.

Figure 2: Conceptual framework



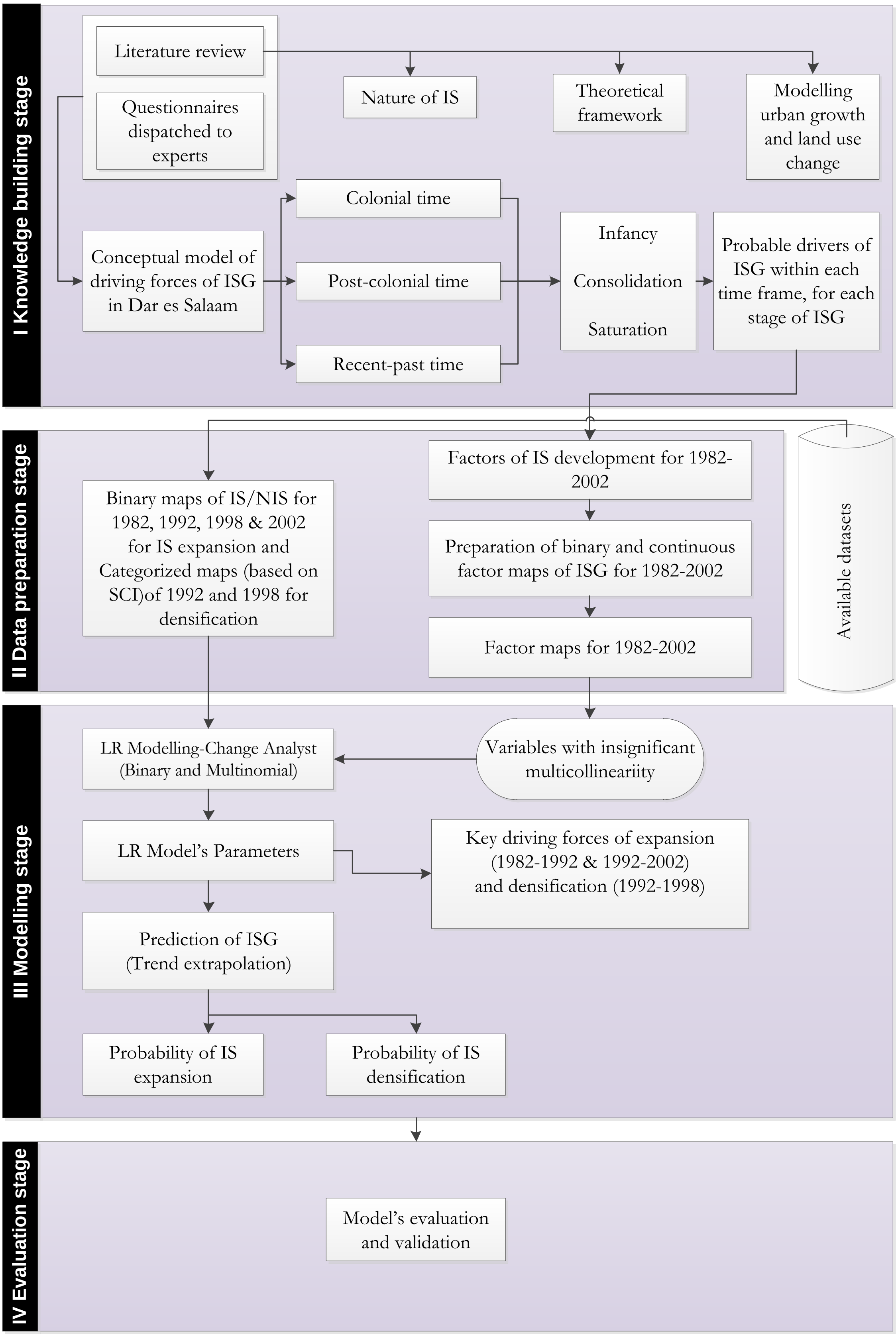

Source: Adapted from Cheng (2003)

[4] Undeveloped land: here defined as any pixel or area in the landscape which is un-built.

[5] Though the basic conceptual idea remains the same, densification here in this study is treated as a multinomial system.

## 1.6. Research design and outline of the thesis contents

Figure 3: Organization of the research



## 1.7. Thesis contents outlined in chapters

**Chapter One – Introduction**

This chapter provides general background information about informal settlements and their status in Dar es Salaam (DSM), introduces the research problem, research objectives and questions, the study area, and also highlights the conceptual framework the research is bound to.

**Chapter Two – Informal settlement issues in Dar es Salaam**

This chapter reviews literatures highly affiliated with the aim of the research with specified themes: urban informality, urbanization and informal settlement growth (ISG) in DSM, spatial character of informal settlements growth, problems and issues associated with ISG, urban planning practice in DSM, modelling urban growth, and previous researches on ISG in DSM. The literature review is supported by spatial data (from ITC), presented in the form of either maps or tables, where applicable.

**Chapter Three – Data and Methodology**

Chapter three gives a brief description of data used and methodological precedents by focusing on how and with what means probable driving forces of informal settlement growth are sorted out and the modelling of ISG is going to come to effect.

**Chapter Four – Results**

This chapter puts forward the ISG trend in DSM, probable drivers of ISG whereby experts differentiate for expansion and densification, conceptual model of ISG, logistic regression model (LRM) of ISG with significant drivers of expansion and densification, and the corresponding probable areas of ISG.

**Chapter Five – Discussion**

This chapter entertains the modelling approach followed (LRM) and its characteristics, discusses the significant driving forces and future probable areas of ISG that have been indicated by the model, looks at model output against actual situation in DSM, discusses the implications of the proposed model for actual urban planning practice, and further compares predicted IS expansion by LRM with predictions done by Cellular Automata (CA) modelling approach for the same study area.

**Chapter Six – Conclusions and recommendation**

This chapter responds to the objectives set forth in this thesis and summarizes the methods and results achieved, and recommend further research in line with it.

Table 1: Research method

| Main Research Objective: To investigate key driving forces of informal settlement growth (ISG) in Dar es Salaam by coupling GIS with logistic regression model | | | | |
|---|---|---|---|---|
| **Sub-Objectives** | **Research Question** | **Method** | **Data Required** | **Source** |
| 1. To build conceptual model of informal settlement growth (ISG) in Dar es Salaam | What is the spatial pattern of ISG in the development of Dar es Salaam? What are the potential drivers of IS expansion and densification across time in Dar es Salaam? | GIS analysis, literature review and questionnaire disseminated to key informants | Land use maps, literature and opinion of experts on driving forces of ISG | ITC archive (spatial data) |
| 2. To build a logistic regression (LR) model of ISG in Dar es Salaam | What are the driving forces of IS expansion and densification in Dar es Salaam? | GIS and SPSS data analysis and Logistic Regression (Change Analyst) | Land use map, shape file of population data, road, rivers, slope (DEM), map showing hazard prone areas (flood, landslide…etc), point data (CBD and other relative urban centres). | ITC archive and Federal government ministries of Tanzania |
| 3. To determine future ISG pattern in Dar es Salaam | How robust is the proposed LR model? Where are the probable areas of IS expansion and densification? What is the implication of future ISG pattern for the actual urban planning process? | GIS and SPSS data analysis and Logistic Regression (Change Analyst) | Derived factor maps of expansion and densification | Derived |

# 2. INFORMAL URBAN DEVELOPMENT ISSUES IN DAR ES SALAAM (DSM)

## 2.1. Introduction

This chapter underpins informal urban development issues in Dar es Salaam and sets background information on the whereabouts of informal settlements across time in the city. It starts by revisiting the concept of urban informality, followed by spatial analysis of informal settlements across time in the city, problems and issues on the surface related with informal settlement growth. Trends in urban planning practice in Dar es Salaam, available land use change models, and previous researches highly affiliated with informal settlement growth in the city are also entertained to give an insight to the context under consideration.

## 2.2. Urban informality

Second to agricultural practice, informal sector hosts much labour force around the world. Especially in the Third World many pays homage to it, to the level they quit the formal sector for the informal. Studies have shown that informal sector is definitely an integral part of the overall industrial sector, enriching the growth and development of many countries (Chukuezi, 2010). However, informality has its own repercussions though many governments had left it in limbo. Nevertheless, it has revived to be one of the concerns of international development and urban planning issues. International agencies and Third World governments are putting high-profile policies to practice to manage informality, let alone the recognition attributed to informal works and housing to constitute significant proportion of urban economies (Roy, 2005). There is a plethora of definitions in literature to informality but with minimum conceptual clarity and coherence which has led to incoherence in analysis and is also liable for some policy failures (Kanbur, 2009). Section 2.2 discusses the concept of informality and its evolving definitions, the relation of informality and informal settlements.

### 2.2.1. Concept of informality

Though the terms ‘formal’ and ‘informal’ were used in anthropological arena in 1960s, they were not put into development studies literature until the early 1970s (Bromley, 1978). In line with this, originally the concept of ‘informal sector’ was introduced by Keith Hart in 1971[6] (Moser, 1978). He used the term to refer to an economic activity that is not regulated at all, and reinforced it recently by claiming, “‘Formal’ incomes came from regulated economic activities and ‘informal’ incomes, both legal and illegal, lay beyond the scope of regulation” (Hart, 2008). Hart’s early paper had diffused immediately with all the recognition and inspired many articles to apply the concept of informal sector in a broader sense, even to self-help and dweller-control housing strategies and policies (Bromley, 1978).

[6] Keith Hart presented his influential paper entitled “Informal Income Opportunities and Employment in Ghana” at a conference on “Urban Unemployment in Africa” at the Institute of Development Studies, University of Sussex, September 1971 (Bromley, 1978).

There are two prominent perspectives towards the analysis of informality in the entirety of economic activities. One approach draws on the idea of dualistic economy and employment and distinguish formal/ informal dichotomy more akin to modern/ traditional divide, while the other stance treats informality as part of an economic continuum (Bromley, 1978; Chukuezi, 2010; Moser, 1978). The former treats informal sector as a totally segregated activity and phenomena to formal sector, but with likely integration with it by legalization process (De Soto, 2003), while the latter considers informality as part and parcel of an ongoing economic activity and mode of urbanization process (Bromley, 1978; Moser, 1978; Roy, 2005).

#### 2.2.2. Informal settlements as a spatial manifestation of informality

A diversified team of political scientists, anthropologists, and sociologists were at the forefront in conducting researches in 1970s and 1980s in Latin America that has shed light for the first time on informal housing and land market studies, which had also left Latin America highly intertwined with urban informality studies since then (Roy & AlSayyad, 2004). Nezar AlSayyad refers to urban informality as, "manifestation of informal process in the urban environment", and the mentioned studies were unique as they emphasized spatial implications of informality, otherwise there were also debates and researches at the same period focusing on the nature of informal work and dual economies (Roy & AlSayyad, 2004).

For the urban poor, in the context of rapid urban growth, unplanned development scheme would be beneficiary as it makes easy access to urban land and relieves the poor from sky-high land prices as the settlement becomes embedded with the urban structure (Baróss & van der Linden, 1990). The informal housing and land markets host the middle income and even elites, beyond the domain of the poor (Roy & AlSayyad, 2004). Mostly the informal settlements are established either by land invading and self-help housing or through informal subdivision of legally owned plot and market transaction, though in violation of land use regulations. These kind of trends lead to a complex continuum of legality and illegality (Roy, 2005).

### 2.3. Urbanization and informal settlement growth in DSM

Dar es Slaam is a relatively new city, established in 1862 by Sultan Sayid Majid of Zanzibar, compared with the historic stone towns of East Africa. The city is exceptional in East Africa for its diversity, yet high degree of social integration, and remaining tranquil and true to its name, the 'harbour of peace' (Brennan, et al., 2007; Bryceson, 2010; Lupala, 2002). Section 2.3 focuses on the urbanization of Dar es Salaam, spatial growth and structure of the city, local understanding of IS, and further elaborates on how ISs evolve and grow in the city and give an insight for the emerged location pattern of ISs.

#### 2.3.1. The urbanization of DSM

Dar es Salaam grew from a small natural harbour and trading centre that hosted almost 900 people in 1867 to be the largest city and leading economic centre of 2.49 million in 2002 (UN-HABITAT, 2010). Before its inception in 1862 as a new settlement, the vicinity of the present day Dar es Salaam was unoccupied land adjacent to a small fishing village. This area is noted to be a meeting point between local ethnic Zaramo inhabitants and the Shomvi people who were engaged in farming, fishing, boat building and slave trading (Brennan, et al., 2007).

The early period of Dar es Salaam, 1862-1887, was very trying in a way as the city struggled to ascertain its place as an economical hub to its rival Bagamoyo, fighting against outbreak of smallpox which has cost three-quarters of the town inhabitants, exacerbated in the years that follow by drought and famine. All these ordeals accompanied by the death of Sultan Sayid Majid in 1870 the city was portrayed after decline and decay till 1887. Nevertheless all these encounters did not abate the sustained growth of Dar es Salaam, which even in the 1880s had been a well-established secondary urban centre to Bagamoyo which is around 60km north of DSM (Brennan, et al., 2007).

Like other eminent African cities, Dar es Salaam (DSM) has also emerged as an important economical centre in the colonial and post colonial period (Lupala, 2002; UNCHS (Habitat), 1996). Thus, the urbanization of DSM can be viewed by two time slots: colonial DSM and post-colonial DSM.

**Colonial DSM (1887-1961)**

Although the year 1887 marks the time when the German East African Company was granted formal rights to collect custom duties in DSM, it was in 1891 that the city became officially the new capital of the colonial German East Africa rule. Nearly in three decades of their occupation till 1916, the Germans had tried to organize urban space of DSM to suit their colonial administration. Unlike other 19th century East-African coastal towns where urban growth was led by private commerce, Dar es Salaam's colonial urban expansion was marshalled by the state – heralded by exceptional architectural edifices erected by the imperial rule that showed their confidence in the potential of the land they already occupied well ahead of any vivid economic progress (Brennan, et al., 2007). The Germans had devised a number of legislative acts that gave shape to German-era urbanization in the city. There was a tripartite racial segregation of building standards among Africans, Asians (specifically Indians and Arabs) and Europeans. In line with this the administration had an active role in the selection of development sites for each social group and even invested vigorously in urban development projects, e.g., the establishment of Kariakoo, a planned African neighbourhood in response to enhance the urban quality of life, though not paralleled with the scale of descent housing demanded from the Africans (Brennan, et al., 2007; Sliuzas, et al., 2004). The Germans also stretch out a radial road network originating from the harbour which is still in use today (Brennan, et al., 2007), and along which many more urban development took place. Although the reliability of figures is questionable, the population of DSM at 1887 was reported to be only 3000 to reach 10,000 in 1894, and then to 13,000 by 1898. With unprecedented growth rate, the population in 1900 was recorded to be 20,000 but subsequent slow growth rates made it to be 22,500 by 1913.

The British colonial rule came to power in 1916 by defeating the Germans, and led the country, the then Tanganyika, till independence in 1961. During those years DSM has made significant progress, and became the undeniable economic, political and cultural centre of the country. The urban context in the British colonial rule can be viewed in two periods: before and after World War II (WWII). In the early years of the former period, the British opt to proceed with the segregation line of urban development already established by the Germans (Brennan, et al., 2007). In 1924 the town was clearly demarcated into three racially segregated zones: Zone I, embraced the earlier German quarter, northeast of the city centre, including the coastal suburb strip to the north, and was dedicated for the Europeans, while Zone II was reserved mostly for the Indians which occupied an area known for mixed use of commercial and residential activities. Zone III hosted the Africans whereby Kariakoo and Ilala were the core settlements along with a number of urban villages (Brennan, et al., 2007). The British further reinforces the segregation by creating an 'Open Space', so called 'neutral zone' between the Africans and Zone I and II, prior to which the area was characterised by racially mixed housing (Brennan, et al., 2007). The pre-WWII period is noted for the emergence of African urban cultural institutions, the looming of DSM as cosmopolitan city in the region, European and Indian amalgamated administrative structure, significant disparities in livelihoods of the different urban population rendered by the town, and the early 1930s depression which had forced an outflow of population that is liable to associated low levels of urbanization. However, the population generally increased dramatically within each respective racial group: Europeans in 1931 had reached 1300, and the Asians dominated by the Indian community had very significant presence, only the Indians had grown to 9,000 in 1937 from 2,600 at the last years of the German rule. The Africans, composed of diversified ethnic groups from all over Tanganyika and surrounding regions, in 1931 were around 15,000 (Brennan, et al., 2007).

The Second World War signalled a turning point for the persistent and accelerated urbanization of the city of DSM. Unlike the previous years, even worsening urban living condition in the 1940s, be it high unemployment rate like that of 1939 or low wages, was accompanied by unprecedented urbanization. The rural-urban migration was led by the perceived opportunity the city would present. For instance, the African community had increased from 26,000 in 1938 to 40,000 in 1944. The highly significant urbanization in 1940s was compounded with shortage in housing which had not been addressed to the scale of the demand and had continued into 1950s (Brennan, et al., 2007). In the late colonial period (1947-1961), though, there had been concerted efforts to enhance the economy, accomplish planned housing developments, provide public services and stretch infrastructures across the city. However, alongside the planned housing developments there had been substantial informal settlements appearance accommodating the ever increasing population. The Europeans in 1957 were recorded to be around 5,000, and the Asian community dominated by Indians reached almost 30,000 while the urban African population had been noted to increase to 93,363 in the same year (Brennan, et al., 2007).

**Post colonial DSM (1961-2002)**

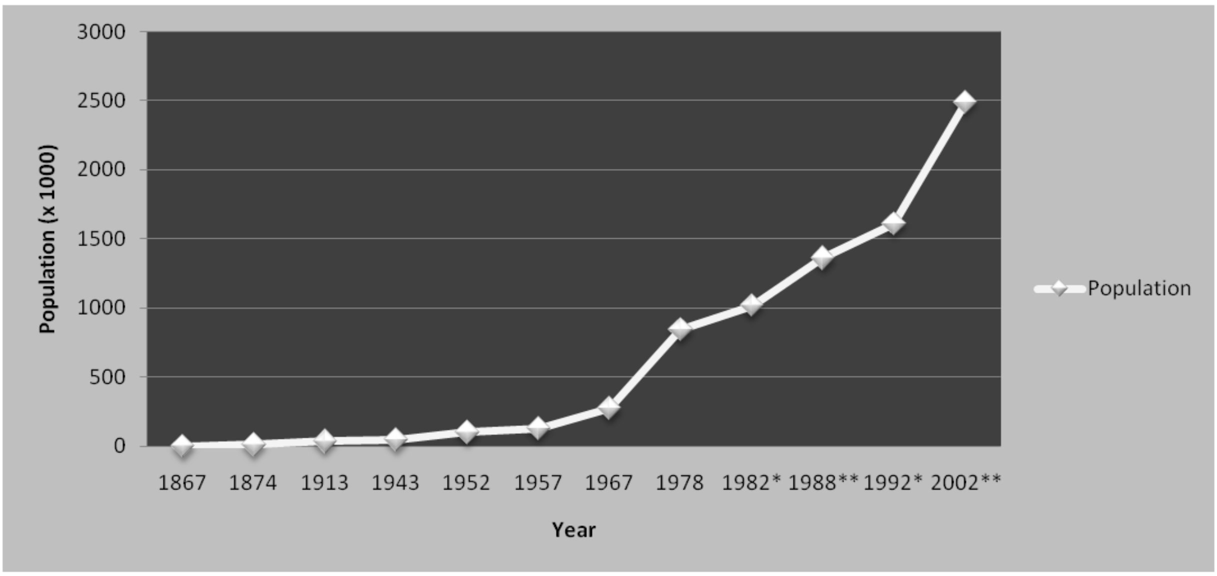
The independence gained in 1961 offered a great merit that propelled further development of the city. Racially informed urban governance was abolished once and for all, though eventual physical urban evolution of post colonial time was highly influenced by, and reminiscent of, late colonial urban development, both planned and unplanned (Brennan, et al., 2007; Lupala, 2002). Most of the early post colonial physical urban development , both planned and unplanned mixed, had gone along with or defined by the major arterial routes already constructed in 1950s: Bagamoyo Road to the north, Morogoro Road to the west, Pugu Road to the southwest, and Kilwa Road to the south. The first census after independence, in 1967, had noted the booming of African population as the Indians and Europeans conversely shrank. In the ten year time, 1957-1967, the African population had shown a change from 93,363 to 272,821, the Indians from 29,986 to 29,192 and the Europeans from 4,479 to 3,547. But in the decade that followed the overall urban population growth had revived rising from 7.5 to 9.8 per annum, DSM hosting a population of 769,445 by 1978 (Brennan, et al., 2007). The 1971 Acquisition of Buildings Act put the building boom witnessed in the 1960s to a halt through nationalization of second homes which resulted in acquisition of 3,000 buildings, of which 96 percent was owned by South Asians. Apart from its perceived role to level the economy, the acquisition of buildings was aimed to de-segregate the urban business centre which is dominated by the Indians. Nevertheless the Indians remained dominant across the years (Brennan, et al., 2007).

Dar es Salaam survived as a vibrant urban agglomeration despite the anti-urban policies enacted in both colonial and post colonial periods. It was in 1974 that DSM happened to be abandoned as a capital of Tanzania for a significantly smaller Dodoma (Brennan, et al., 2007), intentionally to deviate the relentless population growth in DSM and to revitalize the hinterland of Dodoma with urban development which proved to be unsuccessful mission due financial and management problems (URT, 2000). However DSM continued to flourish providing livelihood in both formal and informal sector. It was true that amid rapid urban growth the city could satisfy formal employment only in the first decades after independence. Commensurate with it was the growth of informal residential and economic urban space, though informal urban housing indeed was more significant in the process of urban informality. The proliferation of unplanned settlements that had been a hallmark of the late-colonial town, accelerated after the wake of independence. More than 50 percent of the urban population of DSM has lived in unplanned settlements in 1979, 478,489 out of the general population recorded 769,445 (Brennan, et al., 2007).

The revitalization of Dar es Salaam since 1980s is concomitant with the introduction of liberal economic system that also discarded the socialist sag of urbanization. However, unprecedented population growth spurred the proliferation of pronounced informal settlements and surpassed urban infrastructure to render it dysfunctional, all before the face of prepared master plan. This population increase has fuelled the accelerated land use change at the periphery of the city, peri-urban land from local/rural inhabitants to new settlers who were trading middle-class or salaried citizens. Such an urban growth considered trunk roads available, into and around the city, that would facilitate commercial and commuter transport. These projects have clearly moulded DSM to the present day, with ribbon-style urban development reaching 30 km to the west and north by the early 1990s (Brennan, et al., 2007). Specifically in 1992, Briggs & Mwamfupe(2000) noted that, 'wherever the physical features allowed, the expanding urban areas Dar es Salaam consisted of rural territory pierced by finger-like projections of urban land uses, especially residential'. Brennan, et al. (2007) have noted that the depiction of lack of planning synonymous with unplanned settlements no more hold true as middle income influx to unplanned settlements had become conspicuous reality. It is undeniable that the capacity of major roads has improved in 1980s, even though minor streets were on decline. In 1990s the city centre was preoccupied with intense and lavish building boom, as the decade also marks relentless expansion of informal settlements (Brennan, et al., 2007).

Dar es Salaam has become one of the spots of emerging economies, yet with insufficient and failing infrastructure. Due the relative political stability in the country and reliable security in the city, DSM has become an ideal seat for various profit and non-profit organizations. However both unprecedented economic and demographic growth put unparalleled burden on the limited infrastructure available, and also faced sky-high land and property values. Hence, Dar es Salaam has come to be a burgeoning economy in confrontation with issues presumably impeding its blossom – environment, infrastructure, and widening disparities between rich and poor (Brennan, et al., 2007).

Figure 4: Population growth in DSM 1867-2002




Source: Own illustration, based on data gathered from UN-HABITAT (2010) and census results. * calculated from respective annual growth rates, ** gathered from census result

### 2.3.2. The spatial growth and structure of DSM

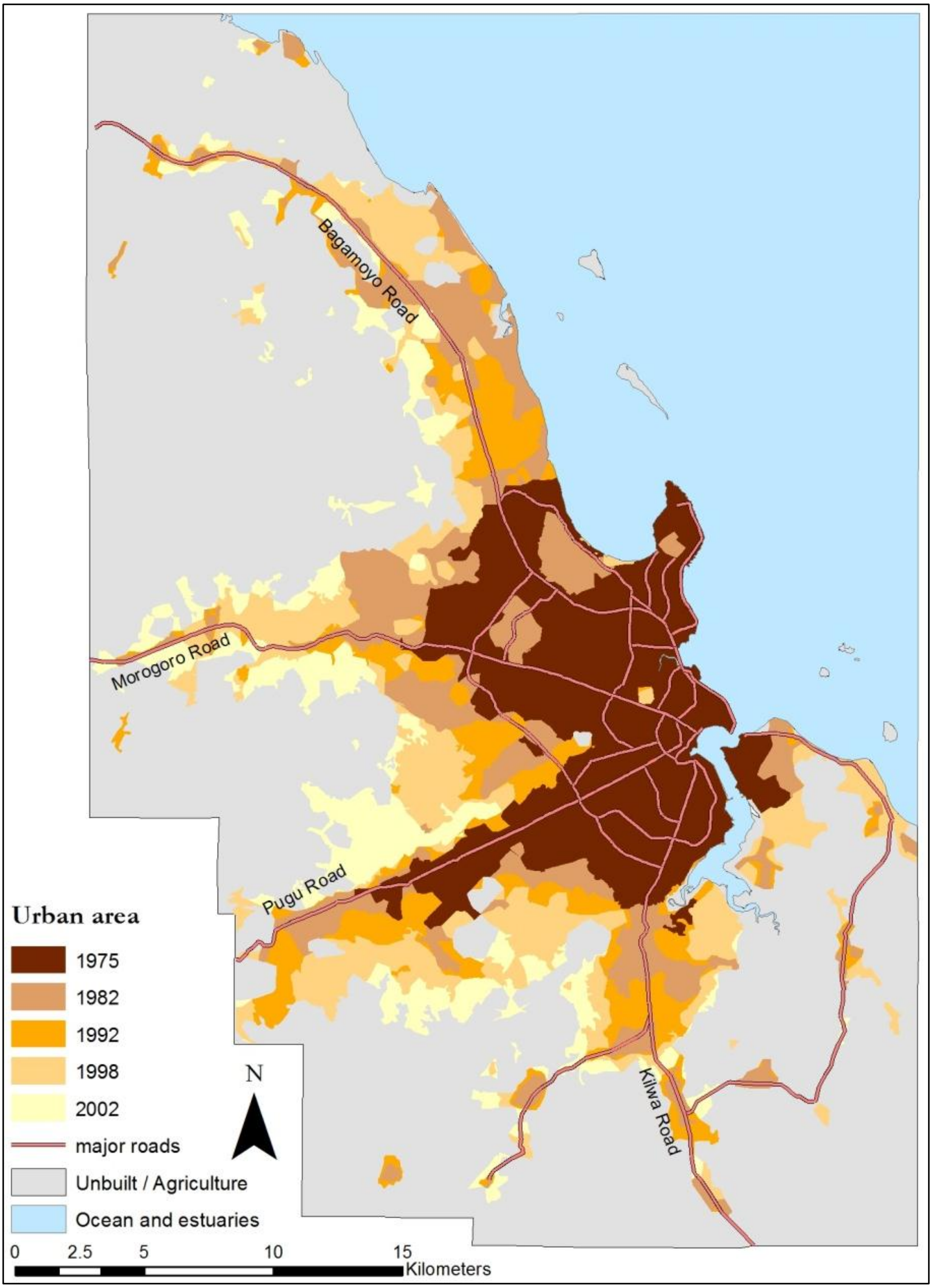
DSM, as a whole, persist to be a radially structured urban agglomeration since the German era to which the predecessor Sultanate administration had left nearly a grid layout that might be, of course, attributed to the then small size of the city (Brennan, et al., 2007). It is a 'finger-like' stretch of urban development along trunk infrastructure services mainly roads, water supply and electricity (Lupala, 2002; UN-HABITAT, 2010). The report by UN-HABITAT (2010), based on consolidated urban area, noted DSM as bounded within 2 km radius in 1945 from the CBD, while in 1963 the radius further increased to 6 km, and subsequently to 14 km in 1978, and 18 km in 1991. In the years that follow the urban development was pronounced mainly after main roads. By 2002, consolidated urban development had reached 32 km along Bagamoyo Road, 28 km along Morogoro Road, 20 km along Pugu Road and 14 km along Kilwa Road.

This ribbon-like leapfrog urban development of DSM has encountered steady population increase over time, yet accompanied by significantly fluctuating gross population density due the spatial extent of built up area witnessed at each period. In 1891, when the Germans officially claim DSM as the capital of their East Africa colonial rule, the city had only 1.22 $km^2$ of built up area with gross population density of 4,500 persons per $km^2$. The figure increased in 1945 to gain the city's ever high population density recorded, 13,000 persons per $km^2$ in built up area of 4.63 $km^2$. Unprecedented urban expansion took place between 1945 and 1963, to which the total built up area dramatically increased to 30.81 $km^2$, leaving the population density at 4,900 persons per $km^2$. However the density has been set on the trajectory as more and more Africans flocked into the city in the wake of independence. Thus, by 1967 the density was noted to be 6,600 persons per $km^2$ with 41.34 $km^2$ built up area, while in 1978 it had reached 7,400 persons per $km^2$ amid tripled population growth in ten years time, i.e., 843,090 in 1978 from what has been 272,821 in 1967. Regarding population density the 1980s and early 1990s accorded similar trend to that of the previous decade. Nevertheless in 2001, with DSM's then estimated population of 3,000,000 within 572 $km^2$ built up area, the gross population density has diminished to 5,200 persons per $km^2$ (Lupala, 2002; UN-HABITAT, 2010). The 2002 census result revealed population density of DSM to be 1,786 persons per $km^2$, taking 2,487,288 inhabitants and 1,393 $km^2$ as total population and administrative area, respectively (URT, 2006).

In light of settlement consolidation, DSM reveals three distinct zones of informal settlements situated in diminishing order of proximity to the CBD across the landscape (UN-HABITAT, 2010), constituting:

- The inner core zone: This zone is characterised by informal settlements with high density, almost 40 houses per ha, and presence of a number of settlements prone to floods. The high densities coupled with usually unstructured settlement layout deter infrastructure services provision for their implied high cost.
- The intermediate zone: This is a zone incorporating informal settlements with hastened consolidation rate without any guidance from planning authorities.
- The peri-urban zone: This zone, situated at the fringe of the city, is typical of informal settlements haphazardly booming without any consideration to future functional structure or environmental protection measures. This zone is often invaded by the urban poor and the middle income alike.

Figure 5: Spatial growth of Dar es Salaam from 1975 to 2002



### 2.3.3. Understanding informal settlement in the context of DSM

Informal settlements are known by different names across the globe: barridas (Peru), kachi Abadis (Pakistan), kampung (Indonesia), shanty towns (English-speaking Africa), favela (Brazil), bidonville (French-speaking Africa), Gecekondu (Turkey), and the like. Despite their localities and associated designations, Fekade (2000) notes that, almost all informal developments share, among many others, the attributes listed below:

- They are constructed by the inhabitants themselves without any public assistance, regardless of persistent eviction threats from public authorities, with an intended aim of housing themselves, renting it out or both.

- They are main refuges to the urban poor for whom formal procedures to access either land or housing unit hardly exist.

- Houses that constitute informal settlements are basically financed through informal means.

- They depend on local building materials, skills, designs and indigenous technology.

- They are not in compliance with legal building codes and standards, more so at the initial stage of settlement establishment.

- They display diversified housing units in terms of type and construction quality. Structures with permanent/modern building materials coexist with temporary/traditional ones.

- They blossom as housing units go along with incremental transformation which ensures flexibility for the owners.

The informal settlements in DSM not only share all the aforementioned attributes, but also display typical characters that are evident of all informal settlements in Tanzania. Although slums and informal settlements are two different phenomena, one may lead to the other – informal settlements could be an ideal breeding platform for slums (Abbott, et al., 2001). But, taking informal settlements synonymous with slums, UN-HABITAT (2010) depicts the unique characteristics of informal settlements in Tanzania as opposed to the official definition of slums. The operational definition of slums incorporates the characteristics: inadequate access to safe water, inadequate access to sanitation and other infrastructure, poor structural quality of housing, overcrowding and insecure residential status (UN-HABITAT, 2003). UN-HABITAT (2010) and Nguluma (2003) claims, unlike the foregoing definition, informal settlements in Tanzania differ in terms of tenure security; structural quality of housing; and nature of inhabitants residing in the settlements (social composition):

- Tenure security: Anyone who erects a structure in informal settlement has 'perceived' security of tenure emanating from three precedents. They are governments' tolerant and sympathetic stance towards proliferating informal settlements since 1970s, supportive principles embedded in the National Land Policy both at 1995 and 1999 that ensure the interest of the dweller, and the progressive human settlement development policy adopted in 2000 by the government.

- Structural quality of housing: Household Budget Survey done in 2000/1 and 2007 showed that the use of permanent and modern building materials throughout the country has increased tremendously since 1991/92, and especially in DSM. This change of behaviour is partly attributed to the aforementioned perceived tenure security.

- Social composition: Informal settlements in Tanzania, with the exception of those in hazardous areas, are host to a wide range of socio-economic groups. Easy access to land as opposed to existing inefficient formal land delivery system is accounted for many to pay homage to informal settlement, let alone the favourable land policy and security of tenure.

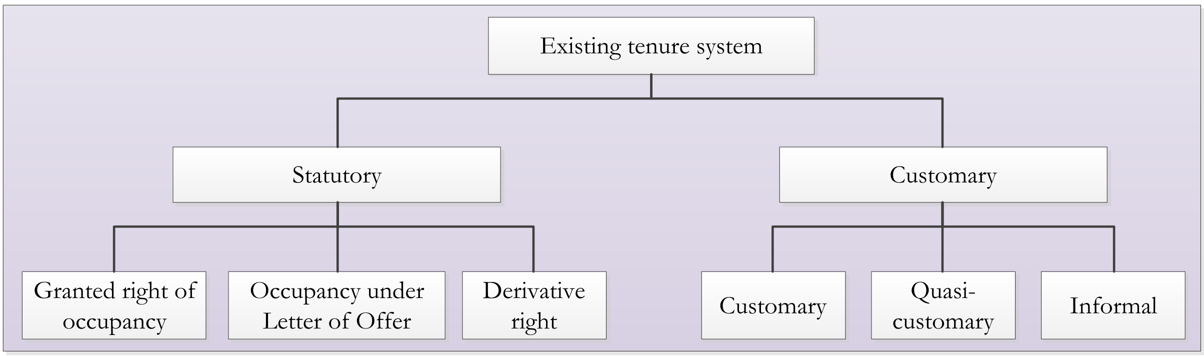
Land in Tanzania is owned by the state, and it is safeguarded by the President for the interest of all the citizens (UN-HABITAT, 2010). This indicates that there is no private ownership of land, and bare land has no value but existing structure upon it. However, this law is in stark contrast with the reality on ground; as land is sold like any other commodity and more so in the informal settlements where selling of plot of land and housing units is a usual practice (Nguluma, 2003).

There are two legally acknowledged land tenure systems in the country: statutory and customary (Figure 6). UN-HABITAT (2010) summarizes the constituents of these two systems as:

Statutory:
Granted right of occupancy: A surveyed land granted by the government up to 99 years with annual rent imposed.
Occupancy under letter of offer: Entitlement to ownership of land after accepting an issued letter of offer.
Derivative right: Based on the Land Act (1999), the government respects the right of occupancy and offers a "residential licence" on non-hazardous land, land reserved for public utilities and surveyed land for a term not less than six months and not more than two years.

Customary:
Customary: Occupation of land that is readily accessible by being member of a community and is totally based on traditional acceptance.
Quasi-customary: Land tenure characterised by less influence of clan or community but local leaders and neighbouring landowners would be consulted on land transfer; however the right to sell lies on the individual right holder.
Informal: land transfer guided by neither customary nor quasi-customary but with the interest of land seeker and land owner.

Figure 6: Existing tenure systems in Tanzania




Source: UN-HABITAT (2010)

### 2.3.4. Evolution, location and growth of informal settlements in DSM

Informal settlements are mainly features of the late colonial period, though showed relentless proliferation to date (Brennan, et al., 2007). These informal settlements had shown certain cohesion with some features and phenomena of the urban landscape. Proximity to major transportation axes, to industrial areas, to city centre, to the harbour, and to institutional areas have had a strong role in the evolution of informal settlements in Dar es Salaam. Among the settlements some are located on environmental hazard prone areas and steep slopes that are host to erosion, flooding and faulting. Under-performance of formal land management and poor land servicing system are also accountable for the growth of informal settlements amid rapid urbanization (Kyessi, 2002).

Informal housing units had grown exponentially since 1960s. W.J. Kombe & Kreibich (2000) noted that in 1960 the number of 'squatter' houses in DSM was only 5000, but increased to 7000 in 1963, and this figure eventually found to be quadrupled in 1972 as it roars to 28,000. Thirty years later, in 2002, 1,696,500 people (68 percent of the total population) lived in informal settlements in the city (UN-HABITAT, 2010).

Figure 7: Informal settlement expansion in Dar es Salaam from 1982 to 2002

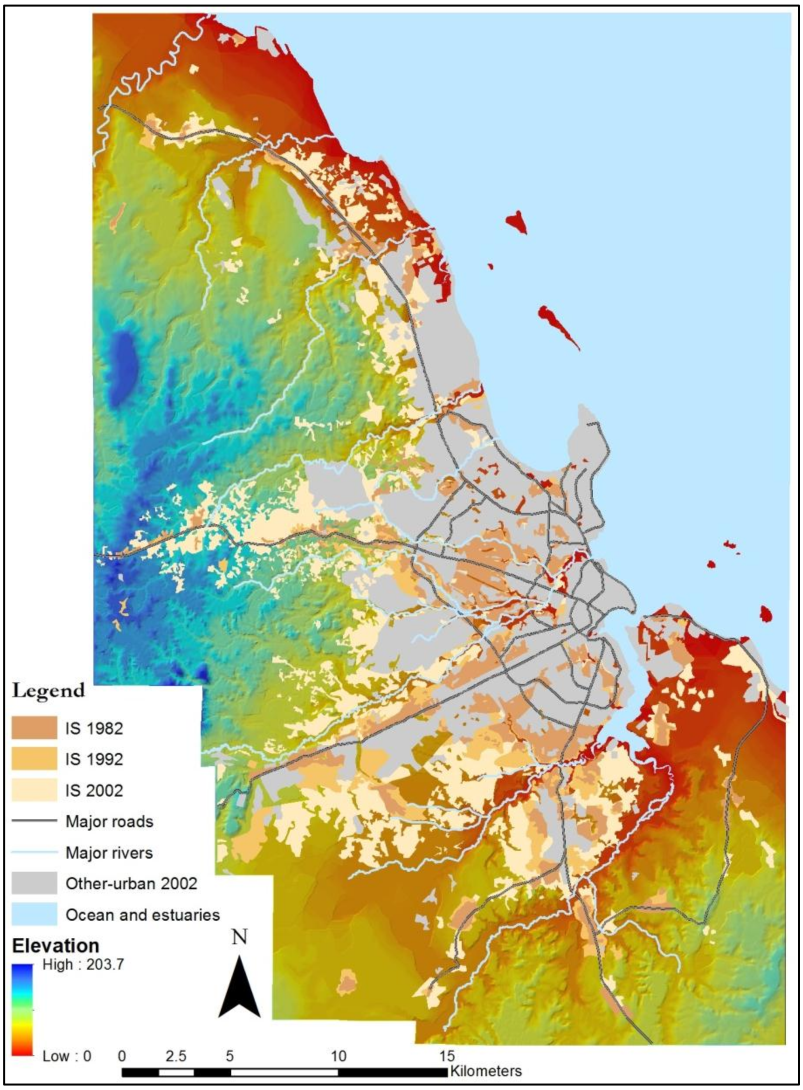


Figure 7 shows the spatial pattern of informal settlements seen at 1982, 1992 and 2002. The pattern does cling to the four main radial roads/outlets that emanates from the city centre. It also depicts that the informal settlement expansion from 1992-2002 is by far larger than the earlier decade.

Table 2: Informal settlement expansion with respect to land form

| Landform | IS area 1982 (m²) | rate of change (%) | annual growth rate (%) | IS area 1992 (m²) | rate of change (%) | annual growth rate (%) | IS area 2002 (m²) |
|---|---|---|---|---|---|---|---|
| Coastal Plain | 42,930,517.00 | 46.51 | 4.65 | 62,899,016.96 | 82.68 | 8.27 | 114,901,344.27 |
| Hills | 6,290,990.85 | 88.88 | 8.89 | 11,882,429.06 | 285.92 | 28.59 | 45,856,258.17 |
| Ocean/Eatuaries | NA | | | NA | | | NA |
| Quarry | 191,360.12 | 61.82 | 6.18 | 309,663.33 | 101.07 | 10.11 | 622,626.71 |
| River Valley | 2,299,159.99 | 167.10 | 16.71 | 6,141,167.36 | 116.12 | 11.61 | 13,272,043.41 |
| Salt pan | 0.00 | | | 0.00 | | | 59,662.12 |
| Swamp | 468,627.96 | 52.51 | 5.25 | 714,721.13 | 26.63 | 2.66 | 905,073.00 |
| | | | | | | | |
| Total | 52,180,655.93 | 57.04 | 5.70 | 81,946,997.84 | 114.31 | 11.43 | 175,617,007.66 |

Source: Own calculation, based on spatial data from ITC.

Informal settlements in 1982-2002 had expanded mostly in areas where the landform is either hilly or river valley. From 1982-1992, high rate of expansion, 167.10 % and 88.88 %, was observed in river valleys and hilly areas, respectively. Similarly, from 1992-2002, it is on hilly areas that high rate of expansion had taken place, 285.02 %, followed by river valleys, 116.12 (Table 2).

Among the three municipalities of DSM, Temeke houses the highest proportion of its population in IS; followed by Kinondoni and Ilala. But, in absolute terms, Kinondoni hosts large amount of population in IS (Table 3).

Table 3: Population living in informal settlements in DSM in 2002

| Municipality | Total area (ha) | Informal area (ha) | Total population | Population in informal areas | % of total population in informal area |
|---|---|---|---|---|---|
| Kinondoni | 53,100 | 2,560 | 1,089,000 | 768,000 | 70 |
| Temeke | 771,500 | 2,000 | 771,500 | 600,000 | 78 |
| Ilala | 21,000 | 1,095 | 637,500 | 328,500 | 52 |
| Total | 845,600 | 5,655 | 2,498,000 | 1,696,500 | 68 |

Source: UN-HABITAT (2010)

## 2.4. Spatial character of informal settlement growth

Informal settlement growth is effected in three distinct but overlapping means: expansion, densification and intensification. This section elaborates on these issues and makes a summary of ISG vis-a-vis how ISs appear, expand, shrink, disappear, densify and intensify.

### 2.4.1. Expansion

Conceptually informal settlement expansion can be achieved in three forms: inward, outward or independent from a known boundary of an existing settlement (Figure 8). Timothy (1995), noted this type of growth as an external growth and refers to it as, '...the extension of a settlement or colonization of new areas whether adjacent or not to the existing settlements'.

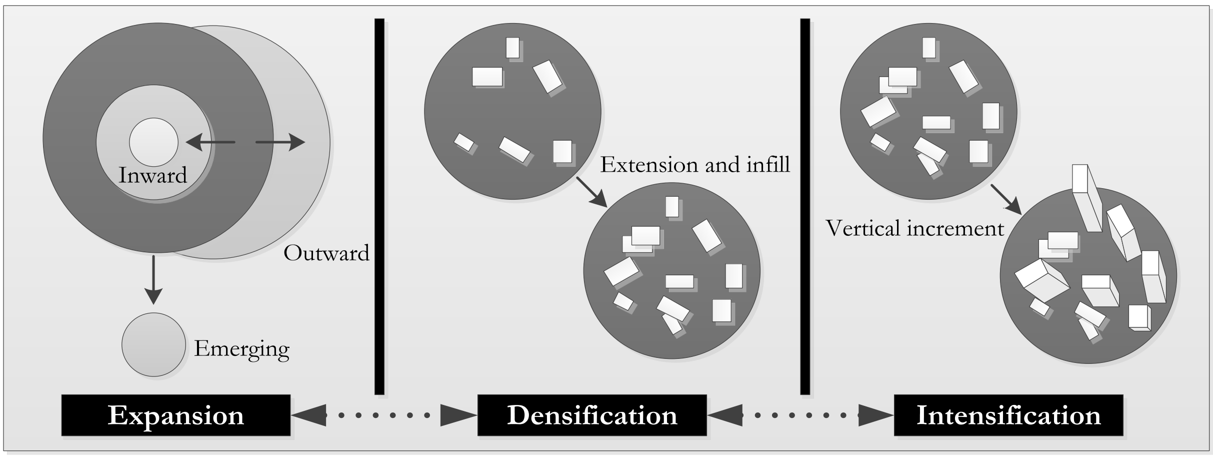
### 2.4.2. Densification

Densification refers to the infilling of empty spaces by building structures built within the realm of an existing settlement (Timothy, 1995). Density is one of the most contentious terms used in urban development issues (Lupala, 2002). There are a number of ways in practice that are used to refer to density: population density, residential density, gross density, net density, perceived density, ...etc (Acioly & Davidson, 1996). Many studies has referred to density as "low", "medium" or "high", which are relative terms that differ between countries and communities, and also depend on the perspective the issue of density is being looked at (Lupala, 2002). In this study, similar density classification has been used based on Settlement Consolidation Index (SCI), data processed from SPOT images as described in Sliuzas(2004). These pixel based density classifications are used to create an aggregate density for each settlement (more on SCI in Section 3.4.5).

### 2.4.3. Intensification

Intensification is the vertical increment of built-up structures. Timothy (1995) considered intensification as one form of the internal growth along with densification. In this study, though, intensification is seen as a distinct form of informal settlement vertical growth.

Figure 8: Concept of ISG




Source: own construct

Figure 8 portrays the three forms of informal settlement growth. Although informal settlement growth/proliferation is said to be effected via expansion, densification or intensification, it is an intertwined phenomena of two or all the three forms. However, in this research expansion is modelled an autonomous form while densification model is accompanied by expansion of settlements.

### 2.4.4. Summary of IS growth process

Informal settlements evolve pertinent to the "utility" value of the specific location they are found in. However the concept of "utility" in occupying land informally would be rather fuzzy as most settlers give high value to a land with relatively low expulsion risk regardless of other alternatives available (de Bruijn, 1991). Notwithstanding the threat of eviction and other pressing challenges, informal settlements often expand, densify or intensify. In the informal housing stock, specifically in DSM, incremental/phase construction is common phenomenon as savings are the main source of funding (Kyessi, 1990). Table 4 summarizes the distinctive processes a settlement is likely to pass through; a generic representation of informal settlement growth.

Table 4: Physical growth process of informal settlements

| Settlement process | Description | Possible causes and implication |
|---|---|---|
| **appear** | New settlement formed | The number of buildings has increased to an extent that they are recognised by the local population as a settlement. Social recognition of a settlement may precede administrative recognition |
| **expand** | Spatial extent of settlement increases | Additional incremental construction of new buildings on the edge of an existing settlement leading to spatial growth |
| **shrink** | Spatial extent of settlement decreases | Loss of some buildings due to natural disasters or human intervention resulting in a reduction of settlement size |
| **disappear** | Settlement totally destroyed | Special case of shrink leading to total loss of all or part of the settlement. Could be due to a natural disaster such as a flood, earth quake or an administrative intervention to relocate a settlement from one location to another |
| **densify** | Horizontal increment of floor space within the settlement area, (increase in BAR) | Results from additional construction (either new buildings, or additional rooms to existing buildings leading to an increase in floor space within the settlement |
| **intensify** | Vertical increment of floor space within the settlement area, (increase in FAR) | Addition of floor space on existing building or replacement of existing building with new multi-storey building, or even the construction of new multi-storey building on unoccupied piece of land within the settlement |

Source: Adapted from Sliuzas, et al., (2004)

## 2.5. Problems and issues associated with ISG

As discussed in previous sections, informal settlements are common place phenomena in developing countries' urban landscape. They are often attributed with "low-standard housing, overcrowding, acute shortage of basic physical and social services and infrastructure, high environment and health threat, non-compliance to planning regulations, insecurity of tenure, faulty alignment of streets, social composition (especially in relation to migration) and unfavourable socio-economic and living conditions." (Sietchiping, 2005). Most informal settlements exist on environmentally conserved areas or areas vulnerable to floods, landslides or other hazards (UN-HABITAT, 2009a).

Though informal settlements are being acknowledged as creative and instinct response of the urban population after inadequacies of public policies (Fekade, 2000; Kombe & Kreibich, 2000; UN-HABITAT, 2009a), it is inevitable that it still needs intervention prior to its intrinsic qualities. International bodies, governments, researchers, and many more concerned bodies have been devising approaches to deal with informal settlements. These interventions may comprise, among others, upgrading, resettlement, sites and services, and guided land development. All approaches have their own financial consequences to which their success is questionable (Sliuzas, et al., 2004). It is also apparent that none could stop further proliferation of informal settlements (Sietchiping, 2005).

Most of the interventions and urban policies towards informal settlements have been reactive, very costly and far way behind controlling further expansion and densification. Understanding driving forces that lie behind the scene and detecting future probable areas of informal settlements growth would help urban planners and policy makers to be proactive and better address the issue. Sliuzas, et al. (2004) notes, "Proactive interventions that are designed to prevent the creation of informal settlements are equated with the formal model of urban development". To this end, modelling informal settlements growth reinforces planning process and supports informed decisions.

### 2.5.1. IS and its societal, economic and environmental attributes

Informal settlements have their own way of establishment and eventual development, as compared to formal development. They are self-planned settlements, as some opt to call them (e.g., Fekade, 2000), where societal regulation in land delivery system plays a pivotal role. (Kombe & Kreibich, 2000). Although, as Nguluma (2003) and (UN-HABITAT, 2010) indicated, informal settlements in Tanzania house peoples from different social and economic background, they have a unique character they attain on a settlement level opposed to planned settlements. The informal built environment is typically characterized by lack of public services and facilities (Nguluma, 2003). Kyessi (2002) summarizes the intrinsic characteristics of informal and formal settlements (Table 5).

Table 5: Characteristics of informal and formal settlements

| Informal settlements | Formal settlements |
|---|---|
| Ease of entry - low entry costs | |
| Informal land allocation according to need (follow flexible standards) | Inappropriate (fixed) standards in land use planning and allocation |
| Build affordable shelter using step-by-step procedure of development | Follow unaffordable building regulations leading to inadequate shelter |
| Unregulated and competitive markets | Controlled markets (land value and rental markets) |
| Efficient socially regulated land delivery mechanism | Inefficient land delivery mechanisms based on 'paper plans' |
| Unserviced land subdivided at will and sold | Shortage of surveyed  and serviced land |
| Labour intensive and adapted technology | Capital intensive and imported technology |
| Indigenous resources - traditional family or class mutual self-help system | Resource constraints - insufficient cost recovery mechanisms and relying on grants/ loans |
| Skills acquired outside the formal system | Formally acquired skills |
| Local governance and informal information flow | Lack of good governance |

Source: After Kyessi (2002)

### 2.5.2. Intervention programs and policies to deal with IS

Since independence there were a number of intervention programs and urban policies to ameliorate the living condition of urban dwellers and boost the economy. Tanzanian government has adopted a number of international practices and made public sector reforms accordingly, most of which did not meet their prescribed goal but burden the urban poor with unprecedented problems. Sliuzas, et al.(2004) noted that high rates of inflation, devaluation, economic liberalization and privatization of manufacturing and service proving entities had by large affected the life of the urban poor. Kyessi (2002) summarizes the urban policies in Tanzania from 1961-2002 and the means through which these policies were implemented (Table 6).

Table 6: Urban Policy in Tanzania and implementation strategies between 1961 and 2000

| Period | Policy context and process | Implementation strategy ( formal and informal) |
|---|---|---|
| **Urban Policy in the 1960's, Theme: Modernisation and political consolidation** | Decolonization and training of urban workforce | De-regularisation, i.e. free movement of people from rural to urban areas |
| | Urban areas for all and Slum clearance Scheme, e.g. Buguruni, Kisutu, (1964-68) | Communal ownership |
| | Co-operative Housing | Demolition of CBD informal settlements |
| | Nationalisation of major means of production | Creation of National Housing Corporation |
| | Free-of-charge community services, e.g. water, health, education | Government control of major means of production - monopoly through creation of parastatal organizations with statutory powers |
| | Arusha Declaration (Ujamaa and Self-reliance) | |
| **Urban Policy in the 1970's, Theme: Decentralization and Socialism** | Decentralisation and creation of regional offices | Nationalisation of housing and creation of Register of Buildings |
| | Growth Pole Policy to stimulate rural development - emphasis on rural development to the relative neglect of urban areas | Establishment of parastatal organisations |
| | withdrawal of workforce from local governments including urban councils | Sectoral planning - public sector led |
| | Sites and services and squatter upgrading | Establishment of sites and services and squatter upgrading unit based in Ministry of Lands |
| | | Sectoral piecemeal infrastructure projects in different ministries as catalyst for development |
| | | Abolition of local authorities |
| | | Private sector discouragement |
| | | Creation of Tanzania Housing Bank |

Source: After (Kyessi, 2002)

Table 7: Urban Policy in Tanzania and implementation strategies between 1961 and 2000, cont'd

| Period | Policy context and process | Implementation strategy ( formal and informal) |
|---|---|---|
| **Urban Policy in the 1980's, Theme: Structural Adjustment** | Urban Development and National Housing Policies | Enactment of Local Government (Urban Authorities) Act |
| | Re-introduction of local governments | Creation of urban and district councils |
| | Liberalisation | Capacity decline - funds, trained manpower |
| | Structural Adjustment Programme | Collapse of parastatal companies |
| | Government withdraw in supply of commercial activities | Retrenchment of workforce in parastatal organization and government departments |
| | Removal of subsidies and sharing costs, e.g. in education and health | Self-help projects - e.g. housing and infrastructure provision |
| **Urban Policy in the 1990's, Theme: Privatisation and Management Efficiency (lean government)** | More decentralisation (Regional Administration Act and Local Government Reform Agenda) | Transfer of central government staff to local (district councils) authorities |
| | New National Land Policy | Privatisation of public companies and public service provision |
| | Environmental sustainability through enactment of National Environmental Policy and Poverty Eradication Strategy | Gender equity in access to land |
| | Privatisation and economic competitiveness | Partnerships (public and private) |
| | Good Governance | Urban infrastructure services improvement - e.g. roads, sanitation etc. |
| | Community Development | Community involvement - formation of CBOs and NGOs for local solutions - Stakeholder involvement |
| | | More retrenchment |
| **Urban Policy in the 2000's, Theme: Economic Growth and Poverty Eradication** | Community development | Partnerships between public/ private/ community |
| | Decentralization of public urban provision functions to settlement/ neighbourhood level | Mobilisation of actors in human settlement development |
| | Job creation and income generation | Community (stakeholder) participation in local solutions, local projects as catalysts for development |
| | Further privatization, economic competitiveness and competitive funding | More urban infrastructure/ environmental improvement |
| | Enabling governance and capacity building - training | Private sector- led commercial activities and service provision |
| | Innovation | De-regulation |
| | Economic sustainability | Empowerment of local institutions |

Source: After (Kyessi, 2002)

### 2.5.3. Managing informal settlements

Managing and planning of informal settlements is one of the challenges facing SSA countries amid scarce data (Sliuzas, et al., 2004). This would be exacerbated more in the middle of inefficient land delivery system for housing. Kombe (1995) after discussing observed under-performance of formal land management in DSM concluded that the dysfunctional land delivery system had had damaging effects on urban land management, and further argues spontaneous urban development, under-utilization of allocated land and over-crowding to be main manifestation of the system's failure. Due this incompetent land management practice in designing, administering and implementing land management policies, an informal land management system led by social regulations had been active (Kombe & Kreibich, 2000). Though informal land management system is noted for being innovative, adaptive and efficient at the early growth stages of peripheral settlements, it would soon get stacked as the settlement gets saturated and land values rise up. This system is concerned about satisfying the interest of the individual and not the public sector that, as the settlements saturate, high densification occurs on land reserved for public uses like road and footpaths. Incompatible land uses, inefficient use of land, absence of any open space devoted for both current and future social infrastructure are some of the challenges associated with informal land management which is believed to be more rewarding if integrated with formal system. (Kombe & Kreibich, 2000). However, the formal system yet needs much enhanced means for managing informal settlements.

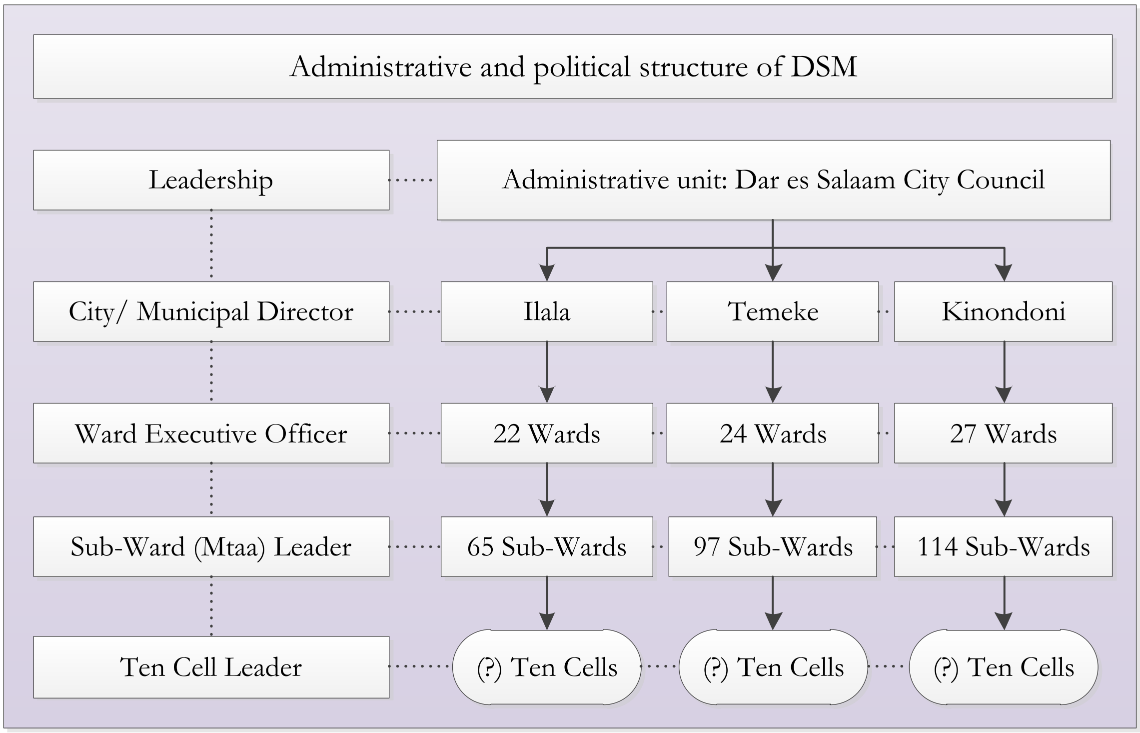
## 2.6. Urban planning practice in Dar es Salaam

Administrative setting

DSM is constituted of three municipalities subsequently divided into Wards, Sub-Wards and Ten Cell Units (Figure 9). Both Ward Executive Officer and Sub-Ward Leader are government representatives in the area, while the former is appointed by the government the latter is elected by residents living in a specific Sub-Ward (Mtaa). Size of Sub-Wards vary according to geographical size of their respective Ward and its population distribution (Kombe & Kreibich, 2000).
In Dar es Salaam City Profile document, Dar es Salaam City Council (2004), it is noted that Dar es Salaam City Council is headed by the Mayor elected by councillors who form the City Council, whereby the City Council is the governing body of the city at the higher hierarchy. Immediately down in the hierarchy the City Director takes the responsibility to administer the city, which incorporates three Heads of Departments, those are:

- City Administrative Officer: in charge of Finance and Administration Department
- City Economist: in charge of Planning and Coordination of all city development activities
- Urban Planner: in charge of Urban Planning, Environment and Utilities Services

Figure 9: Administrative and political structure of Dar es Salaam




Source: Own illustration, based on Dar es Salaam City Council (2004), UN-HABITAT (2010) and Sliuzas, et al.(2004)

Institutional set-up

In Tanzania central-government and local governments (either urban or rural) form a two-tier system of governance, where by the former one is entitled to develop and implement regulatory frameworks while the latter can initiate their own land use plan subjected to central government's approval (Kironde 2006). DSM, as one of the local governments, has its own established institutional set-up. The three municipalities in its administration, Ilala, Temeke, and Kinondoni, are all composed of councillors and department experts that form three committees: Municipal Planning Committee, City Planning Committee, and Urban Planning Committee. Each municipal administration is responsible to its own municipal development and land management issues to which a concerted effort is indispensable. Usually the Urban Planning Department works hand in hand with Surveying, Engineering and Land Valuation Departments; and moreover in partnership with different stakeholders and any interested party in urban development (UN-HABITAT, 2009b). It should be noted that urban infrastructure and services, like supply of water and electricity, and developing road networks are operated by independent agencies that are answerable to the central government (Kironde 2006).

### 2.6.1. Overview of the urban planning context

The urban panning practice in DSM had loomed out in parallel with the paradigm shift in urban planning generations. Its urban planning and management system had followed track of new urban planning ideals through decades, and evolved from technocratic blue print master planning and searching solutions in physical planning towards strategic planning coupled with action planning led by participatory planning approach. However, weak national economy and associated weak public sector performance has hampered qualified/standard local service provision which undermines the quality of life in DSM (Sliuzas, et al., 2004).

#### 2.6.2. Master Plans proposed to Dar es Salaam

Master plans proposed to DSM had hardly addressed the pressing issues that confronted the city. Armstrong (1987), noted that despite the proposed master plans the city was yet with "alarming symptoms of urban crisis" that has been manifested through sustained high rate of population growth with unmatched housing needs, unemployment, poor water and electricity supply, poor sewage and public transport system, urban blight that contributes to health hazards and pollution, and increasing crime rate. He further noted that more than two third of the housing stock was reportedly squatter. Among the three proposed master plans (Table 8) it was only the 1979 master plan that recognized the conspicuous informal development across the city. The late colonial period master plan, at 1949, had three residential classes as low, medium and high density devoted to Europeans, Asians and Africans, respectively, segregated by buffer open spaces which is typical of colonial planning (Armstrong, 1987; Brennan, et al., 2007; Lupala, 2002; Sliuzas, et al., 2004). The high density African quarters were not given any concern but to respect road lines, reduce densities and providing water standpipes, all with high regard to health and security control issues (Armstrong, 1987). The 1968 master plan, although by far better than its predecessor in a number of aspects, had ill conceived attitudes for informal settlements. According to the proposed plan, ISs either in infancy or those against the proposed plan were meant to be subjected to removal, though after three years the government recognized squatters' rights to put further in odds the intent of the master plan (Armstrong, 1987). Though there are some residential quarters that draw their origins from the master plans proposed across the years, no master plan has served as a guiding plan to DSM (Lupala, 2002; Sliuzas, et al., 2004).

Table 8 summarizes the basic planning concepts injected in the master plans whereby most of the ideals were borrowed from western practice and distinctive planning generation at each time, beyond normative considerations.

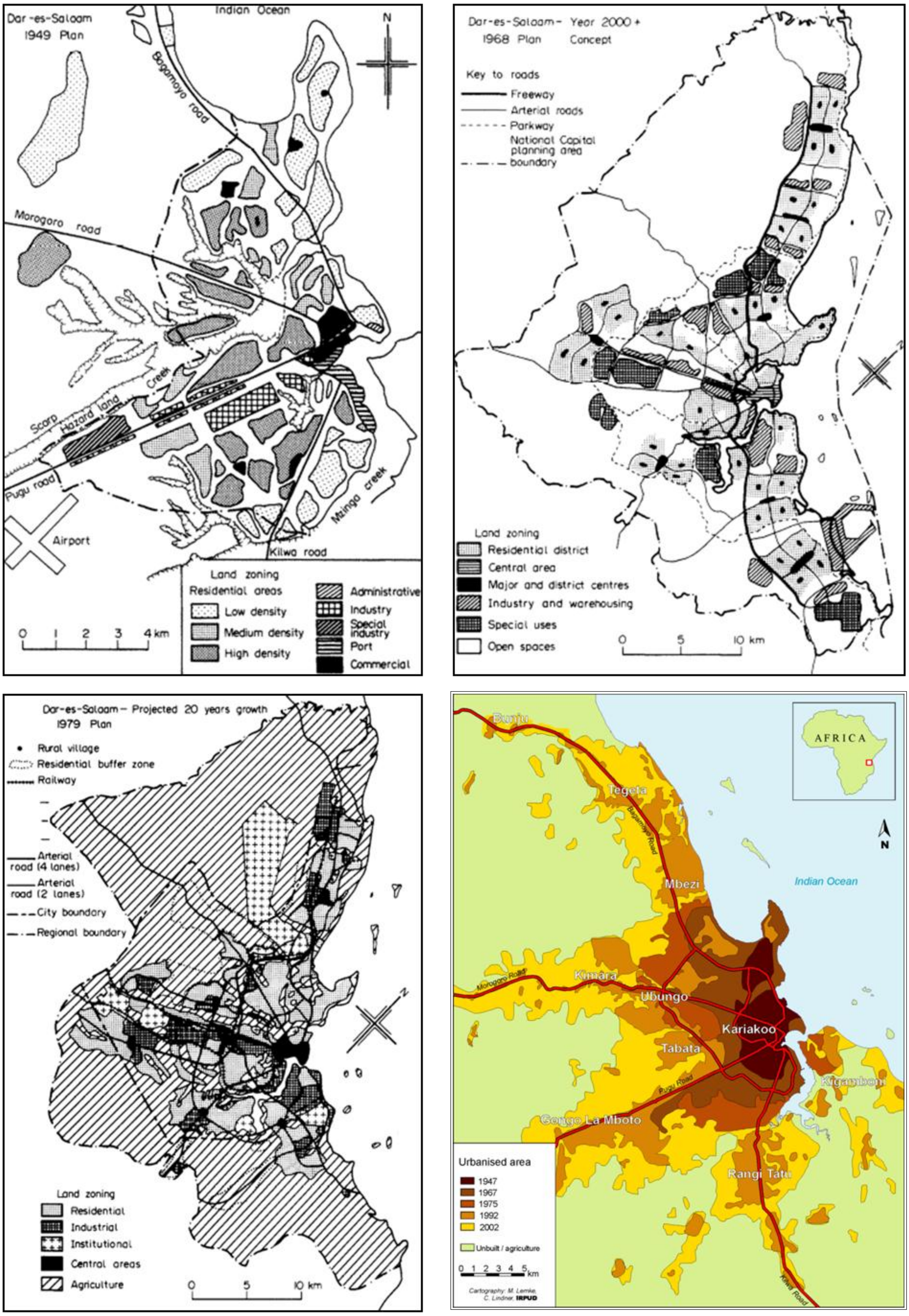
Table 8: Major Master Plan concepts entertained in DSM

| Master Plan | Guiding planning concepts |
|---|---|
| 1949 | Zoning of functions; zoning of residential areas according to density and races; neighbourhood units, Breeze lanes, open space provision; non-geometric street layouts, density and building standards |
| 1968 | Plan 2000 (long range concept) systems approach; ecosystem of growth/hierarchical modular urban structure including neighbourhood units, satellite sub-cities city-region planning; green belt, parkways, landscape corridors, open space provision; sector strategies; five year capital works programme |
| 1979 | Flexibility - population attained rather than target years; hierarchical urban structure based on planning module; sub-classification of residential areas/recognition of squatter areas; participation of implementing agencies; detailed implementation programme including 47 priority projects |

Source: Adapted from Armstrong (1987)

The series of master plans proposed for DSM not only had little influence on the development of the city but also were not wholly beneficial (Armstrong, 1987). Figure 10 shows master plans proposed against actual urban development of DSM.

Figure 10: Proposed Master Plans versus Growth of Dar es Salaam




Source: Proposed master plans, Armstrong (1987); and urbanized area of DSM, Hill & Lindner (2010)

#### 2.6.3. Urban planning and informal development

The urban planning practice in Tanzania has been reported to fail to address human settlement issues. There are a number of drawbacks of the planning process, but to mention few witnessed across time, urban development without guidance, inadequate planning standards and regulations, unsustainable use of resources, absence of institutional co-ordination (Kyessi, 2002). The problem with urban planning can be traced back to the early days of urban layout done by the Germans and the first master plan in 1949 where both and proceeding master plans could not abate the ensuing informal development.

The decision to shift the capital from Dar es Salaam to Dodoma can be regarded as a failure to confront the challenges of urban development. The very intent of the decision was to restrain immigration from rural areas to DSM (Kombe & Kreibich, 2000). Nevertheless, immigration to Dar es Salaam has never ceased and most immigrants have continued to occupy urban-peripheries for its affordability and easy access (Kombe, 2005). The decision to move to Dodoma was accompanied by declining investment in social and physical infrastructure to DSM (Kombe & Kreibich, 2000), which could only worsen the quality of life in informal developments.

### 2.7. Modelling urban growth (Land use change modelling)

#### 2.7.1. Urban growth models

Modelling the dynamics of urban growth necessitates different modelling techniques. There are a number of modelling techniques with underlined aim of understanding the complexity of urban growth. These include, among others, cellular automata (CA) modelling, agent-based modelling, spatial statistics modelling, artificial neutral network (ANN) based modelling, fractal-based modelling, chaotic and catastrophe modelling (Cheng, 2003). Some of the modelling techniques are concerned with the investigation of the driving causes or factors of the witnessed growth so far, while others are simulation models predicting what will be the urban pattern in the future (Huang, et al., 2009).

#### 2.7.2. Drivers of informal settlement growth

Understanding the driving forces that underpin urban expansion is vital for decision makers to formulate policies which heighten economic growth and urban development while greatly minimizing environmental impacts (Karen & Robert, 2003). Identifying the probable driving forces of urban expansion is a prerequisite for modelling urban growth. These driving forces of urban land use change are not universal and possess different weights for each specific urban development case (Huang, et al., 2009). To this end, various researchers have used different categories of driving forces with respect to the case being studied. Notwithstanding the specific case and scale of the phenomena to be modelled, driving forces are generally grouped into three (Turner II B.L., et al., 1995). These are socio-economic drivers, biophysical drivers and proximate causes (land management variables). Theories and physical laws, empirical methods or expert knowledge is used as the basic approach to quantify the relationship between land use change and its driving forces (Verburg, et al., 2004).

However, researchers specifically dealing with informal settlements have developed different categories of driving forces which they find relevant to the case. For instance, Sietchiping (2005) categorizes driving forces of informal settlements growth as physical, economic and socio-cultural which include topography, transportation networks, existing informal settlements, availability of the informal economic sector as source of income, places of worship, and cultural and ethnic groups. Sliuzas, et al. (2004), on the other hand, proposed three categories of data pertinent to the interest to urban planners with regard to informal settlements. These factors attributed to the informal settlement growth are environmental (site conditions), physical – spatial (development of the site and the surrounding environment), and socio-economic (legal aspects and characteristics of the population).

### 2.7.3. Modelling informal settlement growth

Logistic regression modelling approach

Logistic regression modelling is one of the statistical modelling techniques with dependent categorical variable that can be explained either by categorical or continuous independent variables. This modelling approach is advantageous to interpret urban growth patterns with regard to the underlining driving forces. Probabilities of land use changes will be established by a number of driving forces explained in explanatory variables, the relative significance of which can be determined by maximum likelihood estimation (Cheng & Masser, 2003; Hu & Lo, 2007; Huang, et al., 2009; Luo & Wei, 2009).

Most of urban growth modelling approaches mentioned in Section 2.7.1 requires significant data inputs, which limits their utility in developing countries and specifically in informal settlements where the capturing of data is very difficult (Luo & Wei, 2009; Sietchiping, 2004). With this regard logistic regression technique is preferable as it is a spatial explicit method relying on few but widely available data (Luo & Wei, 2009).

Modelling informal settlements growth using logistic regression technique

In this research, logistic regression modelling approach is used as it helps to identify and improve the understanding of demographic, econometric, and biophysical forces that may drive urban growth and for its capability of multi-scale analysis and spatial explicitness, among others (Hu & Lo, 2007). As GIS coupled with logistic regression proved to be instrumental in assessing the effects of various factors on land use change (Huang, et al., 2009), the driving forces of informal settlement can also be investigated to come up with a model built on historical data but predictive enough that best serve understand the nature of informal settlement growth.

## 2.8. Previous researches on informal settlement growth in Dar es Salaam

Informal settlements in DSM had been an issue for a number of researches. In this section some of them with high affiliation with the theme of the research under consideration here are discussed.

### 2.8.1. Modelling researches on ISG (Driving forces of ISG)

Sakah (1991), in his study entitled: 'unplanned areas: a function of spatial distribution of urban activities', proposed IS growth model for the city of DSM in an attempt to help planners for proactive means rather than reactive ones in mitigating problems of uncontrolled spatial developments. The model is a probability model to identify sensitive areas that could easily be occupied by unplanned residential stock. Sakah (1991) pointed out that the main factors influencing the locational patterns of new unplanned settlements in DSM are: proximity to urban activities, acquisition and availability of building land, development pressure zones and nature of land ownership. This model outcome asserts that, specifically in DSM, unplanned areas are also a function of some parameters like affordability (means of land acquisition, availability of land and the nature of land ownership) beyond spatial distribution of urban activities (Sakah, 1991).

Hill & Lindner (2010) also developed a land-use simulation model for DSM which is based on standard GIS software but reminiscent of Cellular Automata (CA) modelling approach. The very intent of the research is to model informal urban growth amid rapid urbanization to enable planning authorities deal with urban growth in a proactive way. The model considers main variables which stand for significant drivers of informal urban growth in categories of: natural conditions, accessibility and local-scale dynamics which are also known as neighbourhood effects. These variables encompass slope, distance to roads, travel time to various urban centres, and informal or planned residential units in a neighbourhood. The model has verified these variables to be sufficient to explain and project urban growth (Hill & Lindner, 2010).

#### 2.8.2. Non-modelling researches on ISG (housing pattern, expansion and densification of IS)

Squatter settlements in DSM located in close proximity to major roads had witnessed to expand with high rate than those on less accessible areas (Sliuzas, 1988). Sliuzas (1988), tried to investigate the effect of accessibility on housing and housing patterns, to which he also enumerate a number of influencing factors. He argued that the spatial distribution of houses in a squatter settlement to be a function of a complex set of physical, social/cultural and economic factors. The physical factors may comprise land quality, accessibility (roads and footpaths) and upgraded utilities, while the social factors may incorporate social contacts, family ties and traditional systems, as the economic factors encompass land price, commercial (possibility of room rental), gentrification and speculation (Sliuzas, 1988). The aforementioned factors are mainly for housing pattern in the emergence of a settlement or further guiding elements once a settlement has been established.

Lupala (2002), citing Kironde(1994), mentioned four urban development areas existed in DSM: the old 'planned' areas, the new 'planned' areas, the old informal settlements and the new 'unplanned' areas. The informal and unplanned areas altogether host the majority of urban population. The old informal settlements, which are established before 1980, are characterised by high density housing with irregular pattern. Settlements like Keko, Buguruni, Msasani, Mwanayamala, Hanna Nassif, Manzese, Mtoni and Tandika belongs to this group. The latter informal development, the new 'unplanned areas', is composed of significant number of high income dwellers or influential personalities in the society in a relatively low density settlement agglomeration that may also allot some land for agricultural use. This new informal pockets of the city are developed since the early 70s onward, and include outer areas of Kimara, Mabibo, Bunju, Mbagala and Ukonga. The intrinsic qualities of the above referred two informal settlement manifestations could have sprung from the location they are found in the city proper, among other things. The former is more close to the inner city, while the latter goes out to the peripheries/fringe zone, implying high density housing in the inner city as many more public services and centres are accumulated in close proximity to the CBD. Sliuzas (2004) also noted a pattern that early settlements which are centrally located to be with highest densities and the density for other settlements eventually fall as the farther away they are to the CBD.

# 3. DATA AND METHODOLOGY

## 3.1. Introduction

This chapter focuses on available data, data quality, and methods followed to achieve the research objectives. Specifically, it explains about data source and qualities, briefs on how probable drivers of ISG are detected, and describes in more detail the modelling of ISG using GIS and logistic regression technique. The chapter winds up by listing a number of software packages used in the thesis.

## 3.2. Data source and qualities

Most spatial data are accessed from ITC's data archive (see Appendix A); from which a number of other data are derived. The original available data are produced with different methods across substantial years, which are outputs of various experts and liable for their interpretation.

Land cover vector maps of 1982 and 1992 are produced based on aerial-photographs at 1982 and 1992 with scales 1: 12,500 and 1: 63,000, and 1: 12,000 and 1: 54,000 respectively. The 1998 land cover map, focusing on urban DAR, is derived from SPOT and SFAP taken in the same year. The SFAP is colour, 35mm, high oblique taken at 500-800m. The 2002 land cover map is also made available extracted from orthophoto, though it is not mentioned explicitly in the metadata.

Shape file for population (population hexagons) is available only for years 1992 and 1998. The 2002 census result can be joined with wards to create a homogeneous distribution of population across each administrative unit. Nevertheless the anticipated analysis may frustrate from errors caused by imparting inconsistent data sources. Moreover, the 1982 population has no spatial reference at all in the available data.

DEM, 20mx20m cell size, processed from 1: 2,500 topographical data and 1: 50,000 topographical map was available. Roads, treated as exogenous variables, are derived from 1: 50,000 and 1: 20,000 topographic maps and city maps respectively.

The Dar es Salaam metadata reveals that, as it has been also mentioned by Sliuzas (2004), most of the data is basically gathered from three sensors (vertical aerial photographs, SFAP and SPOT) and an output of visual interpretations of a number of individuals across a considerable period of time. Owing to this, some errors in the data is inevitable; nonetheless it will not affect the analysis herewith as there is no exaggerated error.

## 3.3. Identifying probable driving forces of ISG

The probable driving forces of informal settlement growth in the study area, Dar es Salaam, were subjected to preliminary assessment. The assessment was based on literature review and opinion of key informants[7]. Due the geographical distribution of prospective respondents a questionnaire (see Appendix

[7] A key informant/expert is an individual who is knowledgeable about informal settlements in Dar es Salaam and associated issues.

C) is selected as primary data collection procedure. It was administered via a web link[8], which served as a platform to collect all responses. The questionnaire aims to evaluate the significance[9] of probable driving forces of ISG in DSM that were structured as site specific, proximity and neighbourhood characters (Dubovyk, 2010; Huang, et al., 2009). The information gathered, combined with literature review, helped construct a conceptual model of informal settlement growth (ISG), (Section 4.2.3).

Driving forces of ISG is looked at different time horizons and opposed to the growth stages of IS as infancy, booming / consolidation and saturation. The time spans are:

- Colonial time, 1887-1961
- Post-colonial time, 1961-1982
- Recent past time, 1982-2002

Here, it should be noted that the LR model to be developed relies upon the driving forces of recent past informal settlement proliferation; and the above time steps are mainly the time frames in which literatures were seen for ISG and associated driving forces.

The questionnaire was dispatched for experts who have done a significant research on informal settlements, mainly DSM, and urban planning experts in office in Tanzania. The composition of experts was designed to incorporate academicians, planners in Ministry of Lands, Housing and Human Settlements Development (Tanzania), planners in municipalities of Kinondoni, Ilala and Temeke, experts and planners in Non-Governmental Offices (NGO's) and consultants dealing with urban planning issues in DSM. At the onset, the questionnaire was released for 26 experts in the aforementioned groups, while only eight experts (see Appendix B) expressed willingness to partake in the study; but then it was only five who completed the questionnaire. Although the response rate can be arguably low, respondents were with ample experience in informal settlement growth in DSM and their responses were structured to proceed to the next modelling stages, conceptual and logistic regression model of ISG in DSM.

## 3.4. Modelling ISG using GIS and logistic regression technique

### 3.4.1. Compilation of probable drivers of ISG

A list of drivers of ISG identified from literature review and provided by key informants are grouped according to their nature which falls in site specific characteristics, proximity extent, and neighbourhood characteristics, (Appendix C), (Dubovyk, 2010; Huang, et al., 2009).

### 3.4.2. Input data preparation for logistic regression model (LRM)

Input data for logistic regression, often called factor maps, were prepared for years 1982 and 1992 in ArcGIS environment (see Appendix B, Appendix E, and Figure 12). These input data represent independent variables, which can either be dichotomous or continuous, while the output is ISG (binary dependent variable for expansion, and multinomial variable for densification). Accordingly, the themes to be explained, dependent variables, are represented at 1982, 1992, and 2002 by binary maps for IS expansion; and at 1992 and 1998 by categorical maps for densification. Both dependent and independent data are represented in a raster format, 20x20m cell size that is determined by the needed spatial resolution and also its compliance with available data, e.g. slope data, (Hu & Lo, 2007).

[8] SurveyMonkey online survey software is used to conduct the questionnaire

[9] Significance level is taken from rating average score, where, very significant = 5, significant = 4, neutral = 3, insignificant = 2 and very insignificant = 0. Thus, if a consensus is reached by the five experts on a single driver to be very significant, it earns the highest rating average, i.e., 5.

**Site specific characteristics**

Population

The population data available were regular hexagon cells of 5.4 ha size with attributed population data for 1992 and 1998, and census population table for 2002 which can be joined with ward boundaries of DSM at 2002. While the former data is spatially explicit to 5.4 ha resolution in built up areas (planned residential and informal), the later is only an aggregate population figure at ward level (73 wards). For the purpose of consistent analysis, population data for years 1982, 1992, 1998 and 2002 were transformed to 500m cell size raster, which is eventually resampled to 20 x 20 cell (see Appendix E). The hexagon based 1992 and 1998 data had been done considering only informal and planned residential land uses as places where population resides (Amer, et al., 2007), which, even rastered to 500m cell size, cannot be used as it fails to be consistent with available data format in 2002. Alternatively, the 2002 population data available at ward level has been updated by subjecting it to GWR (Geographically Weighted Regression), with different weight factors assigned for different land uses as indicated in Table 9 (cf., Yuan, et al., 1997). These weights are considered as DSM housed 70 percent of its population in informal settlements at or around 2002 (Amer, et al., 2007; Sliuzas, et al., 2004; UN-HABITAT, 2010). Accordingly land uses: informal settlements, planned residential, other urban, vacant/Agriculture and Ocean/Estuaries has been given weights considering what they reportedly share. For instance the rural DSM had been reported to share 6.1 % of the total population at the 2002 census (URT, 2006). Consequently, here it is assumed DSM to host 10 % of its population in other urban and agricultural lands, with 5% share each through 1982-2002. Thus reducing 5% share from informal and planned residential population proportions often indicated in reports. Assuming the same administrative ward boundary existed in 1982, the population at 1982 which is found to be 1,016,996 using 4.80 percent annual average growth rate between 1978 and 1988 as indicated in census results (URT, 2006), was distributed to wards with the assumption that each ward experienced identical population growth of 7.06%, a figure calculated considering 4.30 percent annual average population growth between 1988 and 2002 (URT, 2006). After each ward has been assigned its estimated population in 1982, GWR has been conducted with weight factors indicated in Table 9, noting it was around 60 percent of the population that informal settlements hosted at the time (Brennan, et al., 2007; Lupala, 2002; UN-HABITAT, 2010). Similar procedures have been followed to produce grid population of 1992 and 1998. It should be noted that two informal settlements in the south of DSM, Mwandege and Kongowe, lie outside the administrative boundary and their population estimate for 2002 and 1982 was calculated based on available 1992 and 1998 hexagon population data with respective growth rate.

Table 9: GWR and weights considered for different land uses

| Year | Informal settlements | Planned residential | Other urban | Vacant/ Agriculture | Ocean/ Estuaries | GWR_$R^2$ | GWR_$R^2$ Adjusted |
|---|---|---|---|---|---|---|---|
| 1982 | 0.55 | 0.35 | 0.05 | 0.05 | 0 | 0.69 | 0.68 |
| 1992 | 0.65 | 0.25 | 0.05 | 0.05 | 0 | 0.69 | 0.69 |
| 1998 | 0.65 | 0.25 | 0.05 | 0.05 | 0 | 0.68 | 0.67 |
| 2002 | 0.65 | 0.25 | 0.05 | 0.05 | 0 | 0.69 | 0.68 |

Environmental hazards

An area prone to any scale of hazard, i.e., slight, moderate or high, that includes beach erosion, flood, or soil erosion is considered to be a risk zone. Areas which have been designated as sand extraction areas, sand extraction with mining claims, limestone extraction with mining claims, limestone extraction and illegal sand extraction are all considered to be threats for descent habitation.

Slope: Slope is calculated as a percentage from DEM which is 20 x 20 m resolution.

**Proximity characteristics**

Road layers, both major and minor, are considered to exist unchanged throughout the study time. This is true for the major roads, though there might be changes in minor roads. For land use considerations, it is only the 1982 land use which recognized land use classes: industrial, commercial, institutional and recreational that in other time step they are all treated in one land use group called – other urban. For consistency and comparison, other urban land use class has been followed. Although health facilities may assume significant influence (as agreed by experts, Appendix C) for the expansion of informal settlements, the data accessed is availed in year 2000 and there is no information when each facility had been established. For this reason it is cancelled from analysis. Distance to natural landscape elements, main food markets, satellite centres, and central business district have also been considered. Hill & Lindner (2010), argued the urban poor in DSM depends by far to a smaller degree on services delivered at CBD but rather depend highly on informal sub-centres for their daily life, and apparently those areas in close proximity to those informal sub-centres would have high level of attraction for any informal settler. With this respect, Hill & Lindner (2010) noted four informal sub-centres[10] in DSM, viz. Tegeta on Bagamoyo Road, Kimara on Morogoro Road, Gongo la Mboto on Pugu/Nyerere Road and Rangi Tatu on Kilwa Road. All these sub-centers were already a consolidated entity prior to 1982, and they are also considered in this study as probable drivers of informal settlements growth.

**Neighbourhood characteristics**

Proportion of urban land, proportion of IS, and proportion of undeveloped land around an area (a cell size of 20x20m) is calculated using a 21cell (420m) circular neighbourhood (Dubovyk, 2010).

Input data in the aforementioned main categories are all made in raster format. These raster data are either dichotomous (0 or 1) or continuous type. The continuous data have been normalized to a range of [0,1], by minimum – maximum linear transformation of the input raster, as it is required that in multivariate statistical analysis all continuous variables should have the same scale (Cheng & Masser, 2003; Huang, et al., 2010; Nefeslioglu, et al., 2008).

### 3.4.3. Multicollinearity analysis

Independence between variables is a prerequisite in LR modelling (Cheng & Masser, 2003; Kok & Veldkamp, 2001). Variance Inflation Factor (VIF) is an indicator of multicollinearity among variables, and any independent variable with VIF>10 is a concern for the anticipated model as to bias it (Field, 2009). Thus, only variables with VIF<10 are allowed to join the model.

[10] Point data for these informal sub-centres was produced by digitizing them from a map displayed in Hill & Lindner (2010)

#### 3.4.4. Sampling scheme

Whereas correlation statistics were designed to show relationships between variables, autocorrelation statistics are designed to show correlations within variables, and spatial autocorrelation shows the correlation within variables across space (Arthur, 2007). Spatial autocorrelation can obscure the results of regression analysis as regression coefficient and significance level of individual variables are sensitive to its presence (Kok & Veldkamp, 2001), and lead to false conclusions regarding hypothesis tests (Irwin & Geoghegan, 2001). This spatial dependence could emanate from data measurement errors, omitted variables or from spatial interactions of observations (Irwin & Geoghegan, 2001). Frequently in logistic regression modelling either stratified random sampling or systematic sampling has been used. Random sampling is efficient in representing a population but does perform poorly on reducing spatial dependence, while systematic sampling is efficient in spatial dependence reduction but may lose data on isolated sites if population is not homogeneous. A combination of these two sampling techniques can be used to deal with sample size and spatial autocorrelation (Cheng & Masser, 2003). In this study a systematic unbalanced sampling window with a non-overlapping cell size of 3x3 is applied in Change Analyst software; after a couple of higher window sizes which earned less or no significance to a number of variables.

#### 3.4.5. Logistic regression model

Logistic regression model has used to identify the key drivers of the urban dynamics involved in the change of spatial pattern. As an empirical estimation method, it has been used in various disciplines to model the relationship between land use changes and the driving forces based on historic data. Statistical approaches, like logistic regression, are used to identify the influence of independent variables and also to provide a degree of confidence about their contribution (Hu & Lo, 2007). In this study, there are two dependent[11] variables – expansion and densification – and a number of independent variables that would represent the probable driving forces.

The statistical model for logistic regression can be given by:

$$P(Y) = \frac{1}{1+e^{-(b_0+b_1X_{1i}+b_2X_{2i}+\cdots+b_nX_{ni})}} \tag{1}$$

Where, $P(Y)$ stands for the probability of $Y$ occurring (i.e. the probability that a case belongs to a certain category), $e$ is the base of natural logarithms, $b_0$ is a constant, $b_n$ is coefficient (or weight) attached to a predictor, and $X_{ni}$ is a predictor. The resulting value from the equation ranges from 0 to 1. A value close to 0 means that Y is very unlikely to have occurred, and a value close to 1 means that Y is very likely to have occurred (Field, 2009). For instance, the dependent variable – expansion of IS– is binomial, either 1 or 0 which indicates the presence of expansion or no expansion, respectively.

Logistic regression can also be expressed by the logit function:

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x \tag{2}$$

Where, $p$ is a binomial proportion and $x$ is the explanatory variable. The parameters of the logistic model are $\beta_0$ and $\beta_1$ (Moore & McCabe, 2006). Here, the formula indicates only for a single predictor variable. Each estimated coefficient is the expected change in the log odds of being the 'dependent variable'.

[11] The term dependent variable is used interchangeably with outcome variable, while independent variable is synonymously used with the term predictor or explanatory variable.

While binary logistic regression (for expansion of IS) has outcome (dependent) variable with exactly two categories, multinomial logistic regression (for densification of IS) possesses dependent variable with more than two categories. However, multinomial logistic regression essentially works in the same way as binary logistic regression (Field, 2009).

The multinomial logistic regression of densification is made possible by using the Settlement Consolidation Index (SCI). Informal settlements in 1992 and 1998 are grouped into three density classes based on calculated SCI at the specified years: low density ($0 < SCI \leq 33$), medium density ($33 < SCI \leq 66$) and high density ($66 < SCI \leq 100$); which leave the other cells in the study area as 'other' to make the dependent variable in LR modelling of densification composed of four categories (Section 4.3.2, Table 10).

Settlement Consolidation Index (SCI) is an index developed from pixel based density classification with an underlining assumption that building construction in a given settlement will continue till all pixels would fall into high density class (Sliuzas, et al., 2004). This index is calculated with the formula:

$$\mathrm{SCI} = \left(\frac{((a+b)*0)+(l*1)+(m*2)+(h*3))}{(a+b+l+m+h)*3}\right) * 100 \qquad (3)$$

Where: a = the number of pixels classified as vacant/ agriculture
b = the number of pixels classified as bare soil
l = the number of pixels classified as low density
m = the number of pixels classified as medium density
h = the number of pixels classified as high density

It can be noted that SCI, theoretically, range from value 0 to 100, though it is hardly possible to encounter extreme low values in practice (Sliuzas, et al., 2004).

Logistic regression parameters:

Odds ratio: Exp(B): It is the ratio of the odds of an event occurring in one group compared to another (Field, 2009). Odds ratio value ranges from 0 to positive infinity, and when the value is greater than 1 then it implies as the predictor increases, the odds of the outcome occurring increase. Conversely, if the value falls below 1, then it indicates that as the predictor increases, the odds of the outcome occurring decrease (Field, 2009). An odds ratio value of 1 indicates that there is no effect on the outcome by changing a group or amount in the predictor variable, hence the predictor variable will no longer be useful in predicting the odds (Moore & McCabe, 2006).

Goodness of fit and chi-square statistics: The LRMs goodness of fit can be evaluated by chi-square statistics, with the formula:

$$x^2 = \sum \frac{(observed\ count - model\ count)^2}{model\ count} \qquad (4)$$

Where, $x^2$ is chi-square, observed count are observed values of the cell while model count are expected/predicted values of the same cell from the model.

Chi-square tests whether variables are associated or not; and bigger values indicate that independent variables cast considerable influence on the outcome of the model. The null hypothesis, $H_o$, assumes all variables to possess an odds ratio of one, hence, no variable has any use in explaining the dependent variable. To confirm the null hypothesis does not hold true, corresponding p-value is calculated and compared with significance level[12] ($\alpha$) chosen. If the estimated p-value is smaller than $\alpha$, then $H_o$ will be rejected, on the basis that at least there would be one variable having an influence on the model outcome (Dubovyk, 2010; Field, 2009; Moore & McCabe, 2006).

T-Wald statistics (z-value): it is used to assure whether a variable is a significant predictor of the dependent variable; and it is the value of a regression coefficient divided by its associated standard error. The Wald statistics tests whether the coefficient of a predictor variable is significantly different from zero; and if it is significantly different from zero, then one can conclude that the predictor is indeed making significant contribution to the outcome variable (Field, 2009).

$$Wald = \frac{b}{SE_b} \quad (5)$$

Where, *Wald* is the z-value, *b* is coefficient of the independent variable and $SE_b$ is the associated standard error.

### 3.4.6. Model evaluation and validation

Percentage of correct predictions (PCP):

The proposed models are evaluated by the percentage of correct predictions (PCP). As the name indicates, it measures the correctly predicted cells in the model as opposed to observed cells from which the model is made. Its value reflects the capability of the model in prediction (Huang, et al., 2009).

Kappa:

Kappa statistics is used to validate the proposed expansion model[13]. Kappa comparison is a validation method based on a straightforward cell-by-cell map comparison, whereby each pair of cells on the two maps is checked whether they are equal or not (RIKS BV, 2009). However, the cell-by-cell direct comparison would earn a statistics called fraction correct which is calculated as the number of equal cells divided by the total number of cells; and is biased as it tends to consider maps with few or unevenly distributed categories more similar than those with many and more equally distributed categories. Kappa statistics, on the other hand, is used for better explanation of agreement between maps and addresses issues of concern in the fraction correct measure. Kappa statistics is a product of similarity of quantity (the histogram) and similarity of location (RIKS BV, 2009), and can be represented by:

$$\text{Kappa} = \text{KHisto} * \text{KLoc} \quad (6)$$

Where, Kappa is the level of agreement in terms of both quantity and location, KHisto is a Kappa quantity statistics and only depends on the total number of cells taken in by each category, while KLoc is Kappa location statistics and depends on the spatial distribution of the categories on the map (RIKS BV, 2009).

[12] In this research the models are built with significance level, $\alpha = 0.05$ and confidence interval (CI), 95%.

[13] Expansion model is validated by comparing its interpolation output of IS development back to 1998 with the observed IS development at the same year.

#### 3.4.7. Probability maps

Probable areas of IS expansion and probable densification pattern were mapped by extrapolating past trends of ISG. Area (cells) with high probability to host informal settlements were allocated to accommodate the projected IS area at the specific year in the future (see Appendix D). Similarly, densification was extrapolated and areas (cells) have claimed a density class to which the specific cell has high probability to. Both cases of IS expansion and densification are predicted to 2052 to see the expected trend of ISG in the future. The prediction in IS expansion is made by a smoothing model[14] (1982-2002) that is the combined model of the two time steps, 1982-1992 and 1992-2002 IS models (Huang, et al., 2009).

#### 3.4.8. Possible sources of error

Errors may have been introduced in different stages of the LRM operation. First, the causative factors/driving forces considered are the only variables which are supposed to explain ISG in the study area. Second, input data preparation is exposed to a number of assumptions and accumulated errors over GIS operations, e.g. population data preparation, Euclidean distance calculations, other-urban land use class and neighbourhood threshold. Third, low SCI due an increase in settlement area/boundary but not an actual decline of previously consolidated structures on the area; and also modelling of IS densification in a short period of time and trying to extrapolate a trend out of it.

### 3.5. Employed software

ArcGIS 10, ArcGIS 9.3.1, Change Analyst 1.0, Map Comparison Kit 3, PASW Statistics 18 (originally SPSS), SurveyMonkey and Microsoft office

[14] It is an aggregated model of the two time steps which give more weight to the time step with substantial change ratio when prediction is made. More on exponentially smoothed models can be found in Huang, et al. (2009).

# 4. RESULTS

## 4.1. Introduction

This chapter describes the results attained in response to the main objective of the research. It is structured to address the sub-objectives by building a conceptual model of ISG, building logistic regression model (LRM), and predicting the future ISG areas from the LRM. The conceptual model of ISG proposed here is intended to give an insight on how informal settlements grow (proliferate, stay static or degenerate) with reference to the significance level of driving forces of ISG in the study area. Logistic regression model of ISG in DSM follows the conceptual model to unveil the significant drivers of IS expansion and densification in DSM. The final section of the chapter focuses on probable areas of future IS expansion and densification, that also includes the evaluation and validation of proposed models.

## 4.2. Conceptual model of ISG

The conceptual model relates the driving forces of ISG with possible state of ISs. It is intended to frame the modelling environment of ISG where proliferating, static and degenerating settlements coexist together in an urban landscape. However, it is high proliferation of ISs that has been witnessed in DSM. It is learned that the rate of change of IS expansion in the study area was 57.04%, 114.32% and 236.56% for the time steps, 1982-1992, 1992-2002 and 1982-2002, respectively (Table 2). There were already 18 settlements in 1992 and 25 in 1998, among the 65 settlements considered, with high consolidation (SCI>66). Other settlements are observed to gain high rate of change of density, for instance, Kunduchi's SCI rate of change was 112.74 from 1992 to 1998; the highest of all. Informal settlement growth is effected in terms of expansion and densification, and driving forces do play different roles for both (Experts opinion, Appendix C). Thus, the conceptual model tried to outline those facts.

### 4.2.1. Driving forces of ISG in DSM – expansion

Probable driving forces of IS expansion in DSM have been subjected for experts opinion (Appendix C). The outcome of questionnaire revealed proximity characteristics to be the most significant factor in determining IS expansion followed by site specific and neighbourhood characteristics, respectively. From the 14 proximity characteristics driving forces put before experts evaluation distances to major roads, minor roads, and existing informal settlements are said to be the most influential of all with an average rating score of 4.8, 4.4, and 4.2 respectively. Distances to CBD, minor city centres, and main food markets turned out to be the next most influential drivers for IS expansion, each having a rating average of 4. Proximity to industrial sites, commercial sites, planned residential, health facilities, rivers, and ocean constitute the third level significant drivers with a rating average from 3 to 3.4. Although IS usually pay refuge to localities those are in close proximity to serviced areas, the response from experts show this is not true for DSM when it comes to distance to planned residential areas by their unanimous view that it had neutral effect on IS expansion. The rating average also indicated that distance to academic institutions to cast little influence on IS expansion, while a consensus is reached among experts that proximity to railway had had no significance for IS expansion all.

All of the site specific driving forces listed for IS expansion scored a rating average of 3 and above, except master plan. Population density, infrastructure development and migration rate are the three top most influential site specific characteristics for IS expansion, with 4.4, 4.4, and 4.0 rating average respectively. On the other hand, distinct social groups/clans, slope, land value, land form, environmental hazards, income per capita, zoning status of the land, land ownership and employment rate have rating average ranging from 3 to 3.6, indicating they possess second level of significance for IS expansion within site specific characteristics. The Master plan, as discussed in Section 2.6.2, is witnessed by the experts to have no impact on informal settlement expansion.

Neighbourhood characteristics have been agreed by experts to play a significant role for IS expansion. Among them, proportion of IS in a neighbourhood is noted to be the most influential, indicating the more ISs are around an area the higher the probability of the plot to be occupied by informal settlement soon. This driving force has scored 4.4 on the rating average while proportion of urban land and undeveloped land in an area had been reported to have similar influence (Rating average 4).

#### 4.2.2. Driving forces of ISG in DSM – densification

Experts' opinion on the driving forces of IS densification in DSM has set site specific characteristics to be on the lead influencing the densification of IS, followed by proximity and neighbourhood characteristics (Appendix C). Population density, poverty rate, income per capita and infrastructure development form first level influential driving forces for densification among the considered ones (Rating average 4 and above). Population density is said to be the most influential of all as building extensions can be carried to house additional family members. Thus, higher population density in an area is believed to be followed by subsequent densification of a settlement. Most driving forces: migration rate, land value, distinct social groups/clans, employment rate, land ownership, slope, land form and environmental hazards are reported to be significant on a second level, while zoning status of a land and the master plan are considered to have less impact on IS densification with rating average of 2.8 and 2.4 respectively.

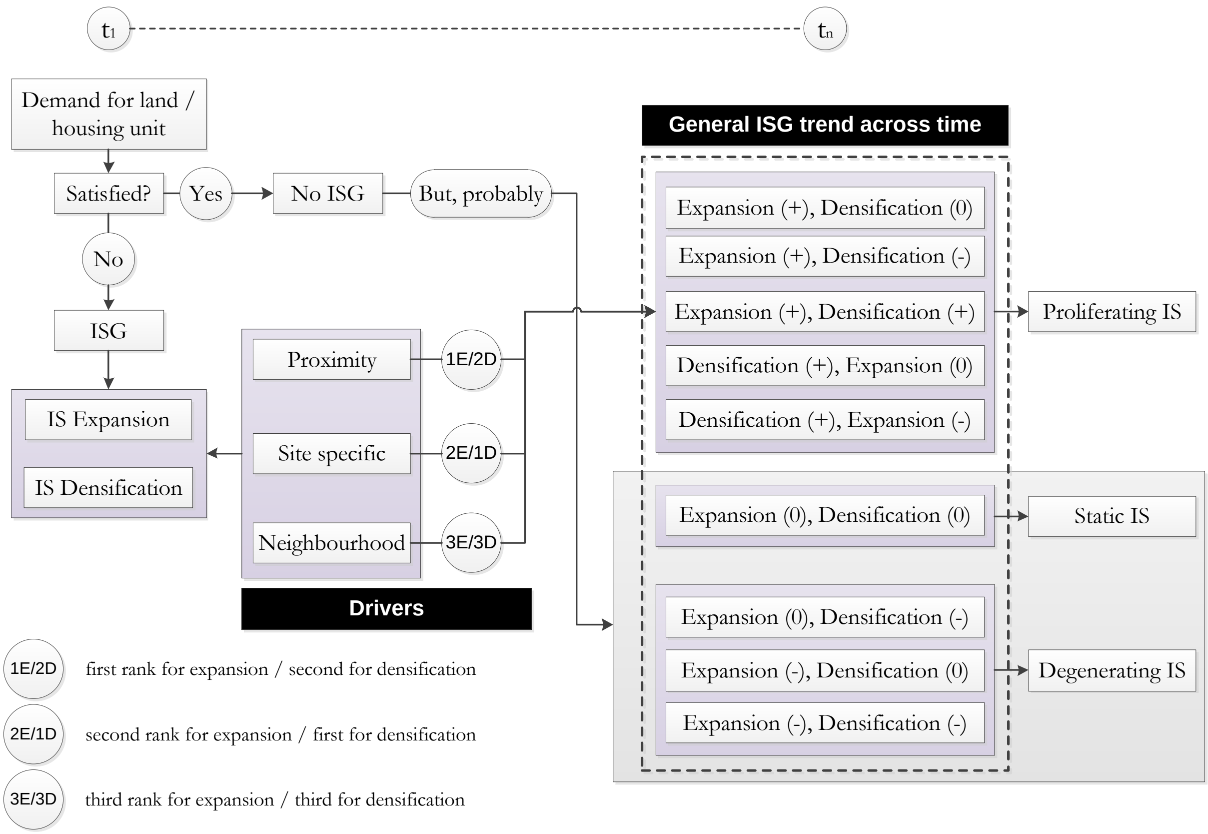
Proximity characteristics are indicated to be the second level driving force category to influence densification of IS. Distances to major roads, minor roads, central business district (CBD), existing informal settlements, minor city centres and main food markets are all the most influential driving forces in the category, with decreasing rating average range of 4.4 to 4. This first class of proximity drivers for densification is followed by distances to industrial sites, commercial sites, health facilities, planned residential, rivers and academic institutions to constitute the second class influential driving forces (decreasing rating average ranging from 3.8 to 3). The remainder proposed driving forces, distances to railway and ocean, are reported to cast the least influence on IS densification process.

Similarly as for expansion of IS, the proposed driving forces in neighbourhood characteristics for densification are indicated by experts to hold a high impact. The availability of informal settlement within a given neighbourhood is believed to be the most influential driver for IS densification, followed by availability of urban land in the locality and proportion of undeveloped land in the area, with rating average 4.6, 4.4 and 4 respectively.

### 4.2.3. Conceptual model of ISG in DSM

The informal settlement growth (ISG) trend of Dar es Salaam is through expansion and densification. Either of these means of settlement development hardly exists in isolation without reference to the other. ISG in DSM is the aftermath of rapid urbanization coupled with unsatisfied demand for land or housing. These informal settlements are established, consolidated and eventually may get saturated with the utility the specific settlement may offer. Certain IS assumes further proliferation due a number of factors, here classified into three: proximity, site specific, and neighbourhood characteristics. Although these driving force categories are liable for both expansion and densification, they do possess different level of influence for their sustained presence. For instance, proximity characteristic would play a significant role for IS expansion rather than site specific characteristic, while the reverse holds true for densification. Figure 11 depicts the context of ISG in DSM starting from demand for descent housing to the different scenarios the un/met demand would be manifested in informal settlement development. The general ISG trend in terms of expansion and densification can claim nine forms which are bound to whether housing demand is met or not. In this study three probable development phases within each phenomenon is considered, i.e., increase (+), no change (0), and decrease (-) of the respective expansion and densification. Considering two time steps, $t_1$ and $t_n$ as two considerably different moments in IS growth, there are five scenarios which are evidences of IS proliferation, one scenario where a settlement can be static or show no more physical growth, and three scenarios at which a settlement is degenerating or declining.

Figure 11: Conceptual model of ISG




Source: Own construct

## 4.3. Logistic regression model of ISG in Dar es Salaam

This section recalls the dependent and independent variables in the LRM of ISG, presents multicollinearity diagnostics and modelling results for IS expansion and densification which leads to models' interpretation.

### 4.3.1. Dependent variables

There are two dependent variables entertained to explain informal settlement growth - expansion and densification. The dependent variable expansion has two categories, the presence of IS (denoted by 1) and absence of IS (denoted by 0), and hence binary logistic regression is conducted for expansion. On the other hand, densification as a dependent variable incorporated four categories which have been subjected to multinomial logistic regression. The four categories are: low density (with $0 < SCI \leq 33$ and denoted by 0), medium density (with $33 < SCI \leq 66$ and denoted by 1), high density (with $66 < SCI \leq 100$ and denoted by 2) and 'other' (denoted by 3), (see Table 10).

### 4.3.2. Independent variables

As described in section 3.4.1 and 3.4.2 probable drivers of informal settlement growth are identified and put into three categories, site specific, proximity and neighbourhood characteristics. Twenty probable drivers have passed to be incorporated in the model based on its perceived impact from literature review, experts' opinion and also considering available data at disposal. Table 10 summarizes the list of variables considered in the logistic regression model (LRM).

Table 10: List of variables included in LRM

| Type of Factor | Variable in LRM | Description | Nature of Variable |
|---|---|---|---|
| Dependent | Z (Expansion) | 1 - IS expansion | Dichotomous |
| | | 0 - No IS expansion | |
| | Y (Densification) | 0 - Low density (0 < SCI ≤ 33) | Multinomial |
| | | 1 - Medium density (33 < SCI ≤ 66) | |
| | | 2 - High density (66 < SCI ≤ 100) | |
| | | 3 - Other | |
| Independent | X | … | … |
| Site specific characteristics | $X_1$ | Population density (persons/km²) | Continuous |
| | $X_2$ | Environmental hazard (1 - hazard, 0 - no hazard) | Dichotomous |
| | $X_3$ | Slope (%) | Continuous |
| Proximity characteristics | $X_4$ | Distance to major roads | Continuous |
| | $X_5$ | Distance to minor roads | Continuous |
| | $X_6$ | Distance to other-urban land use | Continuous |
| | $X_7$ | Distance to CBD | Continuous |
| | $X_8$ | Distance to informal sub-centres | Continuous |
| | $X_9$ | Distance to satellite centres | Continuous |
| | $X_{10}$ | Distance to food markets | Continuous |
| | $X_{11}$ | Distance to existing IS | Continuous |
| | $X_{12}$ | Distance to planned residential | Continuous |
| | $X_{13}$ | Distance to major rivers | Continuous |
| | $X_{14}$ | Distance to minor rivers | Continuous |
| | $X_{15}$ | Distance to river valleys | Continuous |
| | $X_{16}$ | Distance to ocean | Continuous |
| | $X_{17}$ | Distance to hills | Continuous |
| Neighbourhood characteristics | $X_{18}$ | Proportion of urban land in a surrounding area | Continuous |
| | $X_{19}$ | Proportion of IS in a surrounding area | Continuous |
| | $X_{20}$ | Proportion of undeveloped land in a surrounding area | Continuous |

Figure 12: Some raster layers of independent variables of year 1992 for expansion

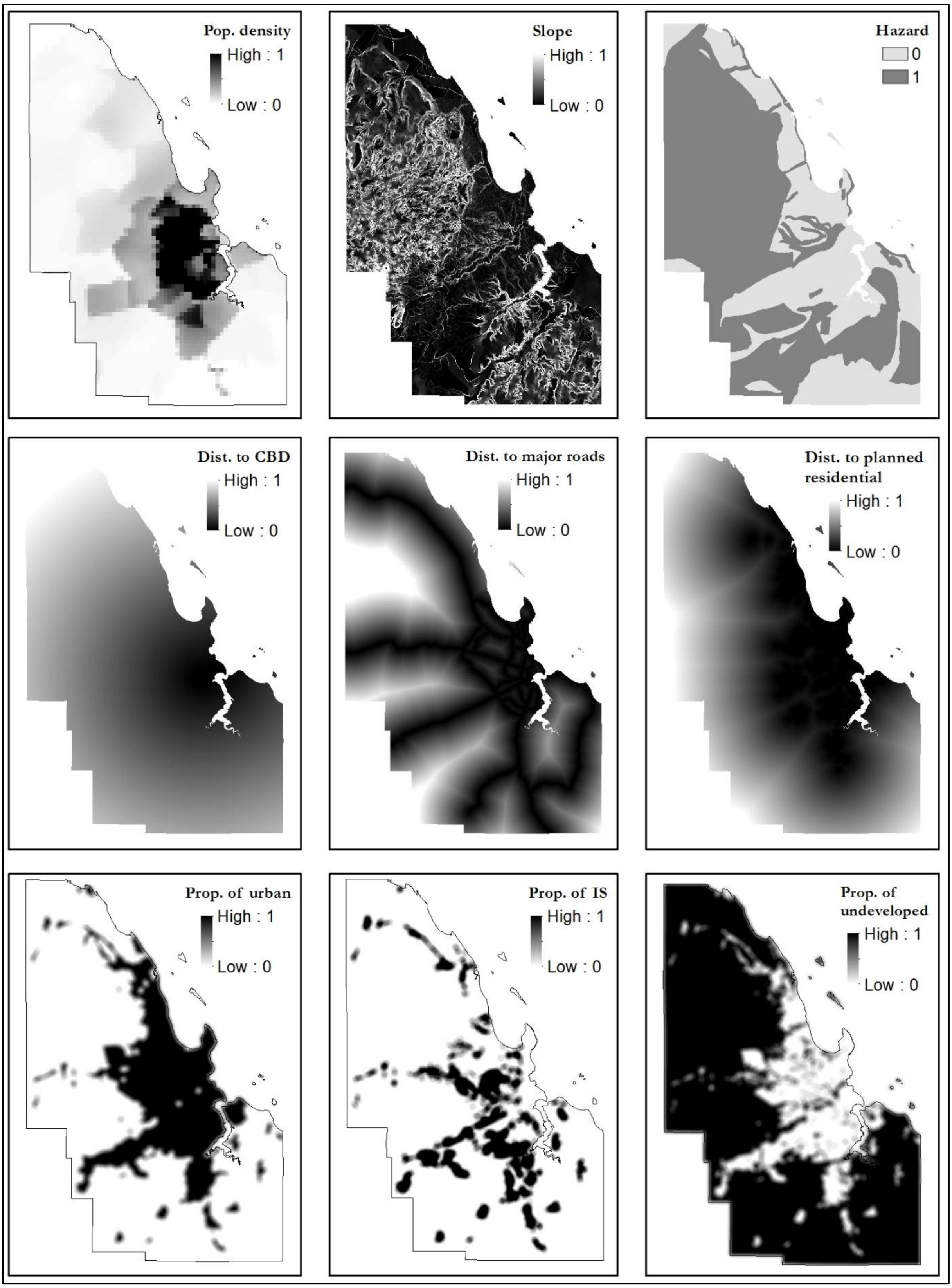
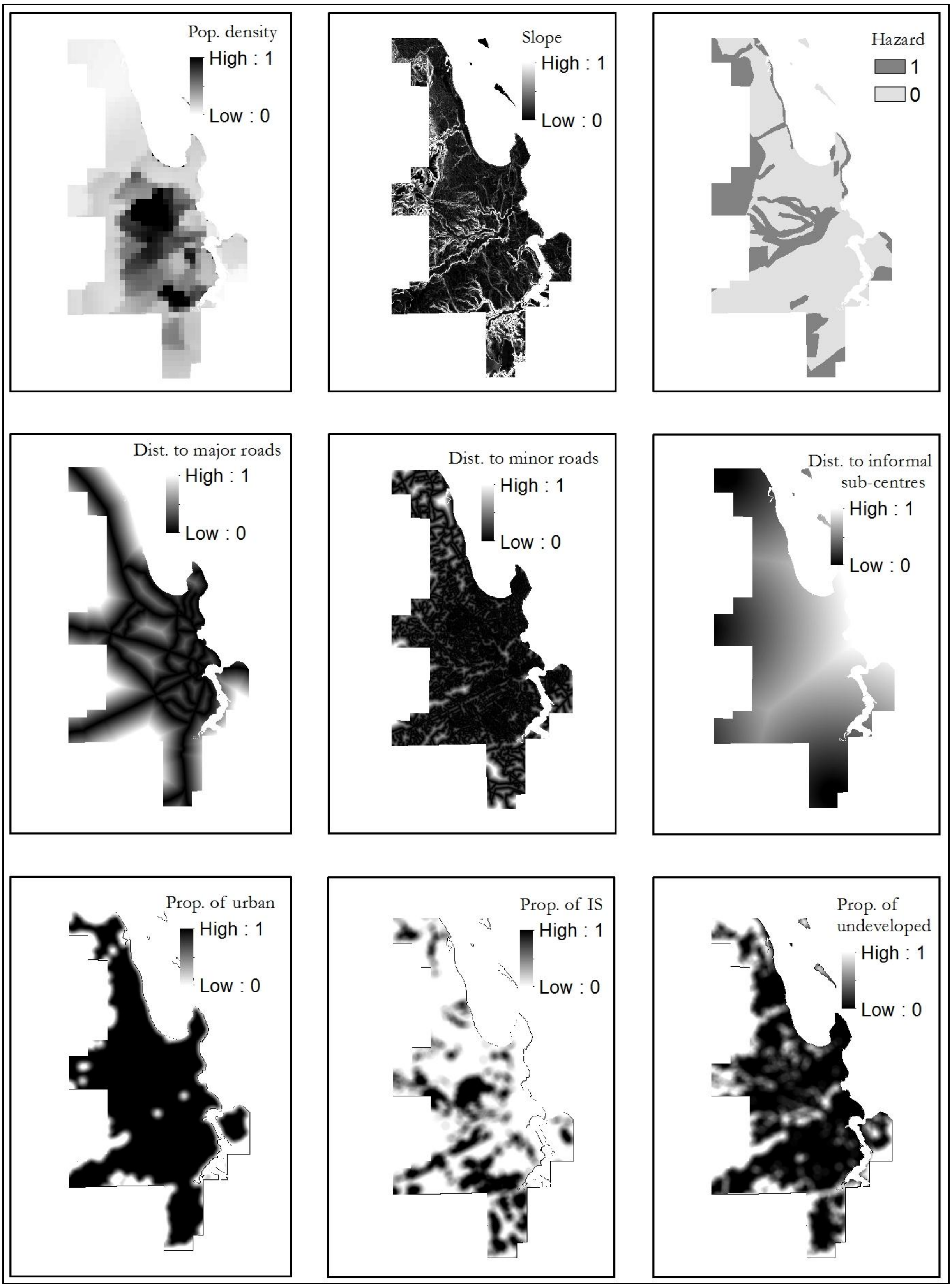


Figure 13: Some raster layers of independent variables of year 1992 for densification



#### 4.3.3. Multicollinearity diagnostics

Multicollinearity diagnostics on 1982 and 1992 variables revealed three variables with variance inflation factor, VIF, greater than 10 (Table 11). Collinearity analysis is done in rounds after one with VIF > 10 was eliminated. For the 1982 variables, $X_{12}$, $X_{10}$ and $X_{18}$ scored 35.77, 11.90 and 10.49 in the first, second and third round of analysis respectively that they are avoided from further involvement in the model as they would bias the model outputs. The same procedure for the 1992 variables earned VIF > 10 for the same variables as that of 1982 but with different sequence of removal. For 1992 multicollinearity analysis, $X_{12}$, $X_{18}$, and $X_{10}$ scored 35.68, 12.04, and 11.74 respectively in sequential rounds of analysis. The binomial logistic regression for expansion, thus, is conducted by seventeen explanatory/independent variables.

Table 11: Result of multicollinearity diagnostics of variables for expansion

| Variable | Description | VIF 1982 | VIF 1992 |
|---|---|---|---|
| $X_1$ | Population density | 2.33 | 2.132 |
| $X_2$ | Environmental hazard | 1.281 | 1.27 |
| $X_3$ | Slope | 1.122 | 1.125 |
| $X_4$ | Distance to major roads | 3.406 | 3.244 |
| $X_5$ | Distance to minor roads | 1.384 | 1.414 |
| $X_6$ | Distance to other-urban land use | 6.231 | 5.948 |
| $X_7$ | Distance to CBD | 3.375 | 3.323 |
| $X_8$ | Distance to informal sub-centres | 2.519 | 2.466 |
| $X_9$ | Distance to satellite centres | 1.582 | 1.631 |
| $X_{10}$ | Distance to food markets | eliminated (2nd) | eliminated (3rd) |
| $X_{11}$ | Distance to existing IS | 4.003 | 3.58 |
| $X_{12}$ | Distance to planned residential | eliminated (1st) | eliminated (1st) |
| $X_{13}$ | Distance to major rivers | 1.955 | 1.96 |
| $X_{14}$ | Distance to minor rivers | 1.918 | 1.872 |
| $X_{15}$ | Distance to river valleys | 3.361 | 3.56 |
| $X_{16}$ | Distance to ocean | 3.482 | 3.323 |
| $X_{17}$ | Distance to hills | 2.555 | 2.392 |
| $X_{18}$ | Proportion of urban land in a surrounding area | eliminated (3rd) | eliminated (2nd) |
| $X_{19}$ | Proportion of IS in a surrounding area | 1.703 | 1.782 |
| $X_{20}$ | Proportion of undeveloped land in a surrounding area | 2.644 | 3.034 |

Similar multicollinearity analysis of variables for densification was done at 1992 time step that showed variable $X_{17}$, distance to hills, to be the only variable with VIF > 10, i.e. 11.45. Overall results are shown in Table 12.

Table 12: Result of multicollinearity diagnostics of variables for densification

| Variable | Description | VIF 1992 |
|---|---|---|
| $X_1$ | Population density | 2.104 |
| $X_2$ | Environmental hazard | 1.109 |
| $X_3$ | Slope | 1.148 |
| $X_4$ | Distance to major roads | 1.975 |
| $X_5$ | Distance to minor roads | 2.530 |
| $X_6$ | Distance to other-urban land use | 2.313 |
| $X_7$ | Distance to CBD | 7.801 |
| $X_8$ | Distance to informal sub-centres | 7.540 |
| $X_9$ | Distance to satellite centres | 4.072 |
| $X_{10}$ | Distance to food markets | 2.968 |
| $X_{11}$ | Distance to existing IS | 2.817 |
| $X_{12}$ | Distance to planned residential | 3.151 |
| $X_{13}$ | Distance to major rivers | 4.874 |
| $X_{14}$ | Distance to minor rivers | 1.788 |
| $X_{15}$ | Distance to river valleys | 3.987 |
| $X_{16}$ | Distance to ocean | 2.692 |
| $X_{17}$ | Distance to hills | eliminated |
| $X_{18}$ | Proportion of urban land in a surrounding area | 3.188 |
| $X_{19}$ | Proportion of IS in a surrounding area | 2.115 |
| $X_{20}$ | Proportion of undeveloped land in a surrounding area | 3.114 |

#### 4.3.4. IS expansion model 1982 – 1992, (Model A)

The model has been interrupted as the p-value found to be insignificant. This might have occurred due the relatively less IS expansion from 1982 to 1992. To this end the sample window has been reduced sequentially from 21x21 cell size to 9x9 cell, and to 3x3 cell, though still it did not qualify to gain the significant p-value. The spatial scale the model is built, resolution and extent, could also have an effect on this premature failure.

#### 4.3.5. IS expansion model 1992 – 2002, (Model B)

Model summary: Log likelihood = -60726.7814, p-value=0.0000, PCP=76.09%, Sample size= 247,734, Overall Model fit: chi-square= 45759.8426, df=17, threshold value=0.105726.

Table 13 summarizes parameters of 1992 – 2002 expansion model, whereby 16 variables are significant at $\alpha=0.05$ and 1 variable at $\alpha=0.10$. From these significant variables: distance to satellite centres ($X_9$), distance to river valleys ($X_{15}$), distance to ocean ($X_{16}$), distance to hills ($X_{17}$), proportion of IS in a surrounding area ($X_{19}$) and proportion of undeveloped land in a surrounding area ($X_{20}$) have positive relation to IS expansion. All the rest variables are negatively associated with IS expansion, indicating the more their presence the less the probability of IS expansion.

Table 13: Parameters of 1992 - 2002 expansion model

| Variable | Coefficient | Standard error | z-value | t-test (p) | Odds ratio |
|---|---|---|---|---|---|
| $X_1$ | -2.342354 | 1.001392 | -2.339099 | 0.0193* | 0.0961 |
| $X_2$ | -0.033507 | 0.018656 | -1.795994 | 0.0725** | 0.967 |
| $X_3$ | -1.421414 | 0.136307 | -10.428 | 0.0000* | 0.2414 |
| $X_4$ | -0.760468 | 0.080879 | -9.402507 | 0.0000* | 0.4674 |
| $X_5$ | -6.371131 | 0.133404 | -47.75835 | 0.0000* | 0.0017 |
| $X_6$ | -5.594638 | 0.085183 | -65.67814 | 0.0000* | 0.0037 |
| $X_7$ | -2.10962 | 0.071552 | -29.48375 | 0.0000* | 0.1213 |
| $X_8$ | -1.382009 | 0.067545 | -20.46064 | 0.0000* | 0.2511 |
| $X_9$ | 0.885541 | 0.060188 | 14.712892 | 0.0000* | 2.4243 |
| $X_{11}$ | -5.326959 | 0.090122 | -59.10864 | 0.0000* | 0.0049 |
| $X_{13}$ | -0.272165 | 0.067889 | -4.008967 | 0.0001* | 0.7617 |
| $X_{14}$ | -1.671694 | 0.087609 | -19.08133 | 0.0000* | 0.1879 |
| $X_{15}$ | 2.278452 | 0.075951 | 29.999113 | 0.0000* | 9.7616 |
| $X_{16}$ | 1.108379 | 0.05458 | 20.307541 | 0.0000* | 3.0294 |
| $X_{17}$ | 1.341721 | 0.059206 | 22.66187 | 0.0000* | 3.8256 |
| $X_{19}$ | 4.092208 | 0.082792 | 49.427611 | 0.0000* | 59.872 |
| $X_{20}$ | 5.492191 | 0.057447 | 95.605077 | 0.0000* | 242.7887 |
| Constant | -4.0869 | - | - | - | - |

*These are variables significant at $\alpha=0.05$
** These are variables significant at $\alpha=0.10$

The relative significance of each driving force of informal settlement expansion can be analysed from the odds ratio value it claims in the model. Variables $X_9$, $X_{15}$, $X_{16}$, $X_{17}$, $X_{19}$ and $X_{20}$ have odd ratios > 1 which shows probability of informal settlement expansion in their presence is higher, while for the rest significant variables odd ratios fall below 1. Detail interpretation of this model and others that follow is presented in Section 4.3.8.

#### 4.3.6. IS expansion model 1982 – 2002, (Model C)

Model summary: Log likelihood = -72311.8296, p-value=0.0000, PCP=76.53%, Sample size= 256,004, Overall Model fit: chi-square=58170.2236, df=17, threshold value=0.135258.

In Table 14, parameters of this 20 years model are described in which all variables are found to be significant at $\alpha$=0.05, except distance to river valleys ($X_{15}$) which is not significant at all. In this model, environmental hazard ($X_2$), distance to major roads ($X_4$), distance to rivers ($X_{13}$), distance to ocean ($X_{16}$), distance to hills ($X_{17}$), proportion of IS in a surrounding area ($X_{19}$) and proportion of undeveloped land in a surrounding area ($X_{20}$) are variables with positive relation with the chance of proliferation of informal settlement, while the rest significant variables are negatively related with informal settlement expansion.

Table 14: Parameters of 1982 - 2002 expansion model

| Variable | Coefficient | Standard error | z-value | t-test (p) | Odds ratio |
|---|---|---|---|---|---|
| $X_1$ | -3.795023 | 0.811511 | -4.676491 | 0.0000* | 0.0225 |
| $X_2$ | 0.110333 | 0.016296 | 6.770371 | 0.0000* | 1.1167 |
| $X_3$ | -0.736714 | 0.122713 | -6.003578 | 0.0000* | 0.4787 |
| $X_4$ | 0.326078 | 0.073873 | 4.414016 | 0.0000* | 1.3855 |
| $X_5$ | -6.861106 | 0.123542 | -55.536775 | 0.0000* | 0.001 |
| $X_6$ | -4.551264 | 0.076525 | -59.473828 | 0.0000* | 0.0106 |
| $X_7$ | -1.488735 | 0.063695 | -23.372968 | 0.0000* | 0.2257 |
| $X_8$ | -1.268483 | 0.058789 | -21.576903 | 0.0000* | 0.2813 |
| $X_9$ | -0.624989 | 0.051542 | -12.125921 | 0.0000* | 0.5353 |
| $X_{11}$ | -5.471 | 0.079825 | -68.537287 | 0.0000* | 0.0042 |
| $X_{13}$ | 0.951959 | 0.062381 | 15.260461 | 0.0000* | 2.5908 |
| $X_{14}$ | -1.469039 | 0.080378 | -18.276525 | 0.0000* | 0.2301 |
| $X_{15}$ | -0.05383 | 0.066262 | -0.812377 | 0.4166 | 0.9476 |
| $X_{16}$ | 2.243572 | 0.050129 | 44.755787 | 0.0000* | 9.4269 |
| $X_{17}$ | 1.123715 | 0.055261 | 20.334765 | 0.0000* | 3.0763 |
| $X_{19}$ | 5.252213 | 0.086006 | 61.068083 | 0.0000* | 190.9884 |
| $X_{20}$ | 4.728622 | 0.05106 | 92.608568 | 0.0000* | 113.1395 |
| Constant | -3.6289 | - | - | - | - |

*These are variables significant at $\alpha$=0.05

All the variables which are positively related with the dependent variable have odd ratio > 1, indicating the high level of informal settlement expansion in their presence. The rest, which are negatively related, do possess odds ratio < 1. Relative significance of the driving forces of informal settlement expansion can then be ordered in terms of the odds ratio value they have in the model.

#### 4.3.7. IS densification model 1992 – 1998, (Model D)

As described in Section 3.4.5, the densification model recognizes four categories of the dependent variable in multinomial logistic regression. Based on multicollinearity analysis only distance to hills, which has shown to possess high VIF, has been avoided and the rest variables were incorporated in the model. The densification model conducted was only significant for low, high and 'other' categories. However, meaningful models that reflect density flux in reality are the change from low to medium density model and 'other' to different density classes' model. To incorporate as much samples as possible the non-overlapping sample window had been reduced from 21x21 cell, to 9x9 cell and eventually to 3x3 cell size sampling window that offered more significant explanatory variables.

As briefly described in Section 4.2.3, informal settlement growth might be a concomitant act of expansion with densification. The informal settlements considered in the model have experienced significant expansion in six years time, 1992-1998, while only 19 settlements among the 65 incorporated in the model have shown density change in the chosen range of density class: low to high, based on SCI (Table 15).

Table 15: Informal settlements with density class change between 1992 and 1998

| No. | IS Name | Density at 1992 | Density at 1998 |
|---|---|---|---|
| 1 | Charambe | Low density | Medium density |
| 2 | Jangwani | Medium density | High density |
| 3 | Kigilagila | Low density | Medium density |
| 4 | Kigogo | Medium density | High density |
| 5 | Kijitonyama | Medium density | High density |
| 6 | Kimanga | Low density | Medium density |
| 7 | Kimara* | Medium density | Low density |
| 8 | Kipawa | Medium density | High density |
| 9 | Kiwalani | Medium density | High density |
| 10 | Kunduchi** | Low density | Medium density |
| 11 | Mabibo_External | Low density | Medium density |
| 12 | Mbagala_Kizuani | Medium density | High density |
| 13 | Mbagala_Mzinga** | Low density | Medium density |
| 14 | Mbezi_Salasala | Low density | Medium density |
| 15 | Msasani_Village** | Low density | Medium density |
| 16 | Mtoni_Kijichi | Low density | Medium density |
| 17 | Ubungo_Kibangu | Low density | Medium density |
| 18 | Vingunguti | Medium density | High density |
| 19 | Yombo_Dovya | Low density | Medium density |

*The only IS declined in density class[15]
**IS which had shrank in area

Table 15 summarizes the density class changes observed from 1992 till 1998, and there are 11 cases of ISs which has increased density from low to medium, 7 cases from medium to high density, and one case from medium to low density. These cases of density change were not enough in type and spatial coverage to be represented in a model. Thus, the proposed density model mainly considers the 'other' land to three density classes, which is an expansion with specified density class, even though the low and high density classes have been modelled as per the changes to a few other density classes.

[15] However, experts confirm that it is not a declining IS and may bias the model that explains change from medium density.

**Low density category**

In this category the two successful models accomplished are the change of low density IS to medium density IS, and the change of low density IS to 'other' land. Here it should be noted that the change of low density IS to 'other' land so far in DSM is very rare and unlikely; hence, result communicated here is the model of low to medium density.

Model summary: Log likelihood = -1228.6547, p-value=0.0000, PCP=90.41%, Sample size= 3,503, Overall Model fit: chi-square=5239.5682, df=57.

Low to medium density IS change is represented in a regression model, where the output parameters are presented in Table 16. Except distance to minor roads ($X_5$) and distance to existing IS ($X_{11}$) all other variables considered are significant at either $\alpha$=0.05 or $\alpha$=0.10. Population density ($X_1$), slope ($X_3$), distance to other-urban land use ($X_6$), distance to satellite centres ($X_9$), distance to food markets ($X_{10}$), distance to existing IS ($X_{11}$), distance to minor rivers ($X_{14}$), distance to river valleys ($X_{15}$), distance to ocean ($X_{16}$), proportion of IS in the surrounding area ($X_{19}$) and proportion of undeveloped land in a surrounding area ($X_{20}$) have positive relations with the change of ISs from low to medium density. Other variables: environmental hazard ($X_2$), distance to major road ($X_4$), distance to CBD ($X_7$), distance to informal sub-centres ($X_8$), distance to planned residential ($X_{12}$), distance to major rivers ($X_{13}$) and proportion of urban land in a surrounding area ($X_{18}$) have negative relationship with densification of IS from low to medium level.

Table 16: Parameters of 1992 – 1998 densification model, low to medium density

| Variable | Coefficient | Standard error | z-value | t-test (p) | Odds ratio |
|---|---|---|---|---|---|
| $X_1$ | 50.294963 | 16.383489 | 3.069857 | 0.0022* | 6.96346E+21 |
| $X_2$ | -0.453602 | 0.188053 | -2.412093 | 0.0159* | 0.635336 |
| $X_3$ | 1.142734 | 0.631634 | 1.80917 | 0.0705** | 3.135328 |
| $X_4$ | -8.000254 | 0.839875 | -9.525529 | 0.0000* | 0.000335 |
| $X_5$ | 0.542821 | 2.428804 | 0.223493 | 0.8232 | 1.720854 |
| $X_6$ | 10.704028 | 1.054119 | 10.154479 | 0.0000* | 44534.90254 |
| $X_7$ | -15.418147 | 1.114988 | -13.82808 | 0.0000* | 0.0000 |
| $X_8$ | -4.958037 | 1.085298 | -4.568366 | 0.0000* | 0.007027 |
| $X_9$ | 5.119297 | 1.069359 | 4.787259 | 0.0000* | 167.217845 |
| $X_{10}$ | 2.362376 | 0.818053 | 2.887805 | 0.0039* | 10.616146 |
| $X_{11}$ | 35.468797 | 25.896214 | 1.369652 | 0.1709 | 2.53456E+15 |
| $X_{12}$ | -6.781135 | 0.847856 | -7.99798 | 0.0000* | 0.001135 |
| $X_{13}$ | -10.455425 | 1.049715 | -9.960248 | 0.0000* | 0.000029 |
| $X_{14}$ | 25.197083 | 1.343677 | 18.752339 | 0.0000* | 87690857547 |
| $X_{15}$ | 1.749841 | 0.981475 | 1.782868 | 0.0747** | 5.753686 |
| $X_{16}$ | 6.963758 | 0.656886 | 10.601171 | 0.0000* | 1057.600572 |
| $X_{18}$ | -5.68125 | 0.543012 | -10.462477 | 0.0000* | 0.003409 |
| $X_{19}$ | 4.122739 | 0.55039 | 7.490583 | 0.0000* | 61.728108 |
| $X_{20}$ | 0.97119 | 0.531299 | 1.827955 | 0.0676** | 2.641086 |
| Constant | 5.9287 | - | - | - | - |

*These are variables significant at $\alpha$=0.05

** These are variables significant at $\alpha$=0.10

### 'Other' category

The model proposed in this category considered change of the 'other' land to low, medium and high density IS; it is the density class of emerging informal settlements[16].

Model summary: Log likelihood = -9733.2454, p-value=0.0000, PCP=93.03%, Sample size= 49,795, Overall Model fit: chi-square=118594.5646, df=57.

Unlike the foregoing category, the model in this 'other' category would indicate the probability of a certain land (that can be developed) to what density class of IS it will turn out to be developed, and shows the significant drivers for the specified density class to happen. Table 17 summarizes the model output for the change of 'other' land to low density IS. Population density ($X_1$), distance to minor road ($X_5$), distance to other-urban land use ($X_6$), distance to CBD ($X_7$), distance to informal sub-centres ($X_8$), distance to food markets ($X_{10}$), distance to existing IS ($X_{11}$), distance to major rivers ($X_{13}$) and distance to minor rivers ($X_{14}$) would negatively influence the probability of having low density IS from 'other' land, the more they have scored an amount. Meanwhile, slope ($X_3$), distance to major roads ($X_4$), distance to river valleys ($X_{15}$), distance to ocean ($X_{16}$), proportion of urban land in a surrounding area ($X_{18}$), proportion of IS in a surrounding area ($X_{19}$) and proportion of undeveloped land in a surrounding area ($X_{20}$) do have positive relationship with the logs of odds of low density informal development.

Table 17: Parameters of 1992 – 1998 densification model, 'other' to low density

| Variable | Coefficient | Standard error | z-value | t-test (p) | Odds ratio |
|---|---|---|---|---|---|
| $X_1$ | -36.068012 | 3.344409 | -10.78457 | 0.0000* | 0.0000 |
| $X_2$ | 0.060172 | 0.096737 | 0.62202 | 0.5339 | 1.06202 |
| $X_3$ | 2.361096 | 0.332214 | 7.107144 | 0.0000* | 10.602561 |
| $X_4$ | 4.6926 | 0.41654 | 11.265652 | 0.0000* | 109.136528 |
| $X_5$ | -9.562508 | 1.148146 | -8.32865 | 0.0000* | 0.00007 |
| $X_6$ | -10.296277 | 0.730087 | -14.10281 | 0.0000* | 0.000034 |
| $X_7$ | -6.32002 | 0.630563 | -10.02282 | 0.0000* | 0.0018 |
| $X_8$ | -5.55726 | 0.666904 | -8.332926 | 0.0000* | 0.003859 |
| $X_9$ | 0.765592 | 0.559035 | 1.369489 | 0.1709 | 2.150267 |
| $X_{10}$ | -7.416012 | 0.476785 | -15.55421 | 0.0000* | 0.000602 |
| $X_{11}$ | -8.742713 | 1.020881 | -8.563889 | 0.0000* | 0.00016 |
| $X_{12}$ | -0.655729 | 0.434986 | -1.507474 | 0.1317 | 0.519063 |
| $X_{13}$ | -1.041503 | 0.42083 | -2.474879 | 0.0133* | 0.352924 |
| $X_{14}$ | -5.327288 | 0.577819 | -9.219656 | 0.0000* | 0.004857 |
| $X_{15}$ | 3.114881 | 0.431373 | 7.220856 | 0.0000* | 22.53076 |
| $X_{16}$ | 0.985333 | 0.394915 | 2.495053 | 0.0126* | 2.678705 |
| $X_{18}$ | 2.234566 | 0.17745 | 12.592634 | 0.0000* | 9.342424 |
| $X_{19}$ | 3.990793 | 0.343021 | 11.634269 | 0.0000* | 54.097773 |
| $X_{20}$ | 9.034229 | 0.297883 | 30.328114 | 0.0000* | 8385.241714 |
| Constant | -1.8516 | - | - | - | - |

*These are variables significant at $\alpha$=0.05

[16] Note that if the emerging IS is due expansion from an existing IS, the density class it claims might not be necessarily its own.

Medium density IS development model is illustrated in Table 18, depicting how each significant variable would contribute for the chance of 'other' land to be changed to medium density IS. It is found that environmental hazard ($X_2$), slope ($X_3$), distance to major road ($X_4$), distance to satellite centres ($X_9$), distance to food markets ($X_{10}$), distance to major rivers ($X_{13}$), distance to ocean ($X_{16}$), proportion of IS in a surrounding area ($X_{19}$) and proportion of undeveloped land in a surrounding area ($X_{20}$) would further increase the probability of a land to be occupied by medium density IS as they increase in size. Here it should be noted that for the dichotomous independent variable, environmental hazard ($X_2$), the result indicates that being a hazardous area would positively contribute to the probability of being medium density IS than otherwise. Distance to minor roads ($X_5$), distance to other-urban land use ($X_6$), distance to CBD ($X_7$), distance to informal sub-centres ($X_8$), distance to existing IS ($X_{11}$), distance to planned residential ($X_{12}$), distance to minor rivers ($X_{14}$), distance to river valleys ($X_{15}$) and proportion of urban land in a surrounding area ($X_{18}$) would add to the probability of medium density IS the nearer or the lesser they are.

Table 18: Parameters of 1992 – 1998 densification model, 'other' to medium density

| Variable | Coefficient | Standard error | z-value | t-test (p) | Odds ratio |
|---|---|---|---|---|---|
| $X_1$ | 1.407821 | 1.124479 | 1.251976 | 0.2106 | 4.087039 |
| $X_2$ | 0.475146 | 0.069181 | 6.868119 | 0.0000* | 1.608249 |
| $X_3$ | 0.937357 | 0.306142 | 3.061837 | 0.0022* | 2.553224 |
| $X_4$ | 6.742991 | 0.308871 | 21.831124 | 0.0000* | 848.093644 |
| $X_5$ | -2.732016 | 0.788427 | -3.465149 | 0.0005* | 0.065088 |
| $X_6$ | -0.646925 | 0.360608 | -1.793984 | 0.0728** | 0.523654 |
| $X_7$ | -4.093745 | 0.368647 | -11.10478 | 0.0000* | 0.016677 |
| $X_8$ | -7.900702 | 0.391307 | -20.19054 | 0.0000* | 0.00037 |
| $X_9$ | 3.505932 | 0.325122 | 10.783438 | 0.0000* | 33.312492 |
| $X_{10}$ | 0.740618 | 0.330662 | 2.239802 | 0.0251* | 2.097232 |
| $X_{11}$ | -19.447202 | 0.955905 | -20.34427 | 0.0000* | 0.0000 |
| $X_{12}$ | -1.85859 | 0.270098 | -6.881159 | 0.0000* | 0.155892 |
| $X_{13}$ | 8.804557 | 0.32289 | 27.267938 | 0.0000* | 6664.54828 |
| $X_{14}$ | -0.933443 | 0.377742 | -2.471113 | 0.0135* | 0.393197 |
| $X_{15}$ | -9.143324 | 0.378506 | -24.15634 | 0.0000* | 0.000107 |
| $X_{16}$ | 3.772356 | 0.220688 | 17.093643 | 0.0000* | 43.482405 |
| $X_{18}$ | -0.309081 | 0.152322 | -2.029127 | 0.0425* | 0.734121 |
| $X_{19}$ | 3.006263 | 0.222159 | 13.53201 | 0.0000* | 20.211719 |
| $X_{20}$ | 4.209632 | 0.184647 | 22.798324 | 0.0000* | 67.331762 |
| Constant | -3.9402 | - | - | - | - |

*These are variables significant at $\alpha=0.05$

** These are variables significant at $\alpha=0.10$

The next logistic regression model, whose parameters are described in Table 19, is about the probability of high density IS development from 'other' land. Distance to minor roads ($X_5$), distance to satellite centres ($X_9$), distance to major rivers ($X_{13}$), distance to minor rivers ($X_{14}$), proportion of urban land in a surrounding area ($X_{18}$), proportion of IS in a surrounding area ($X_{19}$) and proportion of undeveloped land in the surrounding area ($X_{20}$) are all positively related with the proliferation of high density IS, while environmental hazard ($X_2$), distance to other-urban land use ($X_6$), distance to CBD ($X_7$), distance to informal sub-centres ($X_8$), distance to food markets ($X_{10}$), distance to existing IS ($X_{11}$), distance to planned residential ($X_{12}$) and distance to river valleys ($X_{15}$) are negatively related with it.

Table 19: Parameters of 1992 – 1998 densification model, 'other' to high density

| Variable | Coefficient | Standard error | z-value | t-test (p) | Odds ratio |
|---|---|---|---|---|---|
| $X_1$ | -1.944049 | 1.461187 | -1.330459 | 0.1834 | 0.143123 |
| $X_2$ | -0.70548 | 0.144905 | -4.868571 | 0.0000* | 0.493872 |
| $X_3$ | 0.649234 | 0.843255 | 0.769914 | 0.4414 | 1.914074 |
| $X_4$ | 0.463405 | 1.130527 | 0.409902 | 0.6819 | 1.589477 |
| $X_5$ | 27.67098 | 2.271216 | 12.183335 | 0.0000* | 1.04077E+12 |
| $X_6$ | -4.340462 | 1.385956 | -3.131746 | 0.0017* | 0.013031 |
| $X_7$ | -11.832722 | 1.197083 | -9.884626 | 0.0000* | 0.000007 |
| $X_8$ | -1.688025 | 1.018344 | -1.657616 | 0.0974** | 0.184884 |
| $X_9$ | 5.691413 | 0.792433 | 7.182198 | 0.0000* | 296.312018 |
| $X_{10}$ | -2.641155 | 0.692136 | -3.81595 | 0.0001* | 0.071279 |
| $X_{11}$ | -19.548184 | 2.787812 | -7.012016 | 0.0000* | 0.0000 |
| $X_{12}$ | -2.469889 | 1.250832 | -1.974597 | 0.0483* | 0.084594 |
| $X_{13}$ | 6.835579 | 1.106475 | 6.177798 | 0.0000* | 930.367007 |
| $X_{14}$ | 2.157977 | 0.657024 | 3.284473 | 0.0010* | 8.653613 |
| $X_{15}$ | -7.897308 | 1.219974 | -6.473342 | 0.0000* | 0.000372 |
| $X_{16}$ | 0.703832 | 0.446449 | 1.57651 | 0.1149 | 2.021484 |
| $X_{18}$ | 2.729452 | 0.403421 | 6.765773 | 0.0000* | 15.324481 |
| $X_{19}$ | 6.593069 | 0.488421 | 13.498731 | 0.0000* | 730.017954 |
| $X_{20}$ | 7.472803 | 0.415067 | 18.003836 | 0.0000* | 1759.531768 |
| Constant | -9.1452 | - | - | - | - |

*These are variables significant at $\alpha$=0.05

** These are variables significant at $\alpha$=0.10

#### 4.3.8. Models' interpretation

The fitted models are interpreted based on the estimated coefficient value and associated odds ratio for the corresponding variable. It can be recalled from Chapter 3 that each estimated coefficient is the expected change in the log odds of being the 'dependent variable', e.g. IS expansion, for a unit increase in the corresponding independent variable holding the other independent variables constant at a certain value. The influence of each significant independent variable will be investigated with the aforementioned understanding.

**Expansion models**

Driving forces of ISG considered in site-specific characteristics proved to be mainly negatively associated with IS expansion. It has been found that informal settlements tend to expand on areas with low population density. This is unanimously witnessed by the two expansion models, 1992-2002 and 1982-2002, with respective odds ratio of 0.0961 and 0.0225. For a unit increase of population density ($X_1$), and holding the other variables at a fixed value, the odds of being an IS will decrease by 9.61% and 2.25% for 1992-2002 and 1982-2002 expansion models, respectively. Environmental hazard ($X_2$) switched its role in the proliferation of IS. The 1992-2002 model showed environmental hazard to be with odds ratio 0.967 (significant at $\alpha$=0.10), which depicts the odds of having IS expansion is 96.7% less on hazardous lands than otherwise, or the probability of having IS development on hazardous land is 49.16%. However, the 1982-2002 model revealed that the odds of hazard area is 11.67% higher than the odds of non-hazard area, and indicates a probability of 0.528 that IS expansion most likely to happen on hazardous area. On the other hand, slope ($X_3$) is reported to have negative relations with the log odds of IS expansion in both expansion models, increasing the probability of IS occupation on low land areas. The 1992-2002 and 1982-2002 models attributed to it odds ratios 0.2414 and 0.4787, respectively, indicating that there would be 24.24% and 47.87% loss in the odds of IS expansion for each 1% increase in slope.

Most of the IS expansion drivers incorporated within proximity characteristics are found to be more affiliated with expansion of IS. Among the twelve driving forces considered in the proximity category, six are reported to be negatively associated, two positively associated, three changed their role across time and one only significant for the 1992-2002 expansion model. Distance to major roads ($X_4$) is one the variables that reversed their impact on the proliferation of IS. In 1992-2002 model, for every unit distance increase in proximity to major roads the odds of having IS expansion would fall by 46.74%, while in 1982-2002 model one unit increase will promote an increase of 38.55% in the odds of IS expansion, given all other independent variables are set a constant value. The result on the former model regarding distance to major roads is totally in compliance with experts opinion (see Appendix C) and heightened IS expansion along major roads in the 90's (Brennan, et al., 2007). Distance to minor roads ($X_5$), on the contrary, has kept consistent negative relation with IS expansion with nearly the same impact level. It has estimated coefficients -6.371131 and -6.861106 and odds ratios 0.0017 and 0.0010 in 1992-2002 and 1982-2002 model, respectively. In the former model a unit distance increase will result in 0.17% decrease in the odds of having IS expansion, while in the later model the decrease is 0.10%.

Other-urban land use category (industrial, commercial, institutional and recreational land uses put together) has negative relation with IS expansion with an odds ratio 0.0037 and 0.0106 in 1992-2002 and 1982-2002 models, respectively. The probability of an area with one unit distance less from other urban land use group would only be increased by 0.37% and 1.05% in model B and model C, respectively. Here it should be noted that informal settlements in DSM have been occupying lands that are nearby developed areas for easy access to various services (Kyessi, 2002). The closer a plot is located to CBD the higher its probability to be transferred to IS. For a unit increase in distance to CBD ($X_7$), there would be 12.13% and 22.57% decrease in the odds of obtaining IS development, in model B and C, respectively. Experts opinion (Appendix C) also showed unequivocal agreement of experts that distance to CBD had had a 'significant' role in the expansion of IS in DSM. In a similar way, but with more strong impact and sustained impact across time, distance to informal sub-centres ($X_8$) is also negatively related with IS expansion. An area with a unit distant close to informal sub-centres, keeping all other variables at a fixed value, will increase the odds of having IS by 25.11% and 28.13% in model B and model C, respectively. However, proximity to satellite centres ($X_9$), which are nearby centres to the informal sub-centres, has played different roles in the two proposed models. In model B, for a unit distance increase to satellite centres the odds of IS existence will increase by 142.43%, while in model C it will decrease by 53.53%.

Informal settlements expansion in DSM tends to follow track of existing IS. Both models, B and C, depict the relentless negative relation of distance to existing IS ($X_{11}$) with IS expansion, with respective odds ratios 0.0049 or 1/204.0816327 and 0.0042 or 1/238.0952381. This indicates the odds of having IS will drop by 0.49% and 0.42% for a unit distance increase from existing IS, as per model B and C respectively. In terms of specific probability, an area would have 204.0816327 and 238.0952381 times as large probability to be occupied by IS as compared to an area a unit distance away from it, as per model B & C respectively. Distance to major rivers ($X_{13}$) had impacted the development of IS in DSM differently in 1992-2002 and 1982-2002. In model B, distance is reported with an odds ratio of 0.7617 or 1/1.3128528, while in model C it results in odds ratio of 2.5908 or 1/0.3859811. This indicates that probability of IS expansion on an area is 1.3128528 times larger than the probability of IS expansion that is a unit distance far away to major rivers (Model B). Nevertheless, in model C, the probability of gaining IS expansion is reportedly claimed to increase by 0.3859811 times higher than an area a unit distance closer to major rivers. Distance to minor rivers ($X_{14}$) do possess consistent negative relation with IS expansion in both models, with odds ratios 0.1879 or 1/5.3219798 and 0.2301 or 1/4.3459365, in model B and C, respectively. In the former model, the chance of IS expansion on an area closer to minor rivers is 5.3219798 times greater than an area a unit distance away from minor rivers, while the rate is 4.3459365, almost with similar effect, in the later model. Although significant only in model B, distance to river valleys ($X_{15}$) is positively associated with the proliferation of IS with odds ratio 9.7616 or 1/0.1024422, indicating the probability of IS expansion on a land is 9.7616 times as that of land a unit distance closer to river valley. On the other hand, informal settlements seem to have sustained expansion away from ocean/ coast line in DSM. Distance to ocean ($X_{16}$) is positively related to IS expansion in both models, with estimated coefficients 1.108379 and 2.243572, and respective odds ratios 3.0294 and 9.4269, in model B and C, respectively. This means the probability a land, a unit distance away from ocean/coast line, to be occupied by IS is 3.0294 (model B) and 9.4269 (model C) times the probability of a land a unit distance away from it to the ocean. The result collected from distance to hills ($X_{17}$) supports the result explained by the independent variable slope. Distance to hills ($X_{17}$) has odds ratio 3.8256 and 3.0763, according to model B and C, which can explain IS expansion has been affected by hills in consistent way across time. Further the result shows that for a unit distance away from hills the probability to become an IS expansion area would be 3.8256 (model B) and 3.0763 (model C) times larger than that of an area with a unit distance less.

Both proportion of IS in a surrounding area ($X_{19}$) and proportion of undeveloped land in a surrounding area ($X_{20}$) have positive and very significant relationship with the proliferation of IS, as depicted in model B and C. In a 21 cell radius circular neighbourhood the addition of one IS cell will be accompanied by a probability to be occupied by IS 59.872 times (model B) and 190.9884 times (model C) as that of one cell less IS neighbourhood. Similarly, with an addition of one undeveloped cell into a neighbourhood the probability of IS expansion on the plot would be 242.7887 times (model B) and 113.1395 times (model C) the probability without any addition. The aforementioned results show that presence of IS around a neighbourhood has contributed significantly in 1982-2002 IS expansion than it had in 1992-2002, while availability of undeveloped land was more significant driver in 1992-2002 than 1982-2002.

**Densification models**

**Change from low to medium density:**

Population density ($X_1$) plays a significant role in the density transformation of IS from low density class to medium. In this proliferating IS scenario, the probability of medium density IS growth from low density IS is very high on areas with high population density than otherwise. Specifically, the odds of medium IS development would increase by 6.96E+21 if population density increases by one unit. Environmental hazard areas are in negative association with medium densification of IS with estimated coefficient and odds ratio: -0.453602 and 0.635336, respectively. This indicates the probability of medium densification IS on hazardous area is only 38.85%. Unlike the expansion models, for low to medium densification of IS, slope ($X_3$) is positively related with IS medium densification with odds ratio 3.135328 (significant at $\alpha$=0.10). This indicates the probability of IS medium densification is 3.135328 times as large as the probability of medium densification of IS one percent less in slope.

Close proximity to major roads contributes very significantly in the transformation of low density IS to medium density settlements. Distance to major roads ($X_4$) is reported to possess an odds ratio 0.000335 or 1/2985.074627, which indicates the probability of a low density IS to become medium density IS is 2985.074627 times as large as the probability of other one a unit distance away to major road.

Informal settlements have high probability to be transformed from low to medium density the farther away they are located from other-urban land uses. In the proposed IS densification model, distance to other-urban land use ($X_6$) has odds ratio 44534.90254 in low to medium density model (Table 16). This indicates, the probability of medium IS densification of an area is 44534.90254 times as great as the probability medium densification of another area one unit distance nearer to other-urban land uses.

Distance to CBD ($X_7$) is one of the very significant driving forces in changing low density IS to medium density. The closer an IS becomes to CBD the higher its probability to attain medium density IS (Table 16), with an odds ratio of 0.0000. Informal sub-centres also play a pivotal role in the transformation of low density ISs to medium density IS and other urban land uses. Accordingly, distance to informal sub-centres ($X_8$) has scored odds ratio values 0.007027 or 1/142.3082396, indicating the probability of medium densification of an area to be 142.3082396 times as large as the probability of an area that is a unit distance away from it to be in medium density IS. On the contrary, distance to satellite centres ($X_9$) happen to have a positive relation with the change of low density IS to medium density. This means, the farther away from satellite centres the higher the probability of IS to be transformed to medium density IS (odds ratio = 167.217845). Moreover, distance to food markets ($X_{10}$) is also positively associated with medium densification of IS, with estimated odds ratio 10.616146. Thus, the chance of an area for being transformed to a medium density IS is 10.616146 times as large as the chance available for an area a unit distance close to the nearest food market.

A low density IS area tends to change to medium density IS as it becomes in close proximity to planned residential area. Distance to planned residential ($X_{12}$), in low to medium density model (Table 16), is reported with odds ratio 0.001135 or 1/881.0572687. This indicates the probability of medium densification of low density IS is 881.0572687 times as large as another low density IS unit distance farther away from planned residential quarters. Medium density IS are also more affiliated with major rivers, the closer a low density IS is to major rivers the higher its probability to be changed to medium density IS. More specifically, as has been indicated by the variable distance to major rivers ($X_{13}$), the probability of a low density IS to turn into medium density IS is 34482.75862 times as large as similar low density IS a unit distance away from major rivers. Meanwhile, distance to minor rivers ($X_{14}$) has positive relation with the change of low density IS to medium density. This means the farther away low IS is to minor rivers the better its probability to be transformed to medium density. Likewise, distance to river valleys ($X_{15}$) and distance to ocean/coastline ($X_{16}$) are positively related with medium densification of low density IS with an estimated odds ratios of 5.753686 and 1057.600572, respectively. Hence, one unit distance increase to river valleys and coastline would add an increase of 4.753686 and 1056.600572 in the odds of low to medium densification of IS, respectively.

Low density ISs are most likely to blossom towards medium density settlements on the periphery of the city. This generalization is extracted from Table 16, whereby proportion of urban land in a surrounding area ($X_{18}$) has odds ratios 0.003409 or 1/293.3411558 for medium densification. This implies the probability of a neighbourhood to be medium density IS is 293.3411558 times as large as the probability of another settlement with one more urban cell. It is also noted the more informal settlement lands surround a low density IS area the higher its probability to turn either to medium density IS. More specifically, an area would have 61.728108 times as large probability to become medium density IS as an area with one cell less IS in the neighbourhood (Table 16). Proportion of undeveloped land in a surrounding area ($X_{20}$) has positive relation with medium densification of low density IS with estimated coefficient and odds ratio, 0.97119 and 2.641086, respectively. The addition of one cell undeveloped land around a 21 cell radius circular neighbourhood would increase the odds of medium densification of IS by 1.641086.

**Change from 'other' to low, medium or high density:**

Informal settlements with low density are highly associated with low population density areas. Population density ($X_1$) has an estimated coefficient -36.068012 and odds ratio 0.0000 in 'other' to low density IS model (Table 17). Increasing population density by one unit would decrease the odds of having low density by one. Though not significant for low densification, environmental hazard ($X_2$) has different roles to play for medium and high densification of IS. It is positively related with medium IS densification, and negatively with high IS densification, with respective odds ratio 1.608249 and 0.493872. Accordingly, the probability of medium density IS on hazardous area is about 61.66 % while the probability of high density IS to happen on hazardous area is only 33.06%. For all the density classes, slope ($X_3$) is positively related with them, indicating the higher the slope of an area the higher its probability to be occupied by IS. For one percent increase in slope, probability to be occupied by IS is high for low density, followed by medium and high density (as per odds ratios 10.602561, 2.553224 and 1.914074).

Low and medium density ISs are with high probability to be located farther away from major roads. Distance to major roads ($X_4$) is reported to have odds ratios 109.136528 and 848.093644 for low and medium density IS models, respectively. A unit distance increase from major roads would also increase the odds of having low density IS by 108.136528 and the odds of having medium density by 847.093644. Unlike distance to major roads, distance to minor roads ($X_5$) has negative relation to low density IS (odds ratio = 0.00007 or 1/14285.71429) and medium densification of IS (odds ratio = 0.065088 or 1/15.36381). Nevertheless, high densification of IS is positively related with minor roads (odds ratio = 1.04077E+12 or 1/9.60829E-13). Thus, the probability of an area to be low density IS and medium density IS is 14285.71429 and 15.36381 times as large as the probability found one unit distance away from minor roads, respectively. However, the addition of one unit distance to minor roads would increase the odds of having high density IS by 1.04077E+12.

Industrial, commercial, institutional and recreational land uses were attraction points for IS growth. Distance to other-urban land use ($X_6$) proved to be in negative relation with the odds of all IS density categories. It scored odds ratios 0.000034 or 1/29411.76471, 0.523654 or 1/1.9096579, and 0.013031 or

1/76.7400813, for low, medium and high densification of IS, respectively. The magnitude of probability of an area to be occupied by IS is large for low density, then high density and eventually medium density, in a diminishing order, to a unit distance farther away from other-urban land use.

The relative position of ISs to CBD and informal sub-centres had had a significant influence on the settlement density they might have attained. Both distance to CBD ($X_7$) and distance to informal sub-centres ($X_8$) are negatively related with the three IS density classes, indicating the farther a land is to these urban centres the less probability to possess the respective/acclaimed density class. In reference to distance to CBD, the closer a land is to CBD the probability of density class it may possess in a diminishing order is: high, low and medium density IS, based on the respective odds ratio 0.000007, 0.0018 and 0.016677. Nevertheless this order is shifted when the reference is made across informal sub-centres; the chance of an area close by informal sub-centres would have the following density class in decreasing order: medium, low and high (odds ratios 0.00037, 0.003859 and 0.184884). According to the model, an area more close to CBD, rather than informal sub-centres, has a high probability to turn into high density IS. Unlike the foregoing variables, $X_7$ and $X_8$, distance to satellite centres ($X_9$) has a pushing impact on all density classes of IS growth. Considering the specific locations of these satellite centres, at the very end of the city of DSM aligned with major roads (see Appendix E), the results obtained support the opinion that high density exists in the core city and declines to be low density to the peripheries (odds ratios 296.312018, 33.312492 and 2.150267 for high, medium and low density class, respectively). Distance to food markets ($X_{10}$) is negatively related to the extreme density classes, low and high, while it is positively related with medium densification of IS. The probability of low and high IS densification of an area is 1661.129568 times and 14.0293775 times as large as the probability of an area one unit distance farther away to food markets, respectively. But, similar one unit distance increase to food markets in medium densification model would give the farther area a probability that is 2.097232 times as large as the probability found a unit distance less to food markets.

Informal settlements have expansion areas which can claim one of the three density classes. The result collected from distance to existing IS ($X_{11}$) shows that there is high probability for a piece of land to be low, medium or high density class as its distance to existing IS gets smaller. The relative odds ratios 0.0000, 0.0000 and 0.00016 for high/medium and low, respectively, reflect the very high possibility for high/medium density IS to occupy the landscape immediately after existing IS, while low density IS may follow after them. Even though it is not as strong as existing IS, planned residential areas have attracted medium and high density IS. The explanatory variable, distance to planned residential ($X_{12}$), has odds ratio 0.155892 or 1/6.4146974 and 0.084594 or 1/11.8211694 for medium and high densification, respectively. This implies the probability of an area to turn into medium density or high density IS is 6.4146974 times or 11.8211694 times as large as the probability to the respective group of an area one unit farther away to planned residential area.

Informal settlements have revealed different characters, in terms of density, when related to proximity to water bodies. Distance to major rivers ($X_{13}$), for instance, is negatively related with low density IS (odds ratio = 0.352924 or 1/2.8334712) and positively related with medium and high density IS (with odds ratios 6664.54828 and 930.367007, respectively). Thus, probability of an area to be low density IS is 2.8334712 times as large as the probability of an area a unit distance away from major rivers, while the probability of an area to be medium and high density IS would be 6664.54828 times and 930.367007 times as large as the probability of land a unit less distance to major river, respectively. Distance to minor rivers ($X_{14}$) played similar role as distance to major rivers ($X_{13}$), though with different impact, in low densification and high densification of IS, while its role for medium densification is completely opposite with distance to major rivers. Distance to river valleys ($X_{15}$) is negatively related with the logs of odds of both medium (odds ratio = 0.000107 or 1/9345.794393) and high density IS (odds ratio = 0.000372 or 1/2688.172043), while it is positively associated with low densification of IS (odds ratio = 22.53076). This indicates, river valleys are hosts for medium and high density informal settlements. In line with IS expansion model, distance to ocean/coast line ($X_{16}$) also explains in densification model that the farther away an area is to ocean the higher its probability to become an IS with different impact level for a unit increase in distance as shown by the odds ratios 2.678705 and 43.482405 for low and medium IS densification, respectively.

The three driving forces considered in the neighbourhood characteristics, except for proportion of urban land in a surrounding area ($X_{18}$) for medium densification, are all positively related with low, medium and high densification of ISs, though with distinct level of strength. The probability of an area to be occupied by low density IS would be 9.342424 times as large as the probability of an area with one urban cell less compared to it. This probability estimate would rise to 15.324481 times as large, for high densification. However, the probability of an area to be occupied by medium density IS would be 1.3621733 (odds ratio, 0.734121) times as large as the probability of an area with one more urban cell. The odds ratio, 0.734121, is close to one, indicating that the variable has less significance to explain medium densification of IS. Availability of more IS cells around an area significantly promotes the chance of the area to turn into one of the density classes, and eventual probability of a land to settle into a specified density class for a unit IS cell increase is influenced according to the odds ratio. To this effect, proportion of IS in a surrounding area ($X_{19}$) has odds ratio 54.097773, 20.211719 and 730.017954 for low, medium and high densification of IS, respectively. Moreover considerable difference on levels of significance is also observed on the explanatory variable - proportion of undeveloped land ($X_{20}$), with odds ratio 8385.241714, 67.331762 and 1759.531768 for low, medium and high density IS appearance from 'other' land uses, respectively.

## 4.4. Future ISG pattern in Dar es Salaam

This section looks at evaluation of model B, C and D; validation of smoothened expansion model C (A+B), and prediction of future IS expansion and densification.

### 4.4.1. Evaluation of the proposed model

The prediction power of model B (1992-2002) and model C (1982-2002) IS expansion models is similar, with PCP value 76.07% and 76.53%, respectively, as shown in Table 20 and Table 21.

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Table 20: 1992-2002 expansion model evaluation, model B

| | | Predicted | | |
|---|---|---|---|---|
| | | **0** | **1** | **Total** |
| Observed | **0** | 1,499,014 | 495,657 | 1,994,671 |
| | **1** | 37,979 | 197,553 | 235,532 |
| | **Total** | 1,536,993 | 693,210 | 2,230,203 |
| | Correct predictions = 1,696,567<br>Wrong predictions = 533,636<br>Percentage of Correct Predictions (PCP) = 76.07% | | | |

Table 21: 1982-2002 expansion model evaluation, model C

| | | Predicted | | |
|---|---|---|---|---|
| | | **0** | **1** | **Total** |
| Observed | **0** | 1,505,694 | 487,685 | 1,993,379 |
| | **1** | 53,261 | 257,965 | 311,226 |
| | **Total** | 1,558,955 | 745,650 | 2,304,605 |
| | Correct predictions = 1,763,659<br>Wrong predictions = 540,946<br>Percentage of Correct Predictions (PCP) = 76.53% | | | |

High prediction power is noted for densification model, PCP = 93.43, which indicates its high representational value (Table 22).

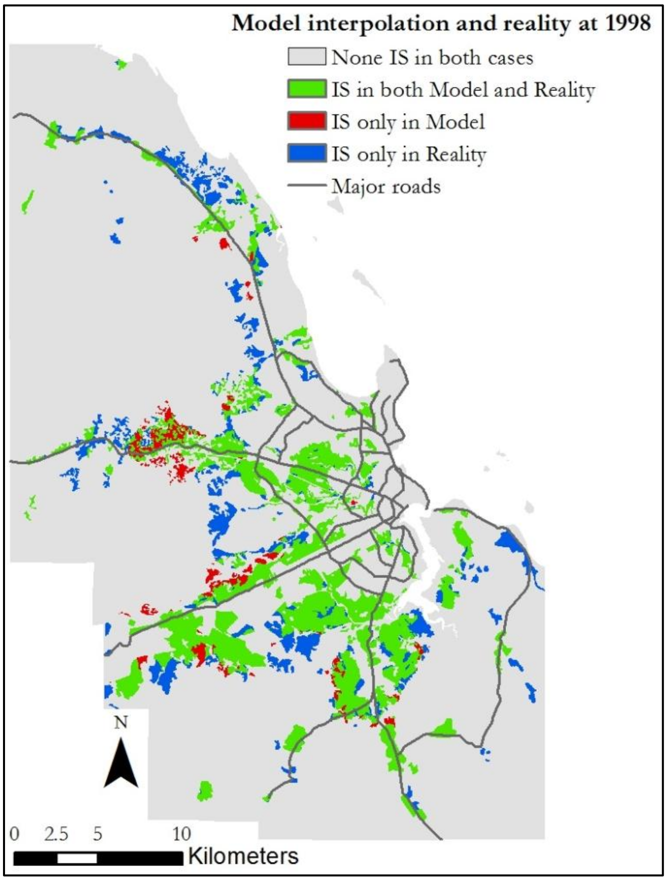
Table 22: 1992-1998 densification model evaluation, model D

| | | Predicted | | | | |
|---|---|---|---|---|---|---|
| | | **0** | **1** | **2** | **3** | **Total** |
| Observed | **0** | 15,832 | 2,104 | 0 | 7,976 | 25,912 |
| | **1** | 1,526 | 21,038 | 0 | 14,229 | 36,793 |
| | **2** | 0 | 0 | 46,810 | 3,380 | 50,190 |
| | **3** | 1,614 | 3,265 | 410 | 407,389 | 412,678 |
| | **Total** | 18,972 | 26,407 | 47,220 | 432,974 | 525,573 |
| | Correct predictions = 491,069<br>Wrong predictions = 34,504<br>Percentage of Correct Predictions (PCP) = 93.43% | | | | | |

#### 4.4.2. Validation of the proposed model

In logistic regression urban growth modelling, validation of a built model is usually made by comparison of future prediction made by the model to a recent data which the model is not based upon (Hu & Lo, 2007; Huang, et al., 2009). The prediction is mainly an extrapolation of past trends to the future. However, due absence of recent land use map, this research makes use of interpolation to validate the expansion model. Spatial distribution of IS in 1998 is known from available land use maps; and interpolating the built expansion model back to 1998 holds probable IS spatial distribution that the model considered to exist (Figure 14). These two maps, model output and reality of IS in 1998, were compared for model's validation. The map comparison resulted in Kappa value = 0.779, KLocation = 0.894, KHisto = 0.871 and 0.951 faction correct (for detailed Kappa statistics, see Appendix E). It is the Kappa value that asserts the models performance in terms of both location and amount estimated; and the achieved Kappa value indicates that the model is indeed representational with substantial agreement (Landis & Koch, 1977).

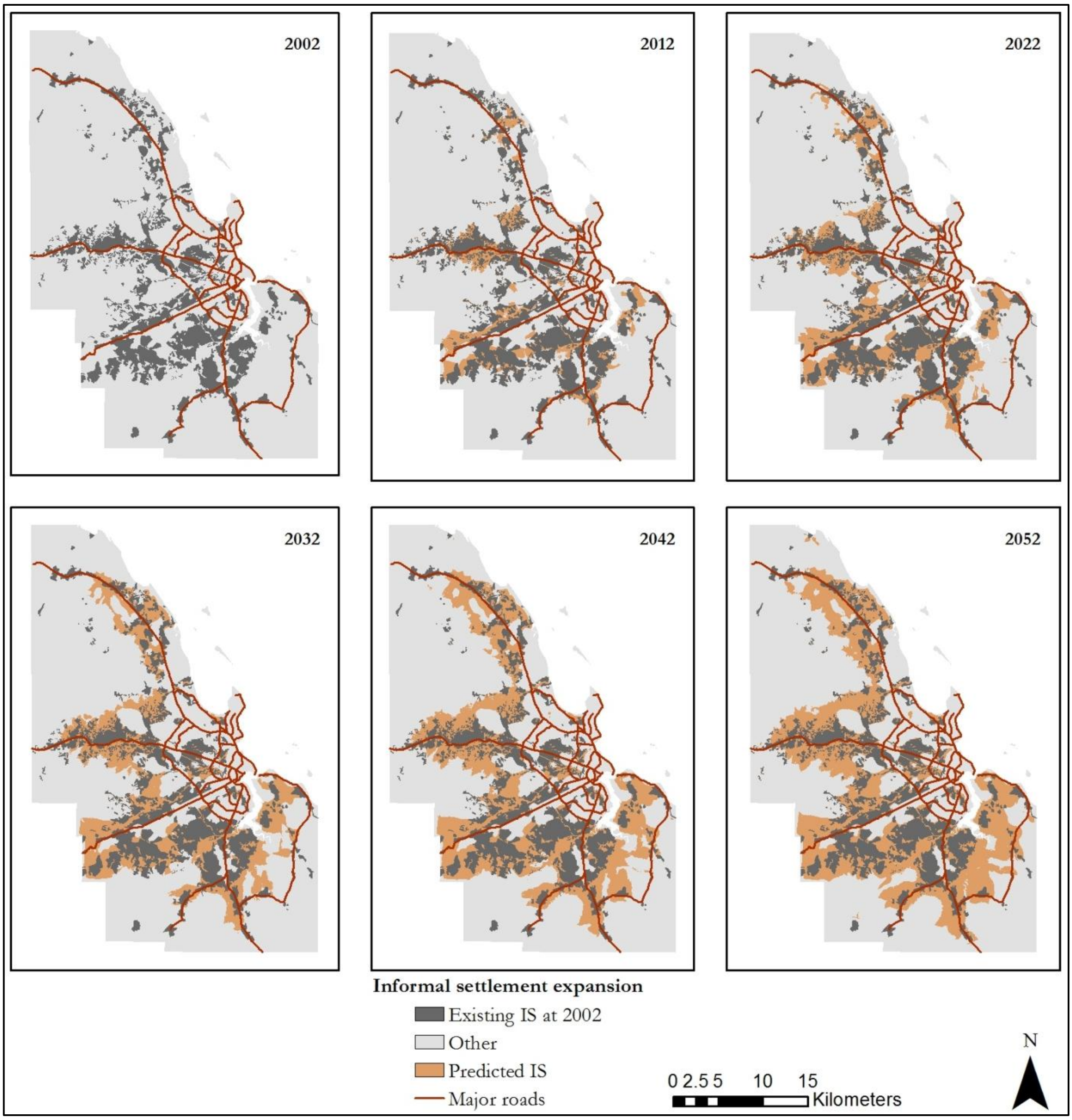
Figure 14: Comparison of interpolated (model) versus observed (reality) IS area at 1998




#### 4.4.3. Probable areas of IS expansion

Probable areas of IS expansion have been predicted based on the expansion model developed by considering IS in 1982, 1992 and 2002, and liable driving forces for the proliferation of IS in DSM. Areas with high probability to be occupied by informal settlements have hosted the anticipated informal settlement increase ahead (Appendix D). The prediction of IS expansion is carried out in an environment assumed to be with high rate of growth. From the predicted IS development areas (Figure 15), it can be observed that the already established trend of ISs land occupation in DSM will be followed. Informal settlements are expanding as an extension of existing IS or around newly formed IS, most of all located along major roads. Figure 15, depicts probable areas of future IS expansion starting from 2012 where by most developments are extensions of existing IS to 2052, a point in time when DSM could be totally bounded in a belt of informal development.; an ideal/extreme scenario but that may happen if trends proceed in the same way as witnessed in the past.

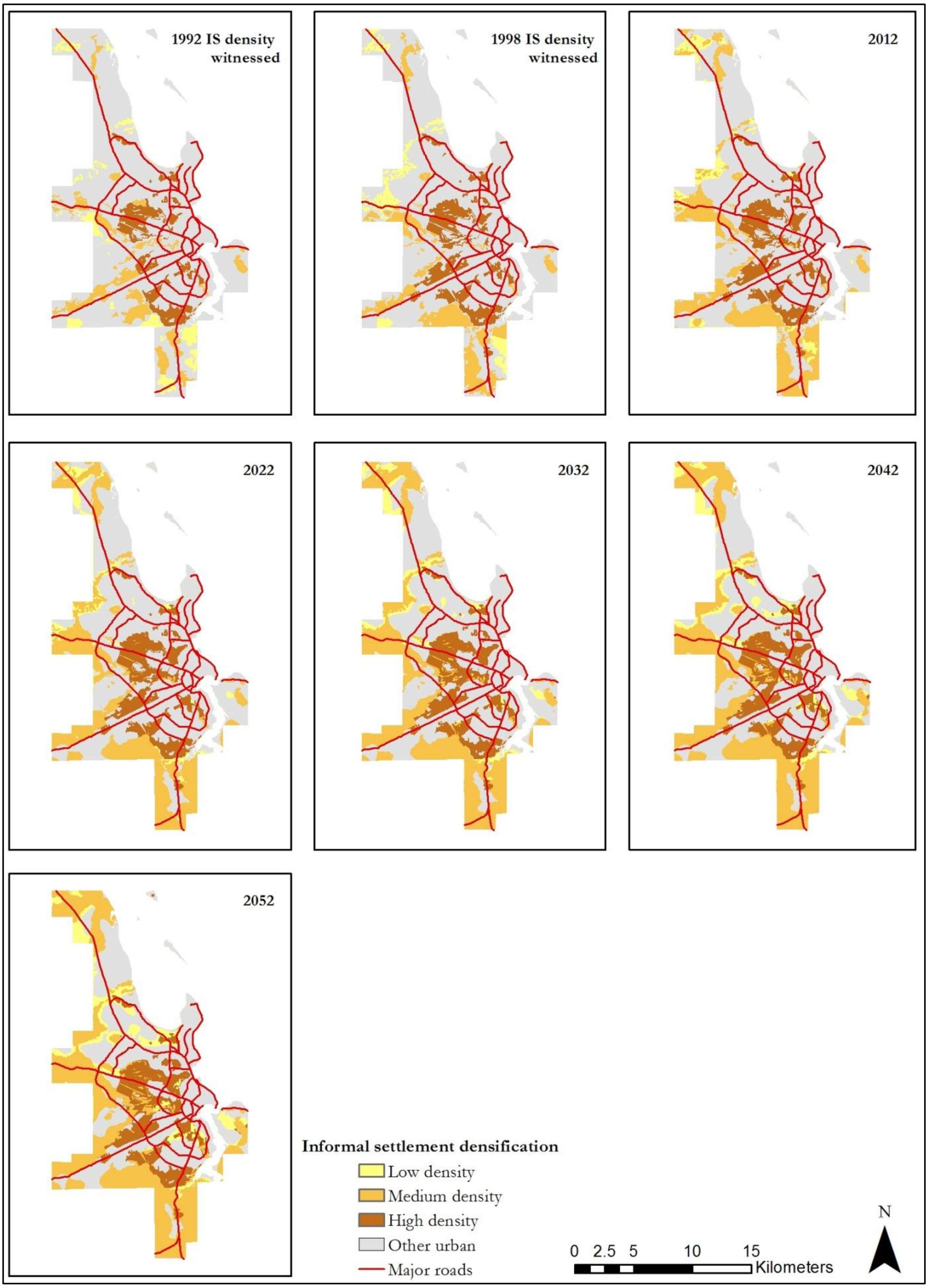
Figure 15: Informal settlement expansion pattern




#### 4.4.4. Probable areas of IS densification

IS densification is most likely to be accompanied by expansion. This was also true for the 1992 and 1998 model input densification data of ISs in DSM. Thus, the future status of ISs in terms of densification may happen to overlap with expansion. However, here, the concern is only on the densification and the driving forces liable for it. The proposed IS densification model mainly outlined the probability of 'other' land category to be converted to low, medium or high density IS entity. This is addressing IS expansion areas with the most probable density class they may claim (Figure 16).

Figure 16: Informal settlement densification trend



# 5. DISCUSSION

This chapter elaborate more on methodological approach taken, results obtained and contributions that can be availed from the research. It incorporates discussions about the issue of modelling informal settlements growth (ISG) by logistic regression modelling (LRM) approach, most important driving forces of informal settlement expansion and densification, and about the future probable areas of IS expansion and densification. The chapter also looks into the implication of the model for actual urban planning practice in DSM and its added value for urban policy development, and it winds up by making a comparison on the outputs of the LRM proposed here with a cellular automata (CA) model proposed for the same study area by other researchers.

## 5.1. Modelling ISG using LRM

In this study, informal settlement growth is subjected to LRM technique for its effective performance in analyzing and interpretation of land use changes (Huang, et al., 2009). LRM is known for its spatial explicitness and explanatory power for urban changes observed in terms of driving forces considered for the acclaimed change (Hu & Lo, 2007; Huang, et al., 2009). In modelling urban growth by LR different scholars reported that the significance level of driving forces might be different either as to the context in which the urban development is taking place (Huang, et al., 2009), or the temporal dimension at which the issue is being looked at, even though it is accomplished in the same geographical region. Cognizant of this fact, binary and multinomial logistic regression models for IS expansion and densification constructed in this study have revealed significant driving forces of informal settlement expansion and densification in DSM, and also attained probability maps (prediction) of each phenomenon.

LR urban growth modelling is an ideal approach to look across significant drivers of urban growth and construct possible scenarios of future developments in data scarce environments (Fragkias & Seto, 2007). From a long list of probable drivers of IS growth (Appendix C), whose impact have been rated by experts, the model in the study considered most that fall in proximity and neighbourhood characteristics and that has been included in site specific characteristics (Appendix B). Although availability of some data is a challenge in developing countries, it is true that by incorporating few, but widely available, spatially explicit data logistic regression model can be constructed to result in relevant information for urban planners and policy makers in detecting where and when certain urban development will take place (Fragkias & Seto, 2007). Accordingly, the study modelled IS growth in DSM by incorporating 17 and 19 probable driving forces of IS for expansion and densification of IS in DSM, respectively. Road and river are the two explanatory variables that had been split into hierarchies: major/minor roads and major/minor rivers. This hierarchy is believed to reveal impact or significance level of each constituent parts of otherwise one big entity. However, modelling with LR approach, which would let the use of fewer variables, has pragmatic essence as it helps for a quick extraction of information by imparting the main driving forces of a phenomenon (Dubovyk, 2010).

The evaluation of both binary and multinomial logistic regression models built was done using PCP values. The models scored PCP values: 76.07, 76.53 and 93.43 for models B, C and D, respectively, and proved valid when they are put in comparison with similar LR led urban growth models. For instance, Cheng & Masser (2003) had 75.7, 81.4 and 83 for three distinct models, Huang, et al. (2009) also built three models with PCPs 75.62, 71.13, and 68.52, and Dubovyk (2010) had shown three models with 84.90, 84.72 and 82.97 PCP values. Absence of recent land use maps and density class of ISs constrained validation of predicted informal settlement expansion and densification areas. Nonetheless, interpolation made to 1998 by expansion model offered IS distribution assumed to exist at that time in history, and map comparisons to the actual IS distribution in 1998 results in Kappa value 0.779, which shows a substantial agreement holds between the model and reality observed (Landis & Koch, 1977).

Multicollinearity and spatial autocorrelation of variables are issues that need utmost consideration in LR analysis to keep away the model from associated bias (Cheng & Masser, 2003). Any variable with high multicollinearity, VIF > 10, has been eliminated in both expansion and densification models, though one would not have any take to decide which one to remove rather the variable with high VIF, as statistically speaking another variable can surely replace the explanatory variable just eliminated (Field, 2009). Systematic sampling scheme has been used to lessen the degree of anticipated spatial autocorrelation. The impact from spatial dependence of records within a variable is argued to be reduced by using a hybrid of sampling techniques, i.e., systematic and random sampling (Cheng & Masser, 2003). However, spatial autocorrelation always persists but with varied significance from variable to variable. In line with it, logistic regression modelling is also sensitive to spatial sampling as it significantly influence parameter estimation and model accuracy (Cheng & Masser, 2003). After a number of tries on sampling window that could result in significant model building and increase significant level of variable estimation, a 3x3 non-overlapping window has been applied. Larger sampling window sizes fail to come up with significant p-values for the model, and significant t-test values for the explanatory variables, as compared to the smaller sampling windows.

LRM is so sensitive to scale issues, specifically for spatial and temporal scales. In the spatial scale, the components usually referred are extent and resolution (Cheng, 2003). For instance, Kok & Veldkamp (2001) revealed that changing spatial extent has substantial effect on the set of land use determining factors coupled with a strong increase in explanatory power when shrinking the spatial extent, as they referred to the specific case they had explored, while coarsening spatial resolution does not change the composition of land use determining factors, though explanatory power increased. In this research, the informal settlement expansion model is done in a spatial extent that covers nearly all the urban agglomeration in DSM city administrative area, while densification model is accomplished in an extent that is a subset of the one devoted for expansion model (Figure 1). As informal settlements are spread across the urban landscape, performing the LR growth model at a bigger spatial extent is essential to explore all the significant driving factors that would have been hidden if it had been done at a district or ward level (Dubovyk, 2010). However, the resolution in both IS expansion and densification models has been kept constant at 20x20 m cell size, that would increase the representational value for dispersed and highly fragmented IS, and comply with resolution of some data, e.g. slope (Hu & Lo, 2007). On the other hand temporal scale, which refers to the smallest temporal unit of analysis in a model (time step) and the overall length of time a model is applied (duration) (Cheng, 2003), is influential in LR urban growth modelling as a model constructed for a region at one time step may not apply for that same geographic area in another time step (Huang, et al., 2009). Here, the research tried to look into drivers of IS expansion from 1992-2002 and 1982-2002, and IS densification from 1992-1998.

LRM has some limitations in modelling urban growth. First, unlike other urban models it does not accommodate temporal dynamics and has no room to incorporate possible urban development scenarios that would impact future urban growth. LRM produces probability maps that indicate where the next generation of urban development will take place, but not when it is going to happen (Hu & Lo, 2007). It is true that by extrapolating the anticipated IS land cover to the future, prediction of future land use can be made. However, since the model does not proceed with time in a self-modifying way, it hardly deserves any dynamic quality. Second, it shares similar traits with other models, specifically CA model, in failing to address personal preferences for locations, urban development policies and globalization of economy that may significantly affect urban growth (Hu & Lo, 2007). This fact would highly affect any predictions of future IS expansion and densification areas as the very issue of informal settlements is a very sensitive issue locally and globally, and different policies enacted from time to time would have a considerable impact on their sustained existence. So, future IS expansion and densification areas predicted in this research are highly tied to "business as usual" scenario.

## 5.2. Driving forces of expansion in DSM, 1982 – 2002

Both model B and C witnessed identical top six driving forces of IS expansion in DSM, each with identical relation with IS proliferation but with different explanatory power. These variables are: distance to minor roads (-ve relation), distance to existing IS (-ve), proportion of IS in a surrounding area (+ve), proportion of undeveloped land in a surrounding area (+ve), distance to other-urban land use (-ve) and population density (-ve). The rating average attributed to these drivers by experts (Appendix C), accordingly was, for minor roads (4.4), distance to existing IS (4.2), proportion of IS in a surrounding area (4.4), proportion of undeveloped land in a surrounding area (4), distance to other-urban[17] land use (3.13) and population density (4.4). Except for other-urban land use, the rest five drivers proved most influential by the LRM are also witnessed by experts to have significant impact on informal settlement expansion. Nevertheless, different studies are in line with the models' output and regarded industrial sites, commercial sites and institutional establishments to be perceived as places of employment and places for easy access to services and infrastructure, among other things, that the majority of informal settlers found close by areas more conducive for their way of life (Kyessi, 2002).

In the purview of modelling ISs expansion, population density reportedly has negative association with further proliferation. This seems to be in contradiction with the already attested view (also supported by the experts) that informal settlements will expand in parallel with unprecedented population growth in weak economies. Although that is true in quantitative terms, the consideration in spatial modelling of ISs is to regress the whereabouts of IS and predict to the future. Thus, the model allocates IS cells on lands with less inhabited/less populated areas, i.e., areas with more vacant land.

The expansion models reveal that major roads do not have strong leverage as anticipated by experts on driving informal settlements expansion. The road variable in LRM is considered in two hierarchies, major and minor, which are exogenous factors in the built model and informal settlements' expansion no more cling to the main roads assigned in the model, but rather highly associated with the remainder road network, i.e., minor roads. Here, it should be acknowledged that the experts may assume different road widths to label it as major road as they were not provided with a specified one; and that by itself limits any conclusions that can be drawn from their response.

The two models, model B & model C, also unveiled four explanatory variables which had shifted roles across time (Table 13 and Table 14), those are: environmental hazard ($X_2$), distance to major roads ($X_4$), distance to satellite centres ($X_9$) and distance to major rivers ($X_{13}$).

[17] Average rating value given for distance to industrial sites, commercial sites and academic institutions

## 5.3. Driving forces of densification in DSM, 1992 – 1998

The most significant driving forces for the transformation of low to medium density IS in decreasing order of influence are: population density (+ve relation), distance to minor rivers (+ve), distance to other-urban land use (+ve), distance to CBD (-ve), distance to major rivers (-ve) and distance to major roads (-ve). Although it is generic, experts indicated responsible driving forces for IS densification (Appendix C). The aforementioned drivers are assessed by experts to have relative significance levels expressed by rating average as: population density (4.6), distance to minor rivers (3.2), distance to other-urban (3.53), distance to CBD (4.2), distance to major rivers (3.2) and distance to major roads (4.4). Unlike for IS expansion models, population density here is positively related with medium densification.

'Other' to low density IS transformation model unveiled significant drivers in diminishing order of influence: population density (-ve relation), distance to other-urban land use (-ve), distance to minor roads (-ve), proportion of undeveloped land in a surrounding area (+ve), distance to existing IS (-ve) and distance to food markets (-ve). Experts opinion revealed rating averages for, population density (4.6), distance to other-urban (3.53), distance to minor roads (4.2), proportion of undeveloped land in a surrounding area (4), and distance to existing IS (4) and distance to food markets (4).

The significant driving forces for the appearance of medium density IS, in diminishing order of influence are: distance to existing IS (-ve relation), distance to river valleys (-ve), distance to major rivers (+ve), distance to informal sub-centres (-ve), distance to major roads (+ve) and proportion of undeveloped land in a surrounding area (+ve). Experts reflection, accordingly is, distance to existing IS (4), distance to river valleys (3.2), distance to major rivers (3.2), distance to informal sub-centres (4), distance to major roads (4.4) and proportion of undeveloped land in a surrounding area (4).

The last model, emergence of high density IS, explains how rapid consolidation of IS would take place. The significant driving forces for this phenomenon arranged in order of diminishing influence are: distance to minor roads (+ve relation), distance to existing IS (-ve), distance to CBD (-ve), distance to river valleys (-ve), proportion of undeveloped land in a surrounding area (+ve) and distance to major rivers (+ve). Experts opinion can be recalled once again that, distance to minor roads (4.2), distance to existing IS (4), distance to CBD (4.2), distance to river valleys (3.2), proportion of undeveloped land in a surrounding area (4) and distance to major rivers (3.2).

In the modelling of densification, the very indicator of settlement density (SCI) is an aggregated value derived from pixels that falls within the settlement boundary (Section 3.4.5). This approach does not inform the actual density an extension of a settlement claims. Settlements hardly preserved similar area in 1992 and 1998; and additional areas engulfed to the settlement at later time will share similar SCI as the settlement itself. But the density class earned from the SCI is not representational of the expanded area, but the whole settlement. However, in this study, the modelling of 'other' to the three density classes has fallen in this trap. The same can be said for the modelling of low to medium density, but as expansion areas are relatively small compared with the already existing settlement the chance of SCI being biased by densities occurring at the new extensions is also relatively low. Nevertheless, new and emerging settlements which appeared in 1998 without any reference to previous settlements are indeed surely represented by their SCI; and the modelling of 'other' to various density classes is compensated by actual and true representation of these settlements. Any conclusions drawn from the model is, thus, limited to the underlining assumptions described above.

## 5.4. Predicted areas of IS expansion

Future probable areas of informal settlement expansion can be discussed in relation to the most influential driving forces detected in both model B and C. IS expansion is found to trace after a land that is, among other things, close by minor roads, near to existing IS, amid huge proportion of IS development, surrounded by considerable amount of developable area, close by other-urban land use and less inhabited/populated area. Despite experts' opinion that major roads (rating average = 4.8) had played a significant role beyond minor roads (Appendix C) and though the major arterial roads (Bagamoyo, Morogoro, Pugu, Kilwa) had played a pivotal role in the establishment of the early informal settlements (Brennan, et al., 2007), it has been found that minor roads by far excel major roads in influencing IS expansion. As indicated in Figure 15, predicted areas of further IS expansion (2012-2052) seem to be aligned with major roads, but they are more abound to minor roads and other factors than to major roads. The predicted IS areas are in contiguity with existing informal settlements, in compliance with experts' judgement (Appendix C) that it had a considerable influence on IS expansion. Experts' opinion to the influence of proportion of IS in an area for further expansion of ISs overweight the other variables considered in neighbourhood characteristics, and the expansion models also assert the opinion. For instance, in 2002 informal settlements area coverage in Kinondoni, Temeke and Ilala municipalities was reported to be 2,560, 2,000 and 1,095 ha of land, respectively, Table 3, (UN-HABITAT, 2010). If only proportion of IS is concerned, then each municipality would have parallel order of probability to host the next generation of IS.

Peri-urban areas, the dividing strips between the more consolidated urban structure and the remaining undeveloped land, are locations where ISs at infancy pay refuge to and where complex organic urban structures are emerging amid rapid urbanization in poverty (Fekade, 2000; Kombe, 2005). In this study, availability of undeveloped land around an area plays a positive role for IS expansion, and nearly all future prediction of ISs land occupation falls in the peripheries. In line with it, the less inhabited/less populated an area is the higher its probability for IS development. Here it should be noted that unprecedented population growth in an economy that wouldn't support its needs will fuel the proliferation of IS (Blanco, et al., 2009); and the further proliferation is taking place on lands which are unoccupied, which will be the urban peripheries. The relation of population density and IS expansion might have been said differently should the population data input was done on ward level, i.e., homogeneous density. In that case, the result may depict the higher the population density of an area the higher its probability to host IS.

Informal settlement expansion has shown strong association with other-urban land use class, which is an aggregate of industrial, commercial, institutional and recreational land uses. As Kyessi (2002) noted informal settlements had kept close proximity with industrial sites, institutions, urban centres, major transportation axes, among others, for easy access for service and employment. Although it is hardly possible to detect the level of influence of each land use class embedded in other-urban land use, the proposed model assures that informal settlements are highly affiliated with it.

The probable future areas of IS expansion are rendered for the city of DSM by extrapolating an assumed housing demand that may fall unmet. The allocation of a cell for informal settlement would be then, of course, by the general utility/probability it may possess from the various explanatory variables. Appendix D shows projected number of IS cells anticipated to hold true, based on historical precedents.

### 5.5. Predicted areas of IS densification

Informal settlement densification trend predicted in DSM (Figure 16) underpins the basic understanding how IS grow. In the projection, that run till 2052, it is shown that high density ISs are kept clustered around the CBD, low density IS are mostly being changed to medium density, medium densities keep on expanding, and also low density IS appears at the edges of medium density IS.

Emergent density characteristics of ISs are the aftermath of highly influential driving forces. For instance, the transformation of low density IS to medium density IS is geared by significant drivers, to mention few: if a settlement turned out to possess high population density, remotely located from minor rivers/small streams, farther away from other-urban land uses, with close proximity to CBD, nearby major rivers, contiguous with major roads, farther away from coast lines, all in diminishing order of influence, among others. To facilitate the ever increasing population density, or increasing family size, residents in ISs are forced to annex a structure to the existing one or erect independent shelter. This extension of a building or infilling of the settlement by houses will result in higher density level (Nguluma, 2003). Unlike the case for expansion of IS, distance to CBD ($X_7$) and distance to major roads ($X_4$) has stronger explanatory power for the transformation of low density IS to medium density IS. It seems contradictory to the actual scene on the ground that low density informal settlements close by other-urban land uses are less probable to be transformed to medium density agglomeration. However, close proximity to planned residential areas is an opportunity for low density IS to gain medium density than otherwise.

The timely predictions, on (Figure 16), also foretell with what density class IS expansion areas would emerge. These are probable areas of IS expansion, with specified density class, predicted after the output of ‘other’ to low, medium and high density class models. It is noted that limited planned and surveyed land against ever increasing high demand for housing has exacerbated the ensuing densification and emergence of new informal settlements (Nguluma, 2003). As time goes by, low density areas are being changed to medium, and again another low density is also being created as a loop around the medium density, while medium density IS keep on expanding across the landscape leaving the high density nearly intact in the centre (Appendix D shows number of cells in each density class across the predicted time).

### 5.6. Model output vs reality of ISG

The LR used for modelling IS growth has its own limitations as portrayed in Section 5.1, as we have a complex set of systems in reality contributing for the growth of ISs that can hardly be represented in a model with a complete nuance they inherit. The relation between the proposed model and reality can be looked at three levels: data input, detecting significant driving forces and setting future predictions. Although the variables upon which the model has based itself emanates from experts’ knowledge/opinion and literature review, the modelling technique suffers from the absence of room to entertain a number of core issues in the growth of IS; to mention few, political will, legal and policy impediments and funding issues (Sietchiping, 2005). A number of assumptions considered, e.g. Euclidean distance, may foster inaccurate picture of the reality and thus, misleading results. Although logistic regression is a statistical approach, all the variables which have rendered significant contribution for ISG in the proposed model also prove the same in reality. Nonetheless, reminiscent of input data quality, type and operation used, probable areas of future ISG might overwhelm a specific area (e.g. the case of IS expansion predicted across Mzinga Creek).

## 5.7. Implication of the proposed model for actual urban planning process

Urban growth probability model could play a significant role in guiding urban development more effectively. de Bruijn (1991) noted that the role and function of a model is highly associated with the effectiveness of planning control at disposal. In a typical Third World urban centre, where rapid urbanization is going along with limited planning control, models can be utilized to predict the possible outcomes of the coupled effect of partial planning and prevalent individual behaviour, and to plan urban infrastructure and services in a more realistic way (de Bruijn, 1991).

The proposed ISG models, in this research, can inform the actual urban planning practice in its endeavour to create a more efficient city amid rapid urbanization. The two proposed model categories, IS expansion and densification, provide information on what are the key driving forces of informal settlement expansion and densification. In line with it, future probable areas of informal settlement expansion and densification can be detected based on probability/utility value the area attains to host such settlements, given we already have a projected figure of IS area (Hu & Lo, 2007). Such models are recommended for spatial decision making process and policy development in urban planning practice and to detect future IS expansion areas (Dubovyk, 2010; Hill & Lindner, 2010; Sietchiping, 2005).

The proposed LRM unfolds significant driving forces for IS expansion that differs considerably from drivers of IS densification. This would help planning authorities to devise ways to treat various issues concerning each phenomenon. For instance, major decision incorporating the stretching of a new road can be evaluated on the basis how it can change the probability of an area for IS development (de Bruijn, 1991; Sietchiping, 2005). When expansion model informs decision makers on the most influential driving forces with future probable areas of IS proliferation, the densification model can also provide key driving forces for density change of a certain settlement or the probable emergent density class of an upcoming IS. Specifically the densification model could help in setting priorities in which areas to intervene, e.g. for any upgrading project, as the sooner the upgrading project (before a settlement saturates) the cheaper it would be in incurred costs for upgrading (Sliuzas, et al., 2004; UN-HABITAT, 2010).

There are practicality issues on how to implement urban growth models in developing countries (Hill & Lindner, 2010; Sietchiping, 2004). The concerns range from how to provide updated data to devising an integrated and user-friendly software working environment. Dubovyk (2010) noted the need for further improvements in the techniques of handling LRM for urban practices, and advised a modelling software environment that should address different sampling schemes, various statistical analysis for LR modelling, and evaluation of built models, among others. Similar notes would apply for the proposed models here, which have been conducted mainly in Change Analyst software, developed by Huang, et al. (2009), whereby currently models are evaluated only in terms of PCP.

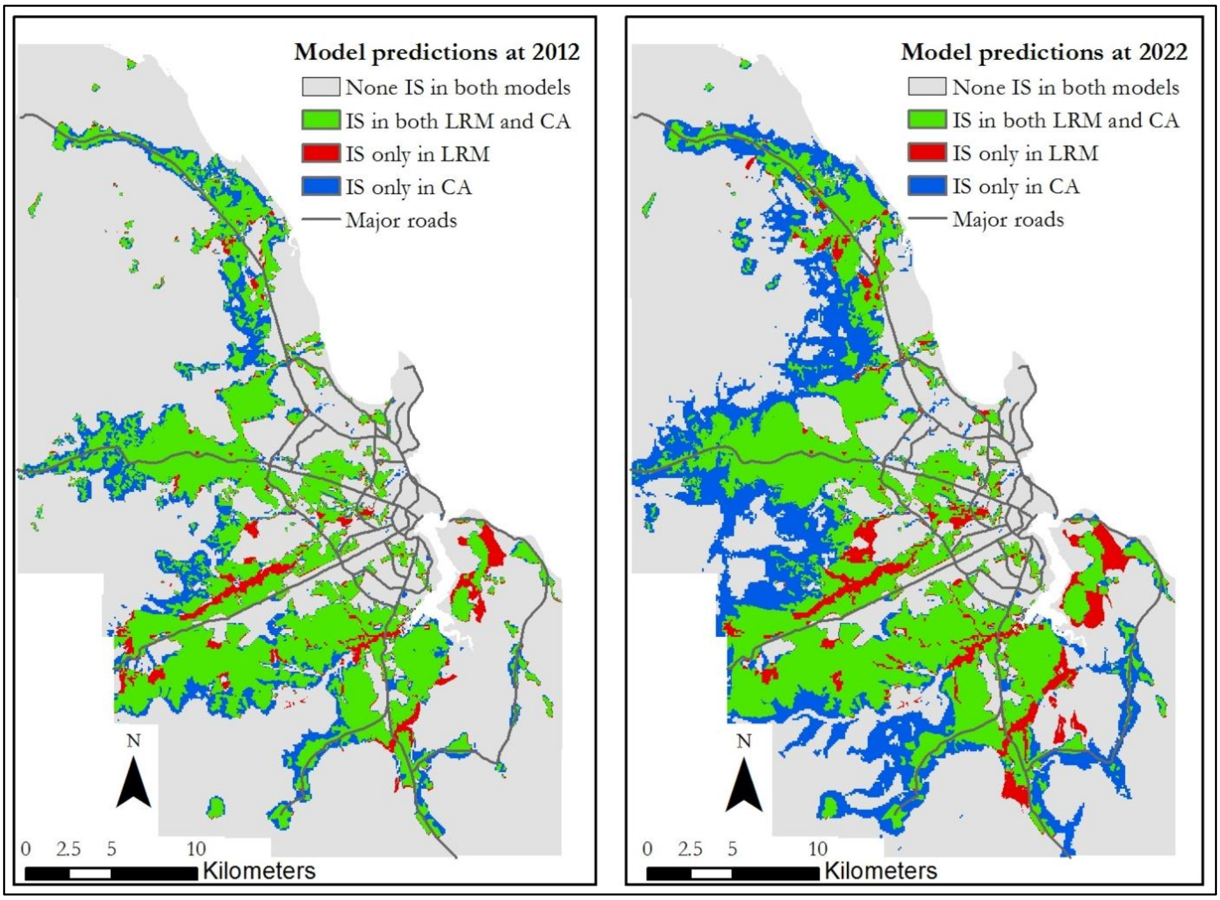
If logistic regression technique of exploring the main driving forces of urban growth is integrated with other modelling approaches, e.g. cellular automata, it will result in a better explanation of urban growth; as the limitation of one would be compensated by the other (Hill & Lindner, 2010; Poelmans & Van Rompaey, 2009; Sietchiping, 2005). Notwithstanding all the challenges in conceiving, designing and implementation of IS growth models, Sietchiping (2005) argues it is dynamic modelling and simulation approach that would bear a better informed policies and facilitate the decision support process.

## 5.8. Comparing IS expansion predicted by LRM with CA model predictions already done for DSM

A dynamic CA model has recently been developed to simulate the informal urbanization of DSM by Hill & Lindner(2010). Their study, briefly described in Section 2.8.1, mainly considers modelling residential land use in general, planned and informal settlements altogether. In this study, probable IS expansion areas at 2012 and 2022 are compared as an output of LRM and CA model.

To allow the comparison[18], baseline scenarios of the CA model, achieved by extrapolating the dynamics based on past conditions and behaviour (Hill & Lindner, 2010), at 2012 and 2022 were used. The corresponding LRM – IS expansion was predicted for years 2012 and 2022. For the first baseline scenario (2012) IS growth is seen to cluster around an existing IS, in both CA and LR predictions. However, while nearly each settlement has expanded in the CA model, the LRM has specified zones of IS development. In addition, it can be observed that, in both models, IS expansion is mainly taking place in terms of extension of an existing IS rather than colonization of new areas. The second baseline scenario (2022) builds on the characters observed in the first one, to result in very distinct features. The CA based IS expansion is more a leapfrog development while the LR predicts a compact IS development.

Figure 17: Comparison of IS predicted in DSM at 2012 (left) and 2022 (right) by LRM and CA model




Source: Own illustration; based on CA model land use prediction data provided by Christian Lindner, TU Dortmund University, Germany

[18] It should be explicitly mentioned here that the comparison between these two methods of modelling is to have an insight where will be future IS area, based on dynamic CA modelling and LRM; and it does not implicate validation of any one of the approach in terms of the other.

It might be due how variables are calculated, e.g., Euclidean distance, to produce the LRM probability maps that significant area has been predicted across Mzinga Creek (Figure 17) while the CA model, making use of network distance, showed insignificant anticipated IS development at the same position. This creek had been a barrier for urban expansion, informal settlement expansion, to the south until the emergence of Mbagala in 1980s (Brennan, et al., 2007).

Further quantitative comparison reveals the two proposed models at 2012 to have substantial agreement, Kappa value of 0.74; while at 2022 the agreement on prediction of IS settlements drops to be with Kappa value of 0.561, showing moderate agreement (Landis & Koch, 1977), (more on the Kappa statistics, see Appendix E). It is true that the LRM has not been set to rigorous calibration which could have enhanced the prediction power. Calibration is the reverse process to regression, and the threshold value of probability can be set in the proposed model to make the model reflect the referred reality it is based on (Fragkias & Seto, 2007; Hill & Lindner, 2010). The CA model is reportedly well calibrated (Hill & Lindner, 2010), and notwithstanding issues of calibration in the proposed model here, policy makers may have concerns as to which modelling type is robust to base decisions on.

It is clear that models are mainly meant to represent the complex reality, and their inherent character is highly tied to uncertainty (Fragkias & Seto, 2007). With this regard, the two models – LRM and CA – have shown a remarkable agreement in predicting where will be future ISs for the first 10 years, but continue to deviate as it proceed to another 10 years to 2022. This will leave policy and decision makers in heightened uncertainty, let alone the uncertainty embraced within each model. Fragkias & Seto (2007) notes the need of policy relevant methodologies to deal with uncertainties amid a number of proposed models and how to maximize the utility by incorporating the averaging of radically different models.

Apart from the inherent methodological approaches involved, the foregoing comparisons are subjected to the estimated demand of IS areas/populations to be housed in IS, each model considered for 2012 and 2022. Nonetheless, the comparison has revealed some similarities on the IS trend to prevail in DSM if past practices and trends continue to persist. The anticipated continuing cultures and practices may include, but not limited to, both individuals' preferences for locations and governments' policies in dealing with them.

# 6. CONCLUSION AND RECOMMENDATION

This research has been necessitated to investigate the key driving forces of informal settlement growth in Dar es Salaam. The growth of informal settlements is considered to be manifested by expansion and densification of such areas, and the study attempted to address driving forces of ISG accordingly. This chapter unfolds general and specific conclusions reached and point out issues for further research.

## 6.1. General conclusions

General conclusions are structured based on sub-objectives:

### 6.1.1. To build conceptual model of informal settlement growth in Dar es Salaam

In 20 years time, 1982-2002, informal settlements in DSM have grown exponentially. The rate of change of IS expansion is observed to be 57.04% between 1982-1992, though in the next 10 years (1992-2002) the rate of change escalated to be 114.32%, double of the previous corresponding era. The overall rate of change in the 20 years is 236.56%, indicating the relentless expansion of IS in the specific period. In parallel to expansion, densification of IS is another form of informal settlement growth in DSM. With this regard the study looked across 1992-1998 to explore the density changes across time. Based on SCI it has been found that considerable number of settlements has consolidated further, while some remained almost stable and very few declined.

A conceptual model is proposed that relates driving forces to a number of probable states of IS. Driving forces of ISG structured into site specific, proximity and neighbourhood characteristics are indicated by experts to play different roles for IS expansion and densification. Proximity characteristics are the most influential driving forces for IS expansion followed by site specific and neighbourhood characteristics; while for densification it is site specific characteristics that play a pivotal role to be followed by proximity and neighbourhood characteristics. If the pressing issue of housing is not addressed well, proliferation of IS is an inevitable phenomena driven by the mentioned factors.

### 6.1.2. To build a logistic regression (LR) model of ISG in Dar es Salaam

Binary and multinomial logistic regression models have been built to explore the driving forces of ISG, in terms of expansion and densification, respectively. The results showed that distance to minor roads (-ve relation), distance to existing IS (-ve), proportion of IS in a surrounding area (+ve), proportion of undeveloped land in a surrounding area (+ve), distance to other-urban land use (-ve) and population density (-ve) are the top six significant driving forces of IS expansion in 1982-2002 model. Similarly, in 1992-2002 expansion model the same variables are found to drive IS expansion but with different order of influence: distance to minor roads, distance to other-urban land use, proportion of undeveloped land in a surrounding area, distance to existing IS, proportion of IS in a surrounding area and population density. The top six main driving forces for densification of IS from low density to medium density agglomeration, in a diminishing order of influence are: population density (+ve relation), distance to minor rivers (+ve), distance to other-urban land use (+ve), distance to CBD (-ve), distance to major rivers (-ve) and distance to major roads (-ve). Notwithstanding the general nature of the model and the explanatory variables considered in the models, IS expansion is influenced highly by proximity characters followed by neighbourhood and site specific characters; while IS densification, pertinent to low to medium class, is influenced highly by site specific characteristics followed by proximity and neighbourhood characteristics. The former deviates from the opinion of experts as the rank is switched between neighbourhood and site specific characteristics while the latter is in agreement with their opinion.

Probable density class of emerging ISs was modelled after 1992-1998 concomitant expansion and densification of IS. The top six driving forces for emerging low density IS, in diminishing order of influence, are found to be: population density (-ve relation), distance to other-urban land use (-ve), distance to minor roads (-ve), proportion of undeveloped land in a surrounding area (+ve), distance to existing IS (-ve) and distance to food markets (-ve). The corresponding drivers for emerging medium density IS are: distance to existing IS (-ve relation), distance to river valleys (-ve), distance to major rivers (+ve), distance to informal sub-centres (-ve), distance to major roads (+ve) and proportion of undeveloped land in a surrounding area (+ve). The emergence of high density IS is found to be highly influenced by driving forces: distance to minor roads (+ve), distance to existing IS (-ve), distance to CBD (-ve), distance to river valleys (-ve), proportion of undeveloped land in a surrounding area (+ve), distance to major rivers (+ve), in a diminishing order of influence.

#### 6.1.3. To determine future ISG pattern in Dar es Salaam

The proposed models are found to be robust enough to explain and predict informal settlements growth in DSM. By extrapolating the trend of IS growth, probable IS expansion areas have been detected till 2052. It is found that future ISs will spread outwards from existing ISs, on areas close by to minor roads with available undeveloped land. This indicates ISs will proceed to occupy the peripheries of DSM, with relentless expansion. Similarly, IS densification is predicted for inner city DSM. These predictions are spatially explicit to raise awareness of the planning authorities and other stakeholders for informed decisions regarding urban development issues.

### 6.2. Specific conclusions

The research has reached specific conclusions in the modelling of ISG:

- Spatio-temporal analysis of IS expansion and densification, and compiling of main driving forces responsible for each phenomenon, in consultation with experts, are prerequisite for understanding the context of ISG and for proceeding with modelling of ISG in a specific geographical region.

- Studying ISG with respect to hierarchy theory would reveal in more detail the actual processes which construct ISG to a wholesome entity, with their specific driving forces. In this research, ISG is conceptualized to comprise three levels: expansion, densification and intensification. However, due the context of the study area only the first two manifestations of ISG are entertained in this research.

- Spatial data availability and quality, if not consistent and with approved accuracy, may foster a big challenge for seamless spatio-temporal ISG analysis.

- In logistic regression ISG models both spatial and temporal scales of analysis play a significant role, and results of the model are valid for the specific spatial and temporal scale. The proposed IS expansion model covers the majority of DSM, and hence, it can represent the whole ISs expansion trend in DSM. On the other hand, IS densification model was done for a specific spatial extent and any conclusions drawn from it only applies to that specific area, not for the whole DSM.

- IS expansion and IS densification have been found to be influenced in different scales by site specific, proximity and neighbourhood characteristic drivers.

- ISG is a concomitant act of expansion and densification.

- LRM of ISG over a set of time-steps can help detect the trends of IS development across the years against the driving forces responsible for their sustained existence. It also gives an insight whether there are any driving forces which has changed roles across time.

- Hybrid urban growth models (integrated models) can inform policy makers in a better way.

## 6.3. Areas of further research

- To repeat LRM in the same spatial and temporal scale by incorporating most of the site specific probable driving forces listed in Appendix C or any other proxy variable.

- To repeat LRM that would be conducted at multi-scale level, different spatial resolutions, and examine the influence of changing scales on parameter estimation and prediction outcomes of LRM.

- To incorporate in LRM mutual effects of interaction between driving forces, and investigate its influence on ISG.

- To repeat LRM based on highly rated (more significant) probable driving forces of IS expansion and densification from experts' opinion; and investigate whether experts' LRM is significantly different from all inclusive LRM or not.

- To enlarge the spatial and temporal scale, for better explanatory power of the LRM. This is in terms of spatial extent, resolution. time step and duration. Thus, repeat LRM with smaller time steps, e.g. 5 years time step, and incorporate recent years' IS developments across the city proper.

- To integrate IS expansion and densification driving forces revealed in LRM with other modelling approach, e.g. CA modelling approach.

- To build a LRM with a thorough statistical tests and procedures in an urban scale.

- To accomplish an integrated ISG model that would address the key driving forces of both IS expansion and densification.

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# APPENDICES

## Appendix A: Data and data sources

Table 23: List of data used

| File | Format | Type | Provided by | Description |
|---|---|---|---|---|
| Municip* | .shp | polygon | ITC | Boundaries of municipalities |
| Population* | .shp | polygon | ITC | Population, 1992, 1998; area, density, ward name, formal/informal |
| CensusDar2002*, Dar_wards_2002* | table | | ITC | Population / education / etc. by ward |
| landform* | .shp | polygon | ITC | Landform categorised: river valley/floodplain, swamp, salt pan, quarry, coastal plains, hills, ocean/estuaries; |
| dem20* | .tif | | ITC | 20x20 meter pixel size DEM covering entire study extent |
| roads* | .shp | line | ITC | Roads, centrelines - categorised: major (1) and minor (2) roads |
| dsmlu75_02* | .shp | polygon | ITC | area; Land use classes 1975, 1982, 1992, 1998, 2002 |
| cbd_markets* | .shp | point | ITC | location of CBD and main food markets |
| rivers* | .shp | line | ITC | Main rivers and streams categorised; ward name |
| Settlement Consolidation Index (SCI) | table | | Richard Sliuzas | SCI for 65 informal settlements in the study area |
| infset92 and infset98 | .shp | polygon | Richard Sliuzas | ILWIS data with named informal settlements at 1992 and 1998 |
| landuse2012 and landuse2022 | .shp | polygon | Christain Lindner | Predicted land use; classes: informal residential, planned residential, other urban |

Georeference: Clarke1880 = GCS_Arc_1960 (Geographic Coordinate System), D_Arc_1960 (Datum), Clarke_1880_RGS (Spheroid)
*File name appears as it does in ITC metadata

## Appendix B: List of experts approached, and list of driving forces considered in the LRM

Table 24: List of experts who expressed their willingness[19] to partake in the questionnaire survey

| | Expert | Institution |
|---|---|---|
| 1 | Dr. Ing. Christian Lindner | Dortmund University, Germany |
| 2 | Dr. Ing. Alexandra Hill | Dortmund University, Germany |
| 3 | Prof. Dr. Einhard Schmidt-Kallert | SPRING group, Dortmund University, Germany |
| 4 | Dr. Eva Dick | SPRING group, Dortmund University, Germany |
| 5 | Dr. Richard Sliuzas | ITC, University of Twente, The Netherlands |
| 6 | Dr. Alphonce G. Kyessi | Ardhi University, Tanzania |
| 7 | Mr. Timoth | Kinondoni Municipality, Tanzania |
| 8 | Mr. George Miringay | Temeke Municipality, Tanzania |

Table 25: Input factor maps prepared for LR, both for expansion and densification

| Analysis category and considerations | 1982 | 1992 |
|---|---|---|
| **Site specific** | | |
| Population density | ● | ● |
| Environmental hazards | < | > |
| Slope | < | > |
| **Proximity characteristics** | | |
| Distance to Other_urban (commercial, industrial, recreation and institutions) | ● | ● |
| Distance to planned residential | ● | ● |
| Distance to existing IS | ● | ● |
| Distance to major roads | < | > |
| Distance to minor roads | < | > |
| Distance to CBD | < | > |
| Distance to main food markets | < | > |
| Distance to informal sub centres | < | > |
| Distance to satellite centres | < | > |
| Distance to major rivers | < | > |
| Distance to minor rivers | < | > |
| Distance to river valley | < | > |
| Distance to ocean | < | > |
| Distance to hills | < | > |
| **Neighbourhood characteristics** | | |
| Proportion of urban land in the area | ● | ● |
| Proportion of IS in the area | ● | ● |
| Proportion of undeveloped land in the area | ● | ● |

●, assume different values for each year.

< >, assumed to be the same across the years.

[19] Although the eight experts listed expressed their willingness to participate, there were only five responses gathered.

## Appendix C: Expert views on the significance of probable dricing forces of ISG in DSM

Table 26: Experts' opinion on site specific characteristics of IS expansion

| Probable driving force | Very significant | Significant | Neutral | Insignificant | Very insignificant | N/A | Rating average | Response count |
|---|---|---|---|---|---|---|---|---|
| Population density | 2 | 3 | 0 | 0 | 0 | 0 | 4.4 | 5 |
| Migration rate | 2 | 1 | 2 | 0 | 0 | 0 | 4 | 5 |
| Income per capita | 0 | 2 | 1 | 1 | 0 | 0 | 3.25 | 4 |
| Distinct social groups/clans | 0 | 3 | 2 | 0 | 0 | 0 | 3.6 | 5 |
| Employment rate | 0 | 2 | 1 | 2 | 0 | 0 | 3 | 5 |
| Environmental hazards | 0 | 3 | 1 | 1 | 0 | 0 | 3.4 | 5 |
| Zoning status of the land | 0 | 2 | 2 | 1 | 0 | 0 | 3.2 | 5 |
| Land ownership | 0 | 2 | 2 | 1 | 0 | 0 | 3.2 | 5 |
| Slope | 0 | 4 | 0 | 1 | 0 | 0 | 3.6 | 5 |
| Infrastructure development | 3 | 1 | 1 | 0 | 0 | 0 | 4.4 | 5 |
| Master plan | 0 | 0 | 3 | 0 | 2 | 0 | 2.2 | 5 |
| Land value | 0 | 3 | 2 | 0 | 0 | 0 | 3.6 | 5 |
| Land form | 0 | 3 | 2 | 0 | 0 | 0 | 3.6 | 5 |
| Other (please specify and also indicate rate of contribution) | | | | | | | | 0 |

Table 27: Experts' opinion on proximity characteristics of IS expansion

| Probable driving force | Very significant | Significant | Neutral | Insignificant | Very insignificant | N/A | Rating average | Response count |
|---|---|---|---|---|---|---|---|---|
| Distance to industrial sites | 0 | 3 | 1 | 1 | 0 | 0 | 3.4 | 5 |
| Distance to commercial sites | 0 | 2 | 3 | 0 | 0 | 0 | 3.4 | 5 |
| Distance to planned residential | 0 | 0 | 5 | 0 | 0 | 0 | 3 | 5 |
| Distance to existing informal settlements | 3 | 0 | 2 | 0 | 0 | 0 | 4.2 | 5 |
| Distance to major roads | 4 | 1 | 0 | 0 | 0 | 0 | 4.8 | 5 |
| Distance to minor roads | 2 | 3 | 0 | 0 | 0 | 0 | 4.4 | 5 |
| Distance to railway | 0 | 0 | 0 | 5 | 0 | 0 | 2 | 5 |
| Distance to central business district (CBD) | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 5 |
| Distance to minor city centres | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 5 |
| Distance to main food markets | 1 | 3 | 1 | 0 | 0 | 0 | 4 | 5 |
| Distance to academic institutions | 0 | 2 | 1 | 0 | 2 | 0 | 2.6 | 5 |
| Distance to health facilities | 0 | 3 | 1 | 1 | 0 | 0 | 3.4 | 5 |
| Distance to rivers | 0 | 2 | 2 | 1 | 0 | 0 | 3.2 | 5 |
| Distance to ocean | 0 | 2 | 1 | 2 | 0 | 0 | 3 | 5 |
| Other (please specify and also indicate rate of contribution) | | | | | | | | 0 |

Table 28: Experts' opinion on neighbourhood characteristics of IS expansion

| Probable driving force | Very significant | Significant | Neutral | Insignificant | Very insignificant | N/A | Rating average | Response count |
|---|---|---|---|---|---|---|---|---|
| Proportion of urban land in the neighbourhood | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 5 |
| Proportion of informal settlements in the neighbourhood | 2 | 3 | 0 | 0 | 0 | 0 | 4.4 | 5 |
| Proportion of undeveloped land in the area | 1 | 3 | 1 | 0 | 0 | 0 | 4 | 5 |
| Other (please specify and also indicate rate of contribution) | | | | | | | | 0 |

Table 29: ISG driving force characteristics ranked for expansion

| Driving force characteristics | First rank | Second rank | Third rank | Rating average | Response count |
|---|---|---|---|---|---|
| Site specific | 2 | 1 | 2 | 2 | 5 |
| Proximity | 3 | 1 | 1 | 2.4 | 5 |
| Neighbourhood | 0 | 3 | 2 | 1.6 | 5 |

Table 30: Experts' opinion on site specific characteristics of IS densification

| Probable driving force | Very significant | Significant | Neutral | Insignificant | Very insignificant | N/A | Rating average | Response count |
|---|---|---|---|---|---|---|---|---|
| Population density | 3 | 2 | 0 | 0 | 0 | 0 | 4.6 | 5 |
| Migration rate | 1 | 2 | 2 | 0 | 0 | 0 | 3.8 | 5 |
| Poverty rate | 2 | 3 | 0 | 0 | 0 | 0 | 4.4 | 5 |
| Income per capita | 1 | 3 | 1 | 0 | 0 | 0 | 4 | 5 |
| Distinct social groups/clans | 0 | 2 | 3 | 0 | 0 | 0 | 3.4 | 5 |
| Employment rate | 0 | 2 | 3 | 0 | 0 | 0 | 3.4 | 5 |
| Environmental hazards | 0 | 1 | 4 | 0 | 0 | 0 | 3.2 | 5 |
| Zoning status of the land | 0 | 1 | 2 | 2 | 0 | 0 | 2.8 | 5 |
| Land ownership | 0 | 3 | 1 | 1 | 0 | 0 | 3.4 | 5 |
| Slope | 0 | 2 | 3 | 0 | 0 | 0 | 3.4 | 5 |
| Infrastructure development | 1 | 3 | 1 | 0 | 0 | 0 | 4 | 5 |
| Master plan | 0 | 0 | 3 | 1 | 1 | 0 | 2.4 | 5 |
| Land value | 0 | 4 | 0 | 1 | 0 | 0 | 3.6 | 5 |
| Land form | 0 | 2 | 3 | 0 | 0 | 0 | 3.4 | 5 |
| Other (please specify and also indicate rate of contribution) | | | | | | | | 0 |

Table 31: Experts' opinion on proximity characteristics of IS densification

| Probable driving force | Very significant | Significant | Neutral | Insignificant | Very insignificant | N/A | Rating average | Response count |
|---|---|---|---|---|---|---|---|---|
| Distance to industrial sites | 0 | 4 | 1 | 0 | 0 | 0 | 3.8 | 5 |
| Distance to commercial sites | 1 | 2 | 2 | 0 | 0 | 0 | 3.8 | 5 |
| Distance to planned residential | 0 | 2 | 2 | 1 | 0 | 0 | 3.2 | 5 |
| Distance to existing informal settlements | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 5 |
| Distance to major roads | 2 | 3 | 0 | 0 | 0 | 0 | 4.4 | 5 |
| Distance to minor roads | 1 | 4 | 0 | 0 | 0 | 0 | 4.2 | 5 |
| Distance to railway | 0 | 0 | 3 | 0 | 1 | 1 | 2.5 | 5 |
| Distance to central business district (CBD) | 1 | 4 | 0 | 0 | 0 | 0 | 4.2 | 5 |
| Distance to minor city centres | 2 | 2 | 0 | 1 | 0 | 0 | 4 | 5 |
| Distance to main food markets | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 5 |
| Distance to academic institutions | 0 | 2 | 2 | 0 | 1 | 0 | 3 | 5 |
| Distance to health facilities | 0 | 3 | 1 | 1 | 0 | 0 | 3.4 | 5 |
| Distance to rivers | 0 | 2 | 2 | 1 | 0 | 0 | 3.2 | 5 |
| Distance to ocean | 0 | 1 | 1 | 2 | 1 | 0 | 2.4 | 5 |
| Other (please specify and also indicate rate of contribution) | | | | | | | | 0 |

Table 32: Experts' opinion on neighbourhood characteristics of IS densification

| Probable driving force | Very significant | Significant | Neutral | Insignificant | Very insignificant | N/A | Rating average | Response count |
|---|---|---|---|---|---|---|---|---|
| Proportion of urban land in the neighbourhood | 2 | 3 | 0 | 0 | 0 | 0 | 4.4 | 5 |
| Proportion of informal settlements in the neighbourhood | 3 | 2 | 0 | 0 | 0 | 0 | 4.6 | 5 |
| Proportion of undeveloped land in the area | 2 | 1 | 2 | 0 | 0 | 0 | 4 | 5 |
| Other (please specify and also indicate rate of contribution) | | | | | | | | 0 |

Table 33: ISG driving force characteristics ranked for densification

| Driving force characteristics | First rank | Second rank | Third rank | Rating average | Response count |
|---|---|---|---|---|---|
| Site specific | 3 | 1 | 1 | 2.4 | 5 |
| Proximity | 2 | 2 | 1 | 2.2 | 5 |
| Neighbourhood | 0 | 2 | 3 | 1.4 | 5 |

## Appendix D: ISG projections

Figure 18: Projected IS area[20] to the future

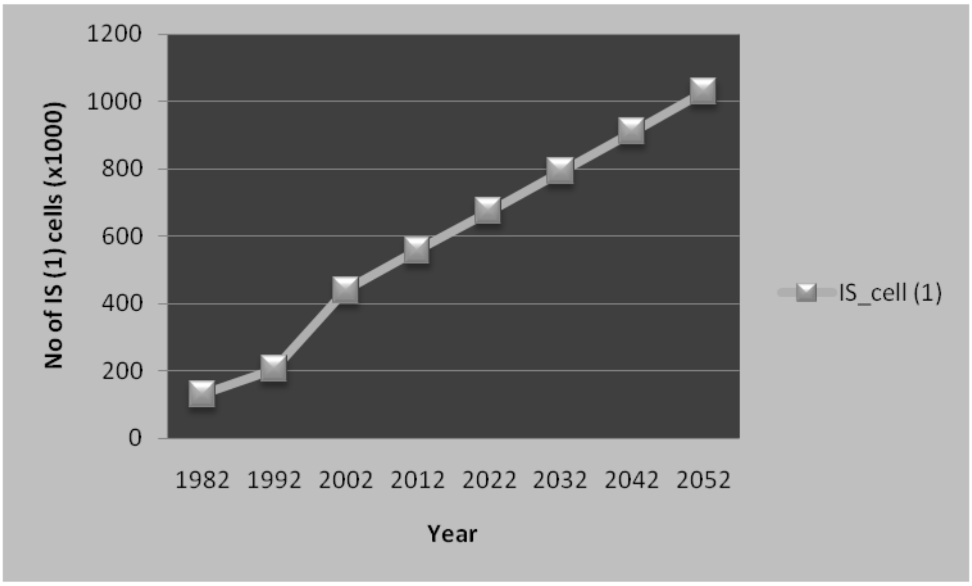
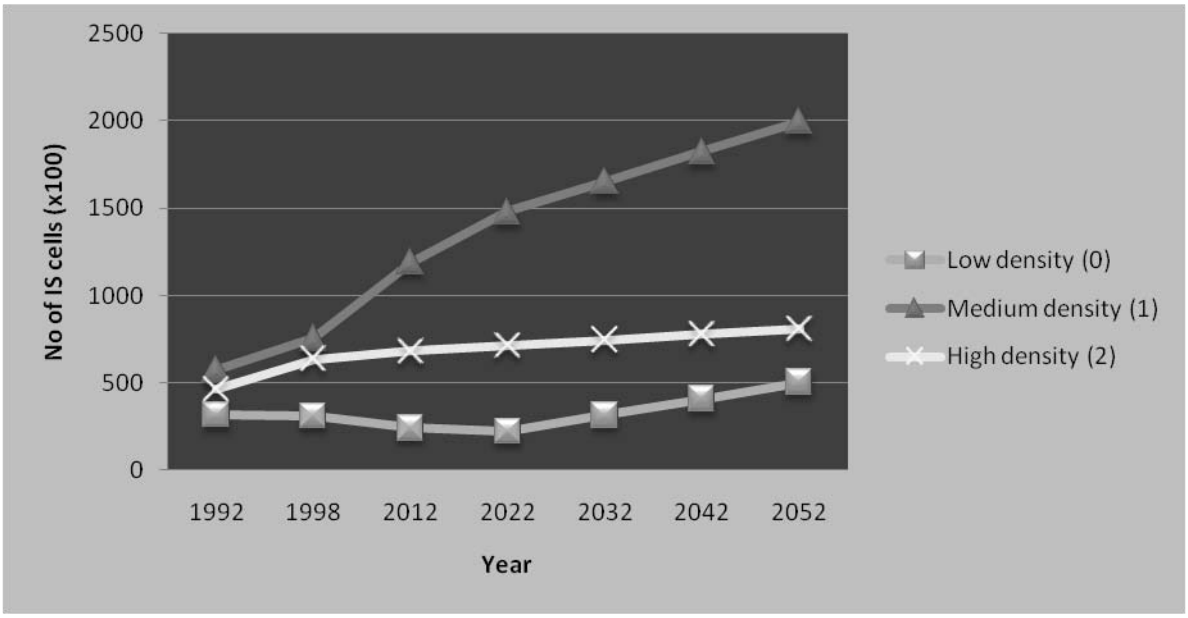



Figure 19: Projected IS area as per density class




[20] One cell is 20x20 $m^2$ of area

## Appendix E: Miscellaneous

Figure 20: Map of some features incorporated in LRM

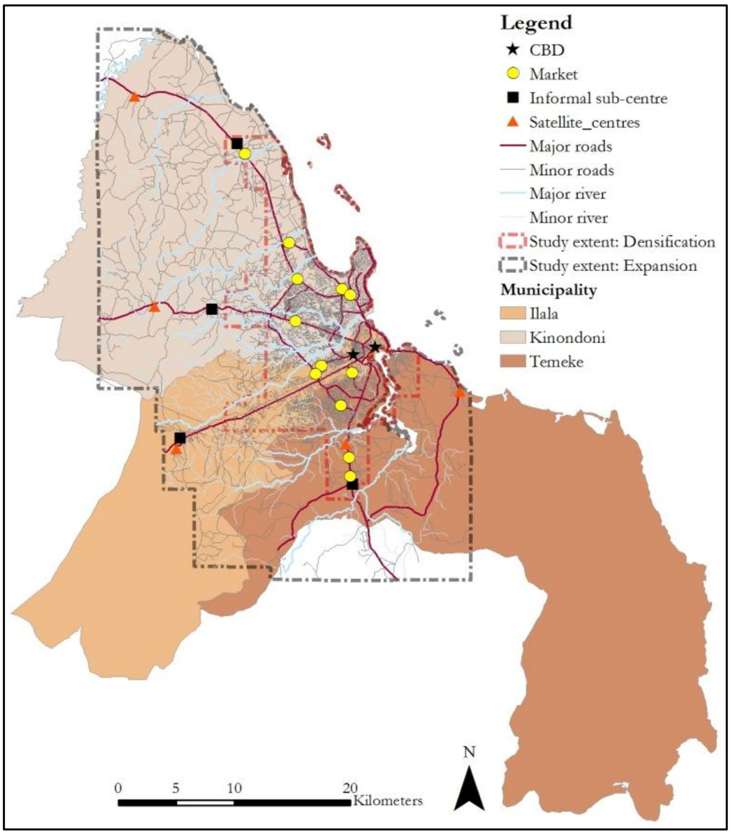



Figure 21: Population in 500m cell grid, but resampled to 20x20m

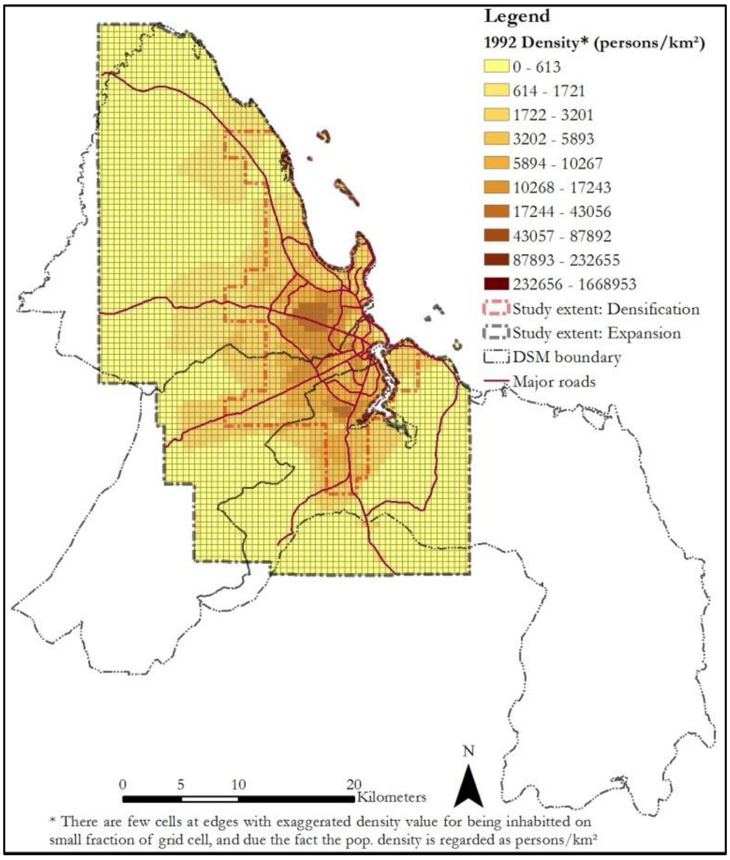
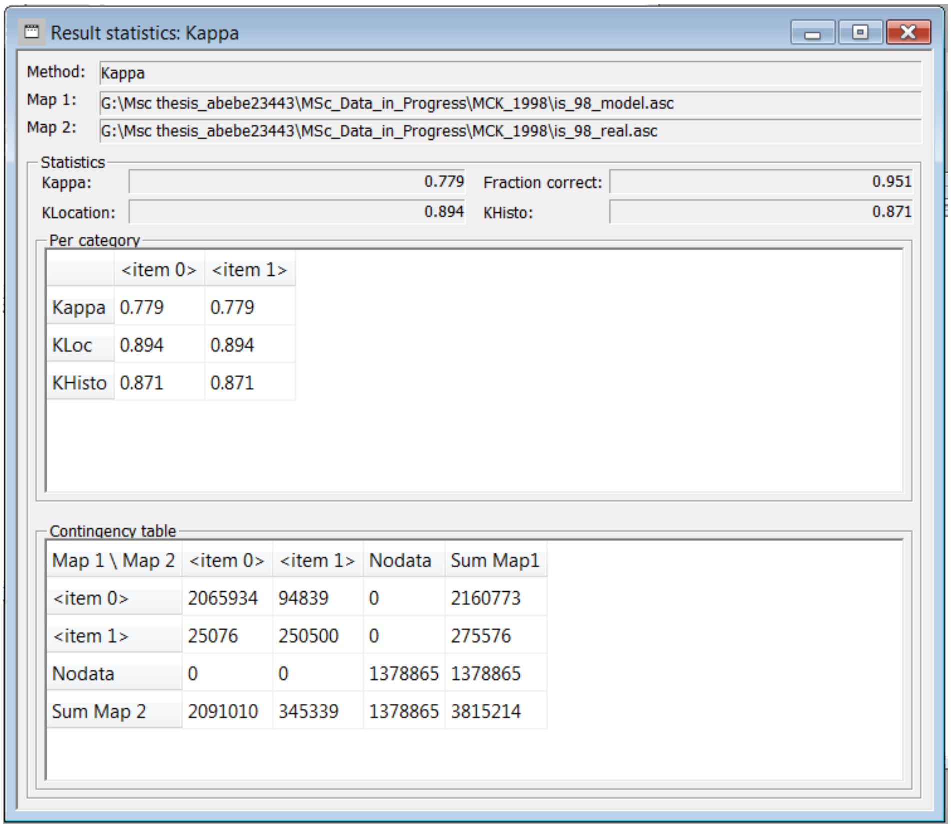


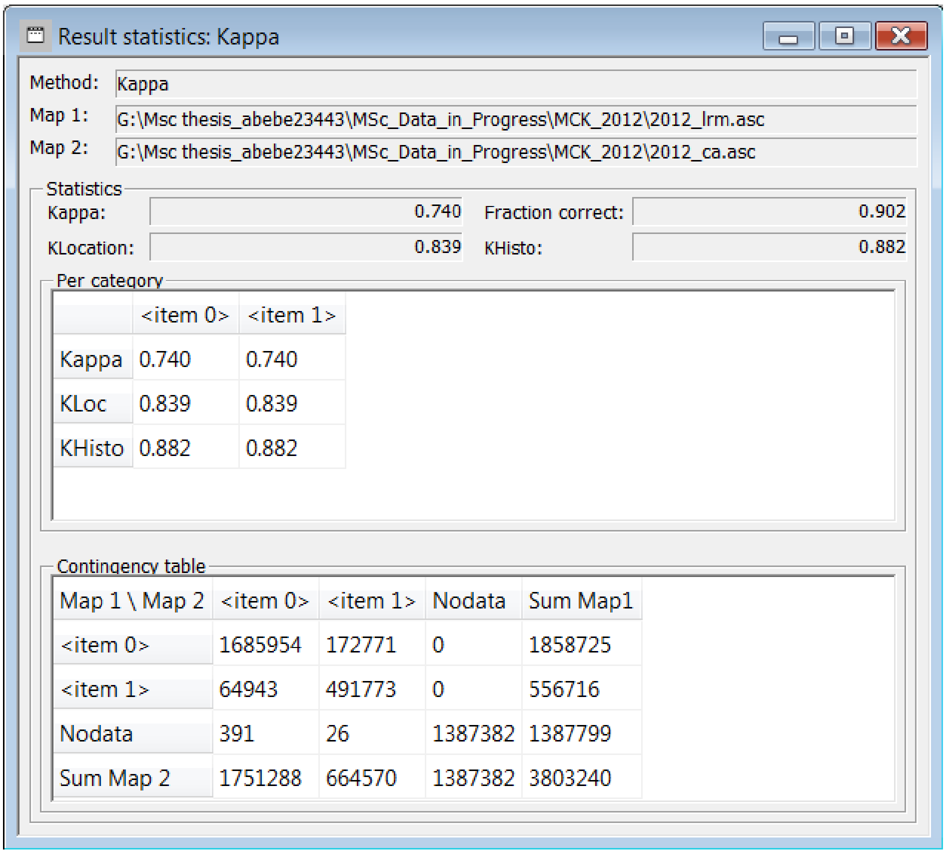
Figure 22: Model validation based on 1998 historical data, Kappa statistics




| | <item 0> | <item 1> |
|---|---|---|
| Kappa | 0.779 | 0.779 |
| KLoc | 0.894 | 0.894 |
| KHisto | 0.871 | 0.871 |

| Map 1 \ Map 2 | <item 0> | <item 1> | Nodata | Sum Map1 |
|---|---|---|---|---|
| <item 0> | 2065934 | 94839 | 0 | 2160773 |
| <item 1> | 25076 | 250500 | 0 | 275576 |
| Nodata | 0 | 0 | 1378865 | 1378865 |
| Sum Map 2 | 2091010 | 345339 | 1378865 | 3815214 |

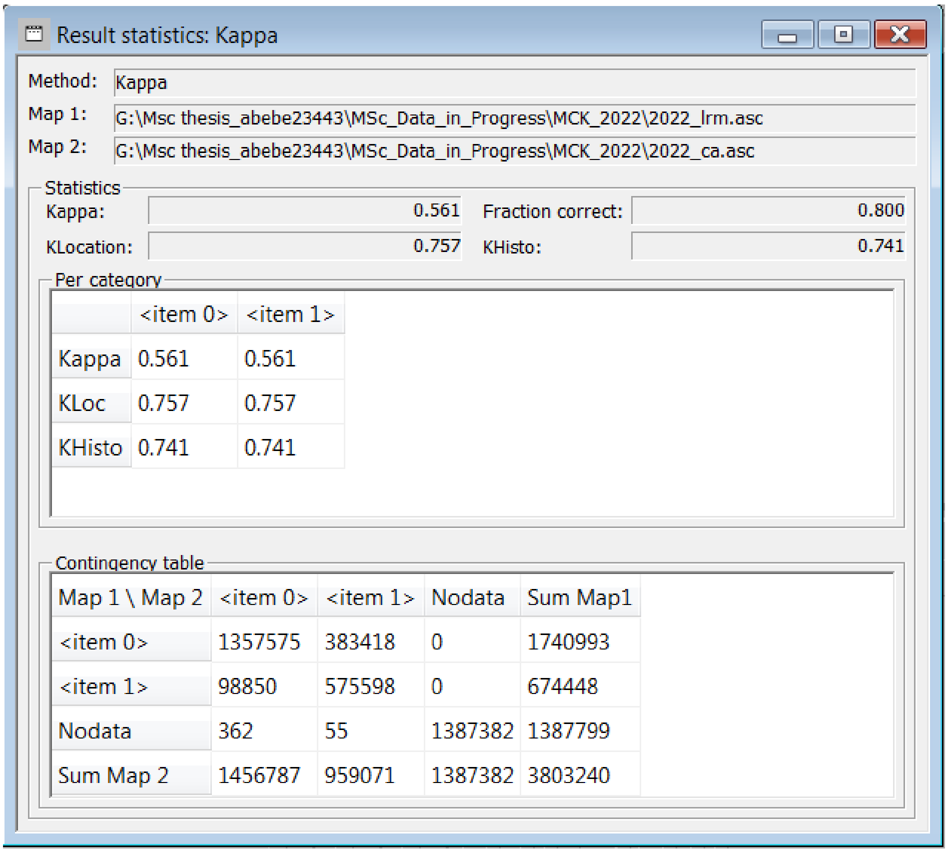
Figure 23: LRM prediction compared with CA simulation at 2012, Kappa statistics




| | <item 0> | <item 1> |
|---|---|---|
| Kappa | 0.740 | 0.740 |
| KLoc | 0.839 | 0.839 |
| KHisto | 0.882 | 0.882 |

| Map 1 \ Map 2 | <item 0> | <item 1> | Nodata | Sum Map1 |
|---|---|---|---|---|
| <item 0> | 1685954 | 172771 | 0 | 1858725 |
| <item 1> | 64943 | 491773 | 0 | 556716 |
| Nodata | 391 | 26 | 1387382 | 1387799 |
| Sum Map 2 | 1751288 | 664570 | 1387382 | 3803240 |

Figure 24: LRM prediction compared with CA simulation at 2022, Kappa statistics


Result statistics: Kappa

Method: Kappa

Map 1: G:\Msc thesis_abebe23443\MSc_Data_in_Progress\MCK_2022\2022_lrm.asc

Map 2: G:\Msc thesis_abebe23443\MSc_Data_in_Progress\MCK_2022\2022_ca.asc

Statistics

| | | | |
|---|---|---|---|
| Kappa: | 0.561 | Fraction correct: | 0.800 |
| KLocation: | 0.757 | KHisto: | 0.741 |

Per category

| | <item 0> | <item 1> |
|---|---|---|
| Kappa | 0.561 | 0.561 |
| KLoc | 0.757 | 0.757 |
| KHisto | 0.741 | 0.741 |

Contingency table

| Map 1 \ Map 2 | <item 0> | <item 1> | Nodata | Sum Map1 |
|---|---|---|---|---|
| <item 0> | 1357575 | 383418 | 0 | 1740993 |
| <item 1> | 98850 | 575598 | 0 | 674448 |
| Nodata | 362 | 55 | 1387382 | 1387799 |
| Sum Map 2 | 1456787 | 959071 | 1387382 | 3803240 |