UNIVERSITY OF CAPE COAST

SIMULATING SPATIAL GROWTH PATTERNS OF URBAN AREAS IN GHANA: AN AGENT BASED MODELING APPROACH

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BY

JUSTICE NANA INKOOM

THESIS SUBMITTED TO THE DEPARTMENT OF GEOGRAPHY AND REGIONAL PLANNING OF THE FACULTY OF SOCIAL SCIENCES, UNIVERSITY OF CAPE COAST IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF MASTER OF PHILOSOPHY DEGREE IN GEOGRAPHY AND REGIONAL PLANNING.

JANUARY, 2013

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Name:.…………………………………………………….…………

Signature: …………………………… Date………………………….

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisors' Name:....……………………………………….……………....

Signature:………………………… Date:………...............................

Co-Supervisors' Name:.....……………..………....

Signature: ………………………… Date:..…………………..........

ABSTRACT

In Sub-Saharan Africa, rapid urban growth has outstripped the capacities of central and local government to control and regulate urban land development; hence people construct their homes on available lands most of which are liable to floods. This research set out to identify the driving forces of spatial growth and to simulate spatial growth patterns of structures in the Shama district of the Western Region of Ghana using an agent-based modeling approach.

The study was conducted within a framework of NetLogo with geographic information systems (GIS) data layers prepared in ArcGIS. The NetLogo assisted to incorporate and simulate driving forces that affect location decision-making by households and the growth of informal structures. A preliminary survey was conducted to obtain household location decision preferences. The study established that the development of unplanned structures and eventual settlement has been a function of land price, proximity to economic centre's, household economic potential, and the location decision-making patterns of households. This exploratory study also found that the majority of spontaneous development took place in areas liable to floods suggesting that some structures fall outside the required building regulations. The application of the proposed model indicates its potential to improve urban planning policies and decision-making processes in emerging cities of developing countries. Also, the result of the simulation suggests potential preferential location for residential development. The research justifies an approach in the area of simulating urban dynamics with agent-based models given the inclusion of empirical data layers.

ACKNOWLEDGEMENTS

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DEDICATION

To my mother Miss Ivy Bentum Annan, my lovely aunty, Miss Agatha Otoo, Mr. and Mrs. Andrea Gibson, Alana Gibson, Trae Heather, and to all my colleagues.

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LIST OF ABBREVIATIONS

ABM	Agent Based Modelling
AOI	Area of Interest
CA	Cellular Automata
CBD	Central Business District
DGRP	Department of Geography and Regional Planning
DLM	Deltaron Land Use/Land Cover Model
DLS	Dynamic Landscape Simulation
EDM	Economic Disparity Model
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GLCM	Global Land Cover Management
GSA	Geo-Spatial Analyser
GSS	Ghana Statistical Service
IBM	Individual Based Modelling
ICES	Integrated Centre for Employee
ISGM	Informal Settlement Growth Model

MCDM	Multicriteria Decision-Making
SDA	Shama District Assembly
SISGM	Shama Informal Settlement Growth Model
SLEUTH	Slope, Land Use, Exclusion, Urban Extent, Transportation & Hillshade
SHASS	Shama Senior High School
SMCE	Spatial Multi Criteria Evaluation
SPSS	Statistical Product for Service Solutions
TCPD	Town and Country Planning Department
UGM	Urban Growth Model
UNSTAT	United Nations Statistics Division
USGS	United States Geological Survey
VHR	Very High Resolution

CHAPTER ONE

INTRODUCTION

Background

Development through growth of settlement has brought changes within the environment in which we live. Features most affected by these changes include the vegetation, water-bodies, wildlife, and fragile lands. Settlement expansion programs meant to enhance human well-being tend to ignore the existence of important natural environmental components such as the urban watershed, wetlands and protected areas (Kombe, 2005).

In Sub-Saharan Africa, rapid urban growth has outstripped the capacities of central and local government to control and regulate urban land development; hence people construct their homes on available lands most of which are liable to floods (Kreibich, 2007). The construction of residential quarters and service centers' on drainage courses, tend to prevent percolation and confine flow of water, thus leading to spread of flow thereby generating flood that causes a lot of damage to property and human life. Of all natural hazards, floods are by far the most hazardous, frequent, and widespread throughout the world (Kizito, 2005).

Most settlements in Africa are characterized by the expansion of unplanned (informal) settlement, unguided spatial pattern, and settlement densification, deterioration of social services and public utilities (Kombe, 2005). In recent times, the development of unplanned settlement has been the main problem associated with expansion of urban areas in Ghana and other developing countries expecting development. Causes of this problem has been associated with the quality of existing formal urban planning policies and regulations and its inability to cope with the pace of the growth and associated hazards (Yeboah, 2003).

Researchers such as Young (2010), Sliuzas, Ottens, and Kreibich (2004), and Kombe (2005) established that spatial growth phenomenon exhibited by settlement is a dynamic and complex process influenced by economic, socio-cultural, and biophysical factors. Hakuyu (1995) discusses socioeconomic and physical characteristics of informal settlements in his analysis of spatial growth. However, the actual volume of housing construction taking place may be a function of households' economic potential at any given time. Population alone may not be the best predictor of settlement growth; instead, the financial capacity to purchase plots and build houses may be a more adequate way of estimating housing volume (Sietchiping, 2004).

The decisions and ideas of household agents (individuals) and their influences on other household agents concerning locations to settle have been known to be a cause of spatial growth which in extreme cases extends (given different patterns of growth) to areas vulnerable to floods (Young, 2010). Previous and present knowledge people have concerning the possibilities that exist for such areas liable to flood also account for the spatial growth of the area. The notion that hazards are simply physical phenomena need to be replaced by one that recognizes human agency as a major contributing factor with its root causes of vulnerability lying in a variety of relational exchanges. It is relevant that the interaction between human agency and the environment or the ecosystem be explored to understand the complexity of phenomenon in space.

Gaps exist in the literature relative to the understanding of current and future expansion of settlement structures and management thereof of such settlements in space.

Problem statement

Deficiencies in land allocation and land delivery, lack of coordination between state institutions and landowners, lack of confidence and unnecessary delays by government institutions responsible for land registration have contributed to the behavior of building outside planning regulation (Kizito, 2005; Yeboah, 2003). Practical capacity of governments and urban planners to effectively respond to the rapid expansion of settlement structures in urbanizing areas remains a challenge in developing countries (Sietchiping, 2004). In Ghana, despite the existence of the Legislation Instrument (LI) 30 which emphasizes that houses built should be at least 30 meters away from the bank of rivers with a thorough observation of the areas topography, the residents (agents) of Shama township in the Shama district continuously ignore or violate laid down rules and regulations with most structural development taking place on floodable zones. According to the Shama District Assembly Medium Term Development Plan (SDA-MTDP), about 54 building structures were located on floodable zones during the flooding incidence in 2008.

However, the decisions and ideas of household agents (individuals) and their influences on other household agents concerning locations to settle have been known to be a contributing factor to spatial growth. Agent based modeling (ABM) technique as a decision making process from the individual level has been introduced in modeling emerging phenomenon such as urban growth (Odunuga, 2009; Young, 2010). Simulating urban dynamics such as the spatial growth pattern of settlements with the aid of agent based models involves understanding the aggregate behavior of urban society and exploration of how the actions or decision making of individuals produce various emergent spatial growth patterns in emerging cities such as Shama. Thus, there is the need to identify the growth pattern of settlements within Shama in order to help reduce the debilitating impact the area has on the people. This research sought to explore the use of ABMs to simulate the spatial growth of settlements structures in the capital of the newly created Shama district.

Research objectives

The general objective of this research is to develop an agent-based model to simulate the spatial growth of settlements in Shama township.

The specific objectives of the research are to:

1. Identify the driving forces that influence the spatial growth of settlements in Shama;
2. Describe the spatial growth pattern of settlements in Shama;
3. Develop a residential suitability map for the Shama area;
4. Ascertain the interoperability of geographic information system (GIS) and the NetLogo platform; and
5. Develop a conceptual model by incorporating the driving forces of spatial growth pattern of settlements and locational behavior of agents.

Research questions

In order to achieve the research objectives, the following questions were posed to guide the study:

1. What are the underlying driving forces that influence spatial settlements growth in the study area?
2. What are the constraints that affect location choice?
3. Is there any relationship between location behaviors of different income groups and the driving forces, which influence spatial growth pattern of settlements?
4. What could be the contribution of GIS and ABM technologies in handling historical and predictive aspects of a proposed dynamic model?

Significance of the study

This research aimed at developing a model capable of simulating the future expansion and distribution of settlement and their resultant relationships with adjoining floodplains. As part of the process, this research explored the use of ABM to simulate the spatial growth of settlements in a bid to help planning authorities influence desired development patterns in the near future. The output of the study could provide valuable information that would inform location decision and spatial planning by landowners, investors, government agencies, and the public to ensure the sanctity of flood prone areas and to help reduce the debilitating effects of floods particularly on waterways in the area. The outcome of this research provides a better understanding of the growth of settlement structures from different household agent’s points of view, and to assist planners in making the rightful decisions of where to place what within a geographic space.

The study appraised the use of agent-based models for understanding the relationship between urban physical structures, its form and functionality, and decision makers that shape these forms.

Scope of study

The study sought to provide an insight into the spatial growth pattern of settlements particularly in areas liable to flooding in Shama. Through investigating the driving forces that influence this growth pattern, an agent-based model was conceived as a laboratory to study the growth pattern of informal settlements on areas liable to floods in Shama at a disaggregated level.

In agent-based modeling, a system is modeled as a collection of autonomous decision-making entities called agents. Agents are defined as the representation and a simplification of complex (including human) behavior, or an autonomous entity with a capability to adapt and modify its behaviors. Against this definition, an agent-based model is developed by extending an existing model (Economic disparity model) by Felsen and Wilensky (2007) in Northwestern University, Chicago. The theoretical basis of this model was the bid-rent model, coupled with the spatial physical structures of the city. The proposed model was based on the effects of agent-based representation of residential decision making of the household agent on the urban physical and economic environment. It sought to consider decisions of influential household agents and their impact on their fellow agents. The model was built and calibrated in NetLogo. Validation was done using subject matter experts approach and the development of hypothetical cases for the model simulation. This process as initiated by comparing maps designed for the spatial growth patterns of the simulated output with the historic data of the city produced for the years 2000 and 2005 respectively.

The study also produced the land use maps of Shama in 2005 for use as baseline data for the study. Another outcome of the study led to the development of a proposed residential suitability map composed with the assistance of the spatial multicriteria evaluation component in the Ilwis platform. This was possible through the availability of toposheet and aerial photograph obtained for the area. Features on the sheets was scanned with high-resolution scanners, and digitized in the ArcGIS platform. Shapefiles obtained from each digitized feature was then merged and grouped into producing a unique map. This routine was conducted on all available toposheet to tease out the extent and pattern of settlement growth. A geodatabase was produced to contain all relevant geospatial information relevant to the study and for future studies.

Thesis outline

The thesis is organized in six chapters with the outline provided in Figure 1. The first chapter presents the context of the research, including the objectives and scope of the research, research questions, and the research methodology. Chapter two, which is the literature review focuses on the concept of settlements and mechanisms of settlement growth dynamics, urban growth models and patterns, urban planning, and the incidence of informal settlement growth, and concludes with the conceptual framework. Chapter 3 presents the methodological context of the study. The study area, research design, data acquisition sources, data processing and the spatial multicriteria evaluation procedures are presented. A residential land suitability map for use as the basis for future model development is developed in this chapter. Captured as the spatial dynamics of Shama, Chapter 4 provides a descriptive analysis of the pattern of settlement growth using the 2000 and 2005 aerial photographs respectively. It also presents the buffer analysis of structures unlawfully located within flood plains.

Chapter 5 describes the proposed agent-based model for simulating spatial pattern of settlements on areas liable to floods by building on the materials and theoretical framework presented in the previous chapters. This chapter further details the overview of the model and its components. Finally, a description of how the model was implemented in the NetLogo simulation environment is discussed. Series of analysis conducted on the model through three major hypothetical construct is presented.

Chapter 6 provides a brief summary of the thesis, highlight the major findings, and suggest some recommendations for further development of this research.

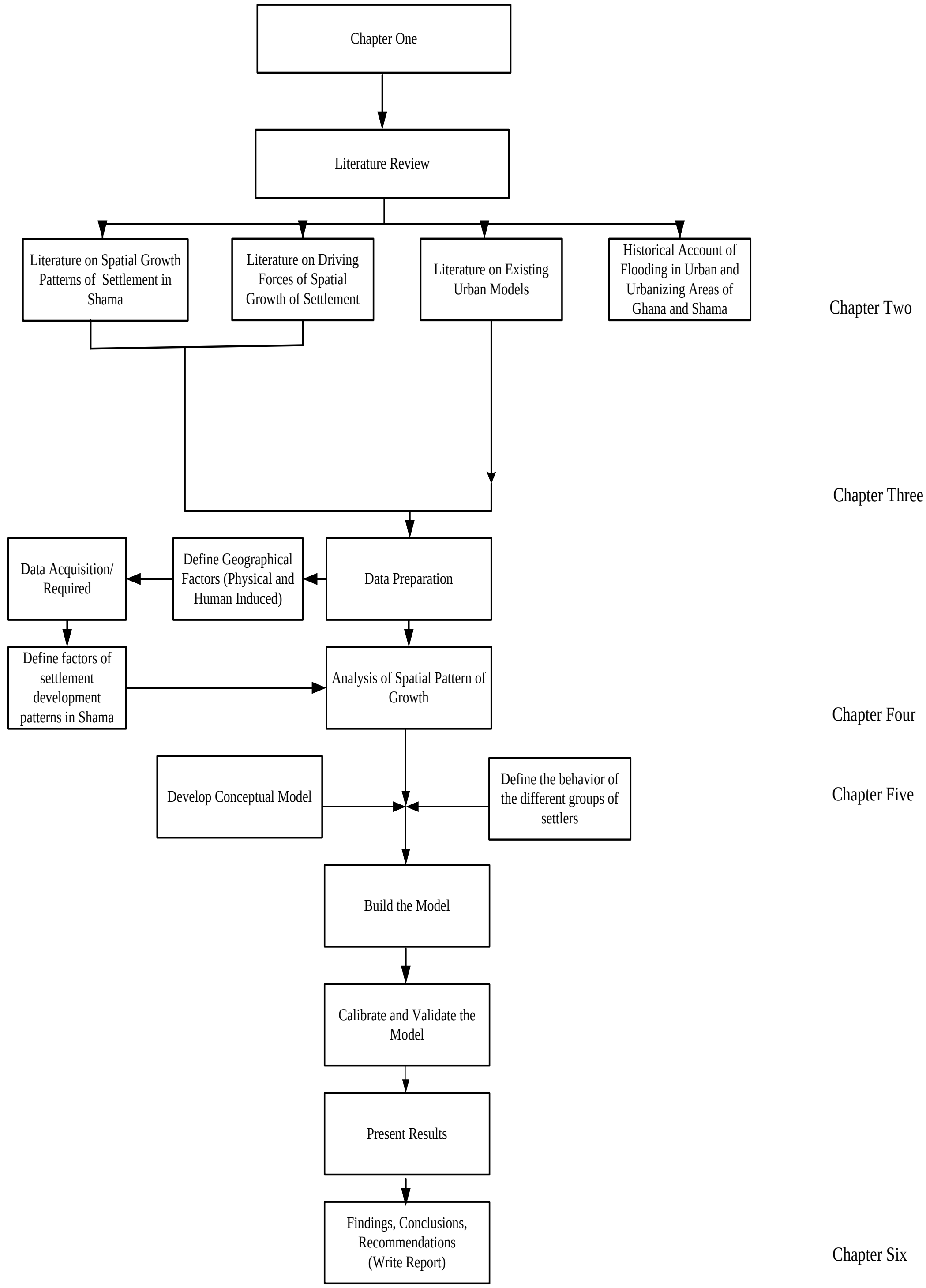

Figure 1: Research Methodological Model (Source: Fieldwork, 2011)

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Introduction

This chapter reviews the concept of informal settlement growth and presents the driving forces that influence informal growth. Available urban growth models, agent based models and cellular automata models and their application in the development of residential urban growth models are presented. Finally, the conceptual framework that informed the model development is presented.

Informal settlement defined

Sietchiping (2005) defines informal settlement as any human establishment or land use in the urban area, which is not suitable and/or is in opposition to the expected standard and regulation. In this definition, informal settlements do not only include urban slums that comprises of deteriorating and decay areas of the city, but also poor housing near the city centre, within the city and those that develop at the city fringes where lands are accessible at a relatively cheap price, which facilitated the construction of building structures on unsuitable places such as flood zones.

In Dar es Salaam, the capital of Tanzania, informal settlements often comprise both affluent and poor residents (Kombe & Kreibich, 2000; Young, 2010). In Ghana however, though majority of the lands are customary owned, registration and ownership of land goes through very cumbersome situations and hence the purchasers of customary land start developing the land without building permits which implies building outside regulations, which contribute to uncontrolled development (Konadu-Agyemang, 2001).

An all-encompassing and very important phrase in all definitions of informal settlements is the lack of requisite permit or legal title for the use of a land; however, regional diversity of urbanization has to be considered in having an adequate definition of the term informal settlement, especially in developing countries (Odunuga, 2009). For the purpose of this study, informal settlement in Shama is termed as any land obtained informally for occupancy without a legal permit from the appropriate planning authority, and are allocated by local leaders, landowners, purchased from the landowner, characterized by an unplanned nature, a lack of basic infrastructure and ever-increasing poverty.

Factors that influence informal settlement growth

The growth phenomenon exhibited by informal settlement is a dynamic and complex process influenced by economic, socio-cultural, and biophysical factors. Sliuzas et al. (2004) puts these factors into environmental, physical, and socioeconomic. Kombe (2005) highlights social and economic factors. Hakuyu (1995) discusses socioeconomic and physical characteristics of informal settlement in his analysis of spatial growth.

Blight and Mbande (1998) are of the view that informal settlement flourishes on marginal or less valuable urban land such as riverbanks, steep slopes, abandoned or unexploited plots, along transportation networks, near industrial areas and market places, and in low-lying areas or wetlands. The actual volume of housing construction taking place may be a function of household's economic potential at any given time (Young, 2010). Fekade (2000) associates the proliferation of informal settlement with the rigidity of urban planning regulations associated with poor governance leading to a severe shortage of land, squatting, and infringements of building regulations.

Young (2010) suggest that population growth alone may not be the best predictor of spatial growth in informal settlements; instead the financial capacity to purchase plots and build houses may be a more adequate way of estimating housing volume.

The economic process is affected by a multifaceted set of influences, which may include physical factors at the micro-level and other factors at the macro-level. Physical factors such as proximity to amenities (CBD, roads, health services, school, markets, industrial site), upgrading and land quality will have individual impacts on other factors such as residents' utility and land price which in turn affects affordability (Young, 2010). Land price is determined by intrinsic and external factors and reflects the principles of hedonic pricing (Grevers, 2007). Macro-level economic influences on housing construction may include GDP, inflation, and real depreciation. Micro- level and macro-level economic conditions need be studied in tandem, as these are interrelated (Young, 2010).

Various physical, social, economic, physical factors (such as infrastructure and services) as discussed above have been found to attract informal settlement residents to a particular location. Sietchiping (2004), citing Blight and Mbande (1998b) lists industrial areas, market places, and transportation networks as factors for residential location. The authors further argued that informal settlements tend to thrive in areas along riverbanks, steep slopes, dumping grounds, abandoned or unexploited plots, low-lying areas, and wetlands.

Young (2010) considered physical, social, religious and economic factors such as the central business district (CBD), industrial area, local market, proximity to planned area, main road, and family and friends among other factors were considered positive and revealed that factors such as CBD, water pump, main road, footpath and local market were ranked as the five most important factors in a study conducted in Dar es Salaam. Proximity to workplace and plot availability among other factors that were revealed outside the major factors considered.

Conceptualising driving forces of informal settlement in Shama

In most cities of developing countries, the manifestation of informality is related to the lack of effective planning, effective land management and zoning regulations for urban and rural development (Tsenkova, Badyina, & Potsiou, 2008). Though the development of informal settlement goes along with urban growth, the driving forces underlying its occurrence differ from those of urban growth. Driving forces primarily refers to socio-economic, environmental, and physical features that influence the growth of informal settlements. The phenomenon could also be associated with the widespread disparity in economic planning and equitable distribution of social and natural capital.

In a related development, Sliuzas (2004) in his study on how to manage informal settlements explained that there are three main factors that describe informal development growth pattern in a typical developing world; they include environmental, physical, and socioeconomic factors. The environmental factors encourage informal settlements development along the slope of the terrain and in environmental hazardous areas where risk of flooding and landslides are pertinent. The physical spatial factors considered involve the proximity to social services (employment, education, school, and transport), infrastructural facilities (water supply, sanitation. electricity etc.), and to major roads. The socio-economic factor considered involve land tenure, housing tenure, value of land and property, demographic characteristics of the settlers, and the economic activities they undertake.

According to Sietchiping (2005), informal growth pattern emerges along riverbanks, steep slopes, dumping grounds, abandoned or unexploited plots, along transportation network, near industrial areas and market areas, and in low-lying areas or wetlands (Blight & Mbande, 1998; Sietchiping, 2005).

Spatial growth pattern of urban settlements

Spatial growth pattern refers to a regular arrangement for logic ordering of urban structure, process, and system. The spatial pattern of an urban region is a consequence of the interaction of various kinds' of driving forces including natural and socioeconomic factors (Sietchiping, 2004; Sudhira, 2004). Spatial heterogeneity of these factors such as topography, soil characteristics, population and market conditions could influence urban morphology and cause different typologies of urban sprawl. A review of the different types of spatial growth existing in urban areas is relevant.

Cheng (2003) described the spatial growth pattern of urban areas as the spatial ordering of objects in geo-space. Different schools of thought have also described different forms and patterns of these growths. Harvey and Clark (1965) described three (3) basic patterns of sprawl development as low-density continuous sprawl, ribbon sprawl, and leapfrog development. The low-density sprawl growth refers to development that occurs at the margin of existing built-up areas supported by basic social and infrastructural amenities. Ribbon sprawl is development that takes place along major transportation network; while leapfrog development is an uncontrolled expansion of the urban area. Sudhira (2004) described the three basic urban spatial growth patterns as radial, ribbon, and leapfrog development. Sudhira (2004) suggested that radial growth pattern represent low-density sprawl growth.

Some researchers have in general terms described the growth pattern of urban areas. In a study of the post-war growth era of British cities, Smailes (1966) identified two fundamental pattern of urban growth: the outward extension and internal reorganization or modification (e.g. densification) (Smailes, 1966). Outward spread refers to the spreading of cities' spatial extent, while internal modification refers to internal growth within the city. According to Odunuga (2009), spontaneous spatial growth refers to development of informal settlements in isolated urban areas without respect to existing urban social and infrastructural amenities. Spontaneous growth means the formation of new urban patches without any direct spatial connection with the existing urban patches. Forman (1995) calls this type of landscape process ‘perforation’, and defines it as *‘‘the process of making holes in objects such as habitator land type.’’* Spontaneous settlements are isolated hamlets and small villages that develop overtime.

Camagni, Cristina, and Paolo (2002) distinguished five types of urban expansion: (1) Infilling (growth that takes place within existing urban area); (2) Extension (growth at the fringes of the city); (3) Linear development (urban development along main transport infrastructures); (4) Sprawl (characterized by new scattered development across the urban area); and (5) Large-scale projects (expansion across the city regardless of existing built-up areas). Infilling and outward spread is another spatial growth pattern of informal settlements that takes place within existing urban area. It could also develop adjacent to urban fringes. Infilling refers to the infilling of free spaces within existing built-up areas. These areas are usually close to the city centre and are well serviced with social and infrastructural facilities. In simple terms, Infilling means the non-urban area surrounded by urban being converted to urban. Wilson, Hurd, and Civco (2002) identified five types of urban growth: infill, expansion, isolated, linear branch, and clustered branch.

Modelling and simulation

Modelling is a tool, which helps people, communicate easier with each other. Otherwise, it makes people understand the complex world, enlarge their knowledge and reduce the uncertain understanding about surrounding world (Feng, 2004). Benders (1996) in his work argued that the second meaning of modelling is to reduce uncertainty. Models facilitate scenario building and provide an important aid to future directed decision-making influential in the area of urban planning (Cheng, 2003). Models offer the possibility to test the sensitivity of land use (pattern) to changes in selected variables and the stability of the entire system by executing a range of scenarios. While a model will always fall short incorporating all aspects of the ‘real world’, it provides valuable information on the system’s behaviour under a range of different future pathways of land use change (Feng, 2002).

Simulation is the process of using a model to study the behaviour, performance, and the existing or proposed characteristics of an actual or theoretical system by manipulating variables that cannot be controlled in a real system. Simulation allows evaluating a model to optimize system performance or to make predictions about a real system. Simulations are useful to study properties of a model of a real-life system that would otherwise be too complex or not too accessible to engage. While a model aims to be true to the system it represents, a simulation can use a model to explore state that would not be possible in the original system (Benders, 1996; Feng, 2002).

Predicting spatial change in the urban environment through modelling

Predicting urban land use change is important if city managers or authorities and municipalities are to provide, even at minimum standard, necessary infrastructure and services to the residents. Forecasting where and how urban change will manifest itself however is a challenge for any city and its planners (Young, 2010). Thus, it is envisaged that if the growth process of urban and informal settlement on flood waterways is better understood, it could be modelled and applied in real situations for the prediction of growth under likely future scenarios. In this light, it is useful to determine the underlying forces that drive the growth and expansion of informal settlements to be used and applied in a modelling environment in order to pre-empt and prepare for this inevitable growth (Odunuga, 2009; Young, 2010).

Veldkamp and Lambin (2001) propose that spatially explicit modelling can be used to conduct experiments that test our understanding of key processes and for describing them in quantitative terms. In the case of informal settlement, appreciating the factors and understanding the economic and social processes is of vital importance if planners and urban managers hope to progress from wishful thinking in shaping the spatial structure and form of urban cities in the developing world (Kombe, 2005 as cited in Young, 2010).

Modelling dynamism and growth of cities may in some instances be a difficult or almost intractable task without tools, which embrace their complexity (Barredo, Kasanko, McCormick, and Lavalle, 2003). In the 1960s, the main weakness of the traditional large scale urban models such as concentric zone model, sector model, and the multiple nuclei model included poor handling of spatial temporal dynamics of cities, the too coarse nature of data representation, and their top-down approach ultimately failed to reproduce realistic simulations of urban systems (Sietchiping, 2004). However, after the 1960s, a number of urban models have been developed to explore the evolutionary pattern of the urban system over time and space. More recently, advances in GIS, computer science, and spatial data availability have made it possible to simulate the space-time dynamics of these cities as a way of understanding the complexity in their processes, forms and systems (Sietchiping, 2004).

Recently, two types of models, cellular automata and agent-based models have been used extensively to study urban dynamics. Both models have shifted the paradigm of urban models towards a more complexity approach, in that they simulate urban system from a bottom-to-top (or bottom-up) approach. The next sub-sections provide a brief discussion on both models considered as the most recent urban modelling platforms, and how they have evolved overtime.

Cellular automata models (CA)

A cellular automaton is a regular lattice of cells appearing in alternating states, which changes accordingly to the cell itself and its neighbours (Benenson, 1998a). A typical cellular automata system comprises of four components namely: cells, states, neighbourhood, and traditional rules (Sudhira, 2004). A cell is a two dimensional space constructed as a discrete object of a particular state that exhibits certain behaviour at a particular point in time. The state of a discrete cell depends on its preceding state and the preceding states of all its neighbours.

The neighbourhood of a cell can be in different forms, agglomerations of adjacent cells is defined by their distance from an individual automata or a cluster of cells defined by their shape around an automata (Crooks, 2007). In most two dimensional cellular automata, the two most used neighbourhood configurations are the five cell "Von Neumann neighbourhood" that include the cell and its four immediate non-diagonal neighbours, and the nine cell "Moore" neighbourhood which include the cell and its surrounding eight neighbours as illustrated in Figure 2.

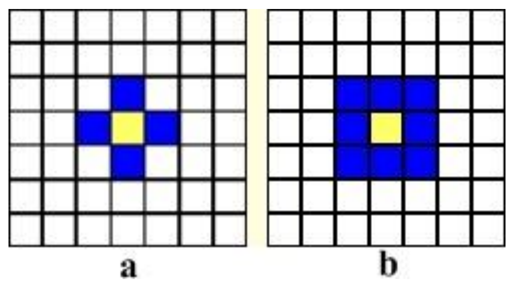

Figure 2: Two-dimensional Cellular automata neighbourhood configuration (a: Von Neumann Neighbourhood. b: Moore Neighbourhood) (Source: Crooks, 2007)**.**

In Figure 2a, the Von Neumann neighbourhood is shown with the cell in question coloured (yellow) and four cardinal neighbours (blue). The Moore neighbourhood in Figure 2b has the cell in question (yellow) and eight surrounding cells (coloured in blue). The transitional rule, which is a set of rules defined to control the transformation of a cell state to another cell state in space and time.

O'Sullivan and Torrens (2000) termed this rule as the real engines of change in a cellular automaton. The last component of CA is the temporal dimension of events; this is considered as being comprised of discrete time steps. The bottom-up approach of CA has made it an interesting tool for simulating urban change as it is based on the idea that complex global patterns emerge directly from the application of local rules (Barros, 2004). However, the main weakness of the cellular automata modelling approach for simulating urban dynamics is its inability to handle top-down processes. Another weakness of cellular automata models is the inability of the automata cells to move within the lattice in which they reside (Crooks, 2007). This makes it impossible to simulate forces such as macro-scale political and socio-economic driving forces that influence urban expansion in the urban system.

Though cellular automata models have been used in an attempt to simulate actual urban features using GIS data, it has failed to incorporate space and geometry into the models. In the simulation process, the cell's space is unable to hold the geographic and topologic details of the urban system (Odunuga, 2009).

Agent-based models

Agent based models (ABMs) also termed 'Individual-Based Modelling (IBM) have been receiving critical attention for their merit over other land use modelling methods such as cellular automata in that they can solve some of the problems of addressing individuals' influences within the urban sphere. ABM's have the advantage over other models in capturing emergent phenomena, providing a natural descriptive system, and flexibility (Bonabeau, 2002 as cited in Young, 2010).

ABMs are said to originate from the field of artificial intelligence, which is defined as the study and engineering of intelligent machines capable of performing the kinds of functions that characterize human thought. It is the study and design of intelligent agents, where these are able to perceive their environment and take actions, which maximize their chances of success (Macal and North, 2006). There is no universal agreement on a precise definition of the term agent, although definitions tend to agree on more points than they disagree (Macal and North, 2006; Crooks, 2007). Some modellers consider any type of system situated within or part of an environment with an ability to sense and interact with its environment overtime to be an agent, others consider any component that possesses an adaptive behaviour as an agent. Hence, the agent-based concept is a mind-set more than a technology, where a system is described from the perspective of its constituent parts (Crooks, 2007).

Agent-based models serve as a miniature laboratory where the attributes and behaviours of agents and the environment in which they are housed could be altered and the repercussions observed over the course of multiple simulation runs (Barros, 2004). Heckbert and Smagl (2005) communicated that the strength of using agent-based modelling approach as a methodology over other modelling techniques lies in the ability to represent the decision making process at individual scale.

The bottom-up approach adopted by agent-based models enables modellers to explore emergence patterns formed from three distinct interactions that take place in the model: agent-agent, agent-environment, and environment-environment. The application field of agent-based modelling is constantly widening, with recent interest developing in using agent-based models for simulating urban dynamics.

Building an agent based model

Building a computer-based ABM generally requires the modeller to follow certain steps as with any other type of model. These include identifying the purpose and the questions to be answered by the model and engaging the relevant stakeholders in the process. Secondly, there should be a systematic model analysis of the system being studied and identification of the relevant agents, their interactions and the relevant data sources (Macal and North, 2006). Specifically for ABMs, additional requirements may involve the following: (1) Identifying agents and get a theory of agent behaviour; (2) Identifying the agent relationship and get a theory of agent interaction; (3) Get the requisite data; (4) Validate the agent behaviour models in addition to the model as a whole; and (5) Run the model and analyse the output from the standpoint of linking the micro-scale behaviours of the agents to the macro-scale behaviours of the system (Macal and North, 2006, p.78 as cited in Young, 2010; p.18).

Macal and North (2006) list the specific steps for building the computer simulation as follows:

1. Agents: Identify the agent types and other objects (classes) along with their attributes;
2. Environment: Define the environment the agent will live in and interact with;

3. Agent Methods: Specify the methods by which agent attributes are updated in response to either agent-to-agent interactions or agent interactions with the environment. This relates to the methods by which learning is accomplished by the agents;
4. Agent Interactions: Add the methods that control which agents interact, when they interact, and how they interact during the simulation. These are specified by the agent behavioural rules set in the design of the model; and
5. Implementation: Implement the agent model in computational software.

Agents

Macal and North (2006) define the fundamental features of an agent being its capacity to make independent decisions, which require it to be active rather than passive. Agent are further characterised as being identifiable (discrete individuals), situated in an environment, goal-oriented, autonomous and self-directed, and flexible (adaptable). The specific definition of an agent is dependent on the discipline, which utilizes the concept. In this research however, it is useful to understand how an agent relates to its environment. Lightenberg (2006) distinguishes between three types of agent-based systems based upon the nature of the agent-environment interaction. These include systems containing dynamically situated agents, statically situated agents, and non-situated agents. Dynamically situated agents are mobile within their environment whereas static agents are tied to specific locations. If an agent is described as non-situated, its location is either undefined or unimportant to its function, and is therefore aspatial.

Recent advances in agent-based models with GIS allow the powerful ability of situating agents within representations of specific real-world environments (Macal and North, 2006; Manson, 2000). Agents acting within such environments are considered as geospatial agents as they act within representations of geographical space. Castle and Crooks (2006) provide several properties common to geospatial agents (as exemplified in the case of Table 1) but note that a single agent rarely exhibits all of these features. It must be noted however that though many of these attributes describe agents in general, geospatial agents in particular are geographically situated and most often mobile within their environments.

Table 1: Common properties of geospatial agents

Property	Example
Autonomous	Agents are capable of behaviour independent of external directions.
Heterogeneous	Agents can be contrasted to have unique characteristics from one another.
Goal directed	Agents can be constructed to seek an objective.
Perceptive	Agents can detect properties of their environment or of other agents.
Boundedly Rational	An agent's perception is limited.
Interactive	Agents can exchange information with other agents or with the environment.
Mobile	Agents are capable of physical movement within their environment.
Adaptive	Agents can be constructed to change behaviours and goals over time.

(Source: Castle and Crooks, 2006)

ABM's for simulating urban dynamics

Simulating urban dynamics with the aid of agent-based models involves understanding the aggregate behaviour of urban society and exploring how the actions/decision making of individuals produce different urban spatial growth pattern in cities all over the world (Barros, 2004; Young, 2010). Several studies have applied agent-based models for simulating urban dynamics to understand the emerging phenomena that develop in these cities (Manson, 2000). Most of these studies integrate cellular automata with an agent-based model where the physical structure of the urban system is simulated with cellular automata, while the behaviour of agents is simulated in the framework of agent-based models (Manson, 2000).

Batty, Xie, and Sun (1999) stated that the combination of cellular automata and agent-based models have been able to address the interactions in space and time by simulating different drivers (behaviours) as objects. This integration is made possible because both models are conceived from the principle of entity acting autonomously in space (Gimblett, 2002). In earlier studies, agent-based models were simulated on a cellular automation framework which consist of agents (households, firms, developers, etc.) and the landscape (houses, city centres, etc.) they inhabit. Though agent-based models at that stage will have all the characteristics of cellular automata but unlike cellular automata, agents in agent-based model would be programmed for spatial mobility within the regions they inhabit (Sudhira, 2004).

Benenson (1998b) developed an agent-based model to examine population dynamics of a city with reference to change in residential behaviour of its residents, this behaviour is characterized by their economic status and cultural identities. The model was strictly developed on cellular automata rules. Manson (2000) developed a model (agent-based dynamic spatial simulation) to address the problem of surface entity integration in GIS and dynamic environmental models. The simulation is an integrated assessment agent-based model that aids policy development and advances understanding of human decision making in environmental context through identifying inter-relationships among socio-economic and biophysical factors (Manson, 2000).

Herold, Goldstein, and Clarke (2003) explored the combined application of remote sensing, spatial metrics and spatial modelling for analysing and modelling of urban growth in Santa Barbara, California – USA. Barros (2004) simulated the dynamic of urban growth in Latin American cities by coupling cellular automata and agent-based model. She observed the spatial growth pattern of three Latin American cities, by simulating how the location decision making of the people shapes the urban area. While agent-based models built in virtual space using the cellular partition of space have provided valuable insights into urban phenomena especially as they can capture geographic detail, they miss the topologic structure of the urban phenomena.

For this reason, a new wave of urban models has begun to take centre stage by developing agent-based models in real-world simulations. An agent-based model developed by Crooks (2007) at the University College, London is one of such agent-based models. In his study, he examined the potential of creating a geographically explicit model, which considers how geographic detail could be included in the simulation process.

Modelling informal settlement

Many of the ABMs found in literature model some of the urban environment in various different global locations; less popular among researchers has been the modelling of the growth of informal settlement (Sietchiping, 2004; Odunuga, 2009). According to Young (2010), this deficiency could be attributed to the complex nature of the physical, economic and social processes occurring within the settlement – processes which are highly dependent on biophysical factors and demographic characteristics of the resident population. Sliuzas (1988, p.27) explains, *"the growth of a settlement is clearly not a random process and is likely to be influenced by a number of physical, cultural, and economic factors."* By Cultural, he meant human induced form of settlement growth.

Need for ABM in modelling informal/unauthorized settlement growth

Agent based models (ABMs) are considered a special type of models as they are able to show how individual behaviour and decision-making can result in complex, emergent phenomenon. According to Young (2010), given the continued informal purchase and sale of lands in Dar es Salaam, it could be understood that the emergent phenomenon of growth of informal settlement is the result of individual and household decision-making. The decision to alter, extend, or construct a new housing structure may result from varying levels of dissatisfaction with present housing conditions, but is also highly dependent on the household's financial capabilities (Seek, 1983). ABM's ability to simulate individual behaviour is where its advantage lies in capturing informal processes and their effects on urban and peri-urban land-use change (Macal & North, 2006; Young, 2010).

Platforms for agent-based simulation

Considering the pervasive diffusion and adoption of agent based approaches to modelling and simulation, it is not surprising that there is growing interest in software frameworks specifically aimed at supporting the realization of agent-based simulation systems (Felsen & Wilensky, 2007). Several computing frameworks for the implementation of agent-based models for simulation purposes exist.

A relevant example of such tools is NetLogo (Figure 3), a dialect of the Logo language. NetLogo does not adopt the term agent to denote individuals, but it rather calls them *turtles;* a typical simulation consists in a cycle, which chooses and performs an action for every turtle, considering its current situation and state. It must be noted that other platforms and tools based on the Logo language exist (e.g. StarLogo, StarLogoT), but they do not present relevant differences from the point of view of this classification (Felsen & Wilensky, 2007).

A second category of platforms provides frameworks that are developed with a similar rationale, providing very similar support tools, but these instruments are based on *general-purpose programming languages* (generally object oriented). Repast (Recursive Porous Agent Simulation Toolkit, Figure 3) represents a successful representative of this category, being a widely employed agent-based simulation platform based on the Java language (North, Collier, & Vos, 2006). The object-oriented nature of the underlying programming language supports the definition of computational elements that make these agents more autonomous, closer to the common definitions of agents, supporting the encapsulation of state (and state manipulation mechanisms), actions and action choice mechanism in agent's class. A third category of platforms represents an attempt to provide a higher-level linguistic support, trying to reduce the distance between agent-based models and their implementations. One of such most prominent infrastructures is Swarm (a platform integrated into a software framework for multi-agent simulation of complex systems) (North, Collier, & Vos, 2006).

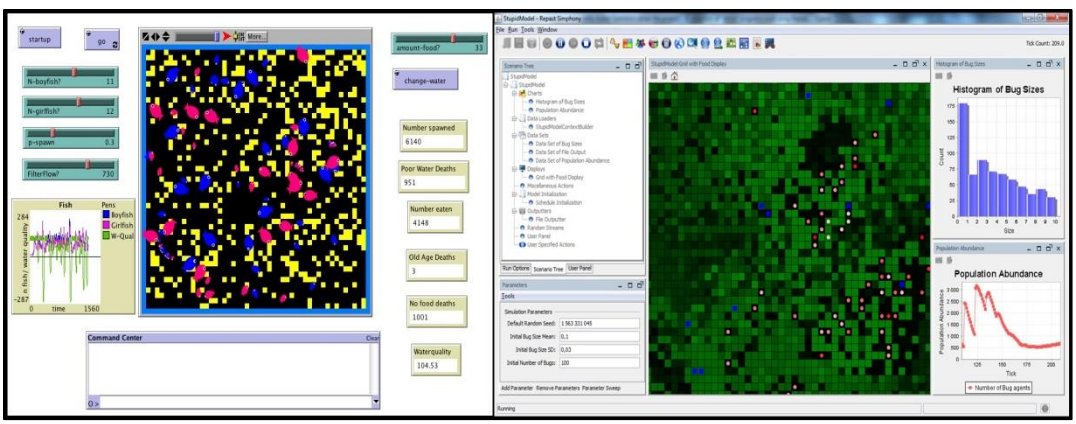

Figure 3: A screenshot of NetLogo simulation applet, to the left, and Repast Simulation Model to the right (Source: North et al. 2006).

NetLogo

NetLogo is a multi-agent programming language and integrated modelling environment designed in the spirit of Logo programming language to be "low threshold and no ceiling," that is to enable easy entry by novices and yet meet the needs of high powered users. The NetLogo environment enables exploration of emergent phenomena and comes with an extensive models library including models in a variety of domains such as economics, biology, physics, system dynamics, and many other natural and social sciences (North et al, 2006).

NetLogo is particularly well suited for modelling complex systems developing over time. Modellers can give instructions to hundreds or thousands of independent "agents" all operating concurrently. This makes it possible to explore the connection between the micro-level behaviour of individuals and the macro-level patterns that emerge from the interaction of many individuals. NetLogo was designed and authored by Uri Wilensky, director of North-western University's Centre for Connected Learning and Computer-Based Modelling (Felsen & Wilensky, 2007).

Models for simulating urban dynamics

In the next section, four urban models that simulate different types of urban dynamics are discussed. These models are examined in order to see how researchers have simulated spatial growth patterns of slum/informal settlements in past researches, and to examine the driving forces considered in these models that influence the dynamics that takes place in the urban system. Two of the models are cellular automata based models, while the other two are agent-based models.

Urban growth model (UGM)

The urban growth model is a part of the SLEUTH model (Slope, Land use, Exclusion, Urban extent, Transportation and Hillshade) developed by Keith Clarke at the University of California, Santa Barbara, USA under the support of the United State Geological Survey (USGS). The SLEUTH model integrates the UGM and the Deltaron Land use/Land cover model (DLM). The urban growth model is a cellular automaton model that represents a city as a regular grid of cells where each cell has one of the two states; urbanized or non-urbanized (Jantz, Goetz, & Shelleye, 2004).

The model was developed to simulate urban growth through the application of four types of urban land use change; spontaneous growth, new spreading centres growth, edge growth and road-influenced growth. The four urban spatial growth patterns were simulated through a set of five growth parameters: dispersion, breed, spread, road gravity, and slope. Dispersion, breed, spread and road gravity coefficients are factors that describe the growth pressure in the urban system, while the slope coefficient captures the effects of steep slopes on the restriction of development in certain areas in the urban area. Hence there are other areas that are restricted from developing, this exclusion layer also include water bodies, restrictive zoning areas etc.

The structure of UGM

The model simulates how five growth parameters; road gravity, dispersion, breed, spread and slope shape four different types of growth patterns in urban areas. When road-influenced growth (Figure 4) occurs, nearly urbanized cells are randomly selected at a probability level that is determined by the breed coefficient. For each selected cell, the existence of a road is sought within a search radius defined by the road-gravity coefficient (Jantz et al. 2004). If a road is found near the selected cell, a temporary cell is placed adjacent to the road. The temporary cell then searches the road in a random direction for a permanent location; the search distance is determined by the dispersion coefficient. The dispersion coefficient controls how many "steps", or pixels will make up a random walk along the transportation network on a road trip. The resultant permanent location becomes a new spreading centre.

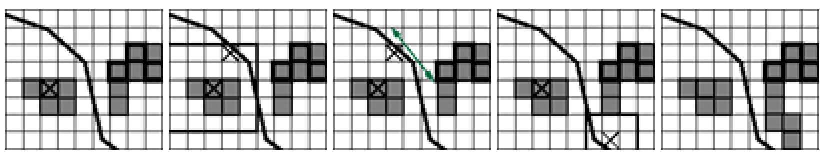

Figure 4: Road-influenced growth (Source: USGS - http://www.ncgia.ucsb.edu/projects/gig/)

The spontaneous growth (Figure 5) simulates the random urbanization of land. A selected single cell has the potential of capturing low-density development patterns without the influence of an existing urban area or transportation network. The overall probability of a single non-urbanized cell in the urban area becoming urbanized is determined by the dispersion co-efficient (Jantz et al. 2004). The dispersion coefficient controls the number of times a cell will be randomly selected for possible urbanization.

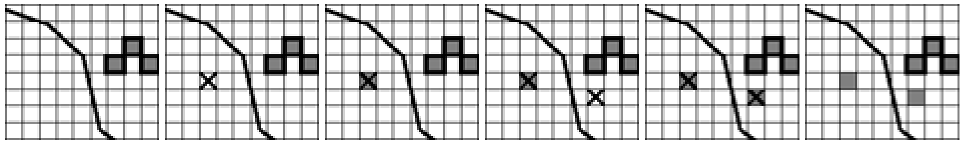

Figure 5: Spontaneous growth (Source: USGS - **http://www.ncgia.ucsb.edu/projects/gig/**).

New spreading centre growth (Figure 6) simulates new urban centres by generating up to two neighbouring urban cells around areas that have been urbanized through spontaneous growth (Jantz et al. 2004). The breed coefficient determines which cell developed through the spontaneous growth will experience new spreading centre.

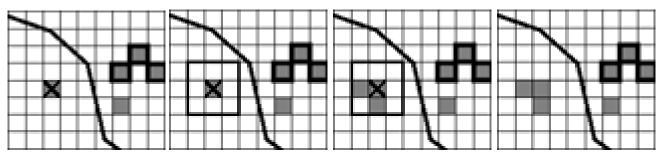

Figure 6: New spreading centre growth (Source: USGS - http://www.ncgia.ucsb.edu/projects/gig/).

Edge growth (Figure 7) is simulated through the spread coefficient. The spread coefficient determines the overall probability that a non-urbanized cell with at least three urban neighbours becomes urbanized. It also determines the probability that any cell that is part of a spreading centre will generate an additional urban pixel in its neighbourhood.

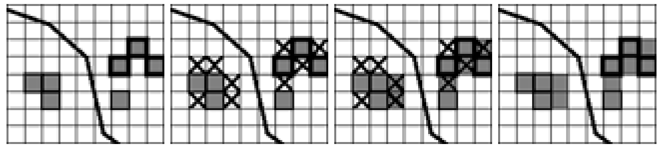

Figure 7: Edge growth (Source: USGS - http://www.ncgia.ucsb.edu/projects/gig/)

The slope coefficient determines the effect of slope on urban development; it acts as a resistance due to its terrain. The slope coefficient determines the probability of a cell to become urbanized; a high slope coefficient value will decrease the likelihood that development will occur on steep slope (Jantz et al. 2004).

The SLUETH model has been applied to many urban areas. The areas of application include simulating land use change in San Francisco, Santa Barbara, Denver, and Chester County, PA all in USA, and the middle Rio Grande river basin in Mexico. The usefulness of this model is its ability to simulate spatial growth pattern of urban areas, it also describes the relationship between the five driving forces that influence urban growth and the four spatial growth patterns. However, this model is not very useful for this research because it does not take into account the actors that interact in the urban system.

Peripherization model

Barros (2004) developed an exploratory agent-based model called Peripherization model (Figure 8) to simulate urban growth in Latin American cities. The model was designed upon the theoretical framework of the Burgess's (1925) succession and expansion theory. The analogy of Burgess's model involves the invasion of the urban area by competing groups (the invaders and invaded dominance of the area). It simulates the expansion of borders of the city through the formation of peripheral low-income settlements that are incorporated to the city by long-term process of expansion. The model simulates how the location decision-making of the people influences urban growth in Latin American cities.

The structure of the peripherization model

The logic of the Peripherization model is divided into four modules; the first module investigates the dynamics of the formation of the core-periphery pattern of urban areas. The second module focuses on the formation of spontaneous settlements by incorporating certain consolidation rules into the model; module three examines the processes that take place in the interiors of the city; and the last module introduces urban spatial constraints into the simulation (Barros, 2004).

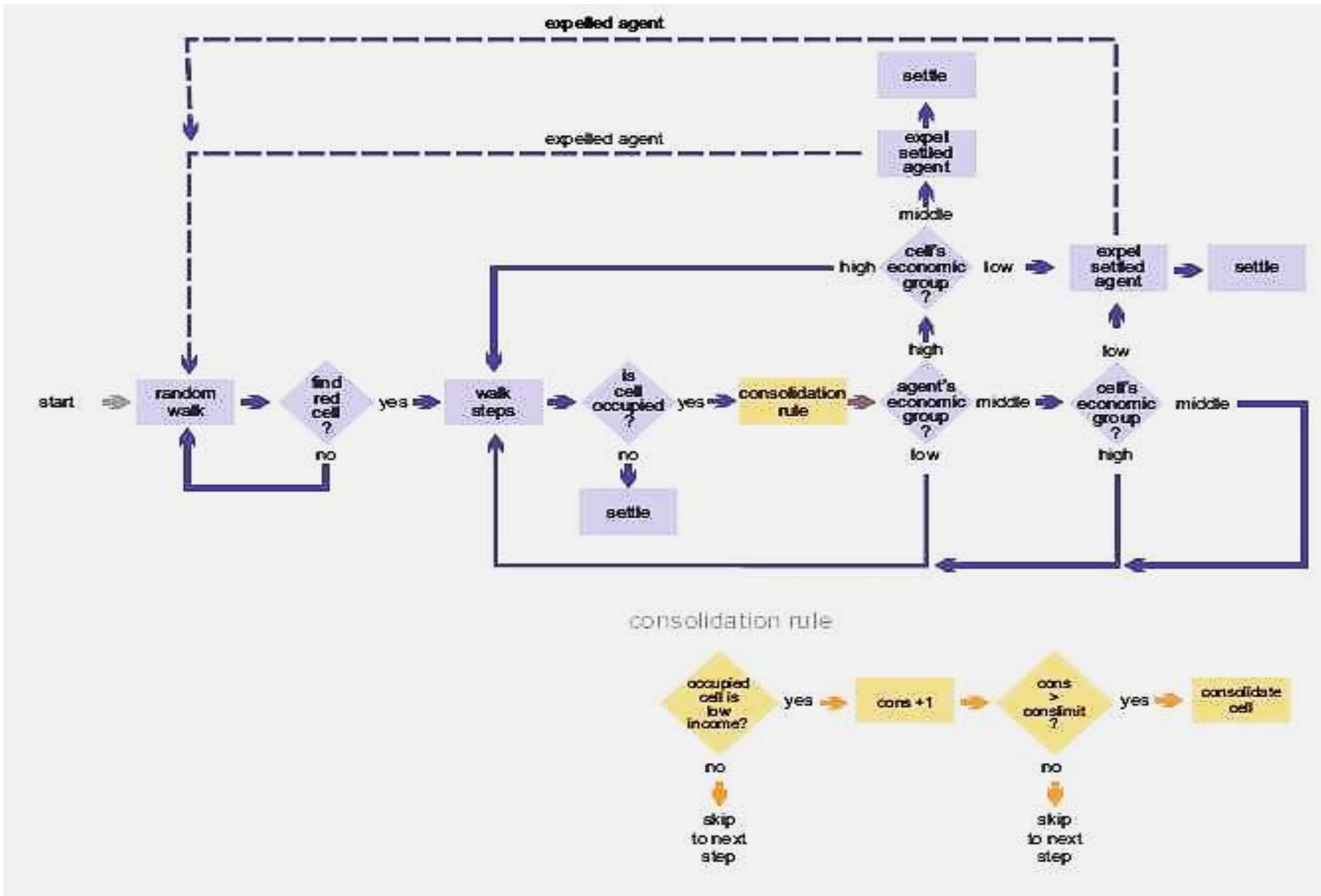

Figure 8: The peripherization model (Source: Barros, 2004).

There are three types of agents in the model, divided according to their economic power based on the pyramidal model of distribution of income (high, middle, and low income) in Latin American countries. All the agents have the same location preference in the sense that they all want to be settled close to the city centre, which is well serviced with social and infrastructural amenities. However, locating close to the city centre is restricted by the economic power of the agents and how far they are willing to travel in search for an ideal location. The high-income agents can locate everywhere in the area except areas occupied by agents of the same income group. Middle-income agents can locate everywhere except areas where a high-income or an agent of the same income group is settled, the low-income agents can locate only on vacant lands (Barros, 2004).

The consolidation process which define changes that occur in the model at iteration is built into the model through a "cons" variable; which has its value increased at each time step of the model run, and at a certain threshold (cons limit) the cell turns into the consolidation state. The occupant of the cell is immune to eviction regardless of its income status (Figure 9).

The model's third module deals with inner city decay and the transition in the income status of agents. The three transitional rules of the model are the transition from higher to lower income group, transition from lower to higher income group, and movement of higher-income groups towards the suburbs (Barros, 2004). In this module, agents settle in a place based on neighbourhood density and closeness to agents of the same income class. Age and density variables are also introduced into the model at this stage to simulate the housing transition of agents from higher to lower income group and from lower to higher income group. The last module introduces spatial constraint such as water and steep slope into the model. The cells that hold the various spatial constraints are defined as exclusion cells, meaning they are restricted areas for settling (Figure 9).

The main limitation of the model is that it is built in a virtual environment, that is, it is not spatially explicit. As a result, the major driving forces behind urban growth such as roads, topographic and demographic information (income data, population data etc.) were excluded from the model. It does not consider conditions that occur in cities of other parts of the world such as land and housing tenure systems, proximity to major roads, locating in swamps amongst others.

However, the Peripherization model investigates the influence of people's location decision making on urban growth of Latin American cities. It also examines the forces that drive the spatial growth pattern of these cities. Another strength of the model is its usefulness in studying the influence of spatial constraints such as rivers and steep slope on different spatial growth pattern developed in these cities.

Informal settlement growth model (ISGM)

The ISGM is a cellular automaton based model developed by Remy Sietchiping (2005) to simulate and predict the emergence and growth pattern of informal settlement in cities of developing countries. The ISGM was developed from existing urban dynamics models that were based upon the integration of GIS and CA models such as those developed by Batty et al. (1999) amongst others

(Sietchiping, 2005). Hence, the model is loosely coupled with GIS, where GIS serves as a tool for preparing, analysing and visualizing data that are fed into the CA where the actual simulation is carried out. The model also simulates the factors underpinning the emergence and growth pattern of informal settlement, the factors considered in the model include proximity to roads, rivers, market places, existing informal settlements, cultural and ethnic groups (Sietchiping, 2005).

Structure of ISGM

The ISGM was conceived on cellular automata principles where pixels or cell-based grid squares change one by one (Sietchiping, 2005). The model's space is a two dimensional grid cells that accommodate an unlimited input data (multi-environments) in the same format and map extent. In the model, the state of a cell at a given iteration depends on the previous states of neighbouring cells, each data layer consist of at least two states, e.g. road or non-road. Changes occur only on vacant or available land on the defined matrix of 4*4 extended Moore neighbourhoods (Sietchiping, 2005).

There were a couple of transitional rules incorporated in the model, however, the general conditions under which informal settlements develop in the model include:

1. Existing formal land use classes do not change; all new informal settlements develop only on vacant lands;
2. No cell dies off; rather they evolve or maintain their state;

3. A new informal settlement cell emerges only when at least one of its neighbouring cells is informal settlement; and
4. Cells within four extended neighbours away from cells occupied by a driving factor (road, river, market place, worship places, slope) have a great probability of developing into an informal settlement.

The model is divided into five sequential modules; setting up, calibration, looping, application of rules and display with the sequence of flow as shown in Figure 9. In the second module, a number of iterations (annual changes of growth), the net pixel gain (proportion of new informal settlement), and the annual target (a constant that divides the expected number of new informal settlement cells by number of iteration) were generated from the base year and final year. The third module involves making checks on the model to see its functionality.

The transitional rules are incorporated into the model in the form of probabilities and conditions under which a vacant cell can turn to an informal settlement cell. The calibration output is automatically displayed in the user-defined GIS environment in the final module (Sietchiping, 2005).

The ISGM was applied to simulate and predict the growth of informal settlement in Yaoundé, Cameroon with slum allocation of up to 75 percent (Sietchiping, 2005). The model made use of GIS data in simulating the dynamics of informal settlement in the study area, the land use map of Yaoundé was used as the environment of the model. However, one of the weaknesses of this model is that it does not consider the actions of people in the cities that also influence the growth of informal settlement in urban cities.

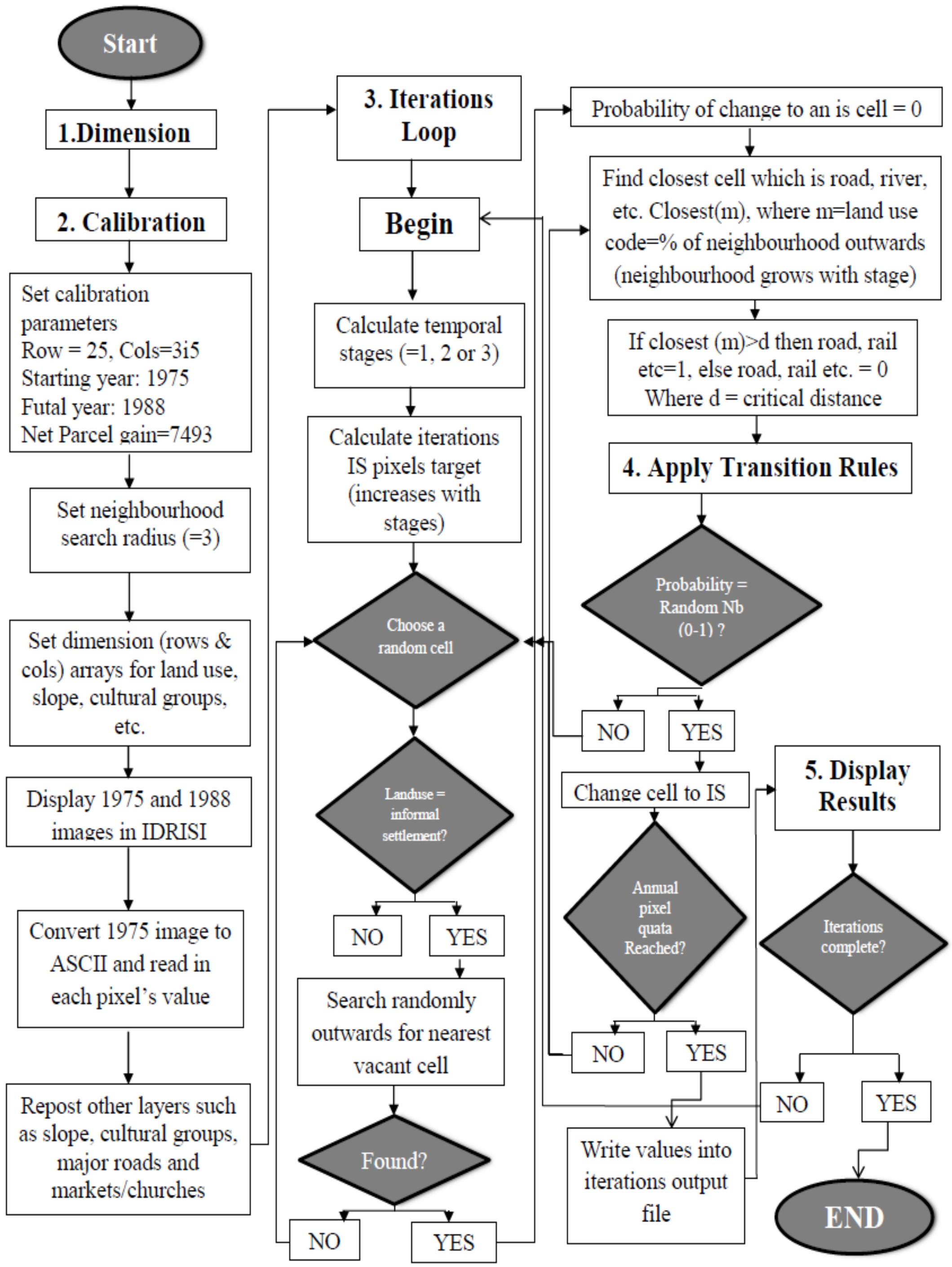

Figure 9: The informal settlement growth model (Source: Sietchiping, 2005).

The usefulness of the ISGM lies in its ability to simulate the driving forces that influence informal settlement development such as proximity to roads, rivers, market places, existing informal settlements, and cultural and ethnic groups. Rivers and roads were combined together to simulate the linearity of informal settlement growth pattern; transitional rules demonstrate how to simulate an agent locating close to a cell occupied by an agent of the same income group. The model also account for some socio-cultural forces such as market and worship places.

Economic disparity model (EDM)

Martin Felsen and Uri Wilensky both of the North-Western University, Chicago, developed the economic disparity model based on the bid-rent theoretical framework. This model was largely based on an original one written by William Rand and Derek Robinson as part of the SLUCE project at the University of Michigan (Felsen & Wilensky, 2007). Prices and demand for lands changes with increase in distance towards the city centre. This is based on the idea that retail establishments wish to maximize their profitability, so they are much more willing to pay more money for land close to the economic centres and less for land further away from this area.

The economic disparity model explores residential land use patterns from an economic perspective, using the socio-economic status of the agents to determine their preferences for choosing where to live.

The structure of the economic disparity model

The model is based on two main variables: population growth and landscape of the city. It simulates the growth of two populations (rich and poor), who settle in the city based on three properties of the landscape, the perceived quality, the cost of living, and the proximity to services (employment centres). The two population agents have the same location preference; they all want to locate close to city centres (employment centres), however their location decision is restricted to their economic power to afford living in these places (Figure 10).

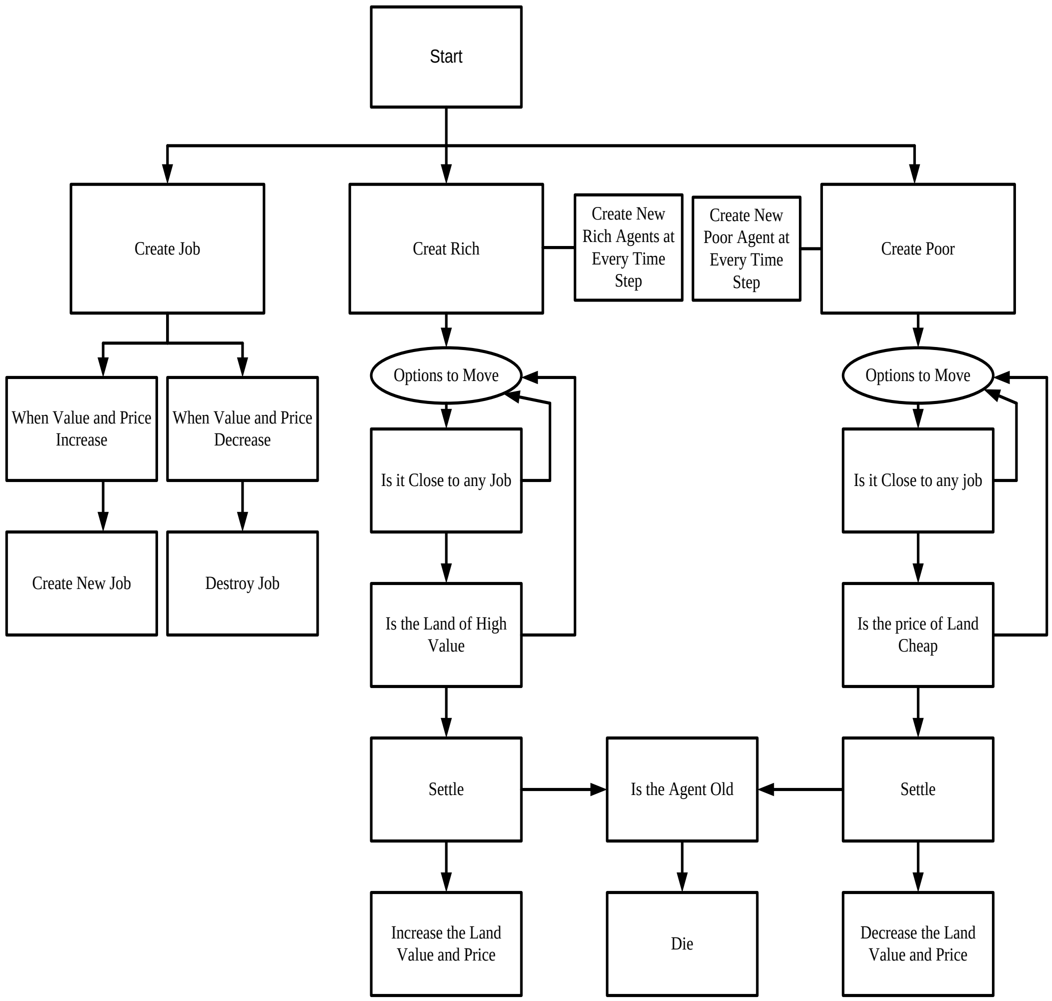

Figure 10: Economic disparity model (Source: Felsen and Wilensky, 2007)**.**

Odunuga (2009) citing Felsen and Wilensky (2007) underscored four major structures used in building the Economic Disparity model. These structures are as follows:

1. Job sites: They are created and destroyed. When the land value in an area increases, a job centre is created, but when the value decreases the job site

is destroyed. The people want to live close to this job sites but consider the price (cost of living) and the quality of the potential location;

2. Location: Both agents (rich and poor) wish to locate close to a job site (employment centre) but have different priorities. The rich people seek a location that has a good quality regardless of the price, while the poor people seek locations of low price disregarding the quality of the land;
3. Consolidation rules: Rich people moving into an area cause the land price and quality to increase, while the poor people cause the land price and quality of the land to decrease; and
4. At each time-step, new people (rich and poor) enter the city, but when they get old, they die. As the quality and price of the cell changes, the colour of cell changes, this lead to the developing of different pattern.

The economic disparity model simulates the relationship between agents of different income groups and economic features in an urban area. This model is useful for studying informal settlement growth models serving as the starting point for the model proposed in the present study. It is basic and its major components are adopted in the model proposed (Felsen & Wilensky, 2007).

One of the challenges with the four models reviewed is that they do not necessarily take account of the residential location decision making of the urban people and the driving forces that informs or influences the growth pattern of informal settlements in cities of developing countries. In order to understand the growth pattern of informal settlements and structures as in the case of Shama, it is important to mention and consider both the processes, structures, and actors that contribute to the proliferation of these informal settlements in the proposed agent based model.

Justification for the choice of model

The four (4) urban models discussed were found not to be adequately suitable for simulating the growth pattern of informal settlement. Either they did not consider the residential location behaviours of a city's inhabitants or they were inadequate to simulate spatially explicit agents that interact in the urban area. Thus, there exist different aspects of the four models discussed that could be incorporated into the proposed model in an attempt to build upon existing theories and assumptions.

Three (3) of the land use changes simulated by the UGM was explored by the proposed model to explain the pattern of settlement growth. The pattern selected includes road influenced, spontaneous growth, and new growth spreading centres. The relationship between driving forces of urban growth and the simulated growth pattern was found to be very useful for defining the rules of the proposed model. Relationships such as how road gravity influences urban development along roads. Another relationship found to be interesting is the effects of spatial constrained features (such as water bodies, restrictive zoning area) on the restriction of development in certain areas. This will also be incorporated in the proposed model to move the simulation closer to reality.

Some residential location decision making of people such as neighbourhood proximity to similar income groups defined in the peripherization model will be included in the proposed model. One of the rules is the classification of the economic group of people into high, middle, and low-income agents. Another rule of importance is the eviction rule, where lower income agents are evicted from their residential locations by higher income agents. The neighbourhood density rule will also be incorporated into the new model; it will lead to segregation in the location pattern of the three income groups. Influence of road and water bodies on settlement growth are amongst the driving forces considered in the proposed model design.

The ISGM is found to be useful for this present study because it is the only model found in the literature that simulates informal settlement growth. They include how rivers and roads were combined together to simulate the linearity of informal settlement growth pattern; and how to simulate neighbourhood density of agents described in the peripherization model. The economic disparity model provides the socio-economic angle of simulating urban systems for the proposed model. The economic rules of the model was found to be particularly useful for the proposed model, example is the dynamics of land price. When a rich person settles in a location, the value and price of the land will increase; while the land value and price will decrease when poor agents settle in a location. The rule that affects segregation of the people based on income will also be incorporated into the model. This rule decision made by people to settle in a location is based on quality or cost of the location. Rich people based their emphasis on the quality of the land, while poor people based their emphasis on cheap lands.

Spatial multicriteria evaluation (SMCE)

There are four analytical functional groups present in most GIS models: selection, manipulation, exploration, and confirmation. These four (4) functions can be considered as a logical sequence of spatial analysis as an important next step in supporting decision-making (Anselin & Getis, 1992). To obtain information for the decision-making process, the data are processed using Multi-Criteria Decision Making (MCDM) within the GIS platform.

Spatial multicriteria decision analysis is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences, and the manipulation of the data and preferences according to specified decision rules. In this process, multidimensional geographical data and information are aggregated into one-dimensional value for the alternatives.

The combination of multicriteria evaluation methods and spatial analysis within Ilwis platform is referred to as spatial multiple criteria evaluation (SMCE). SMCE is an important way of producing policy-relevant information about spatial decision problems for decision makers. An SMCE problem can be visualized as an evaluation table of maps illustrated in Figures 11 and 12 respectively (Sharifi, van den Toorn, Rico, & Emmanuel, 2003). If the objective of the evaluation is a ranking of the alternatives, the evaluation table of maps has to be transformed into one final ranking of alternatives. The final ranking of alternatives has to aggregate not only the effects but also the spatial component. To define such a function is rather complicated.

Therefore, the function is simplified by dividing it into two operations: (1) Aggregation of the spatial component, and (2) Aggregation of the criteria. These two operations can be carried out in different orders (Figures 11 and Figure 12) as Path 1 and Path 2 respectively. The distinguishing feature of these two paths is the order in which aggregation takes place. In the first path, the first step is the aggregation across spatial units (spatial analysis is the principal tool); the second step is the aggregation across criteria (multicriteria analysis playing the main role). In the second path, these steps are taken in reverse order. In the first case, the effect of one alternative for one criterion is a map. This case can be used when evaluating the spatial problem using the so-called ‘Path 1’. In the second case, every location has its own zero-dimensional problem and can best be used when evaluating the spatial problem using the so-called ‘Path 2’ (Figure 12).

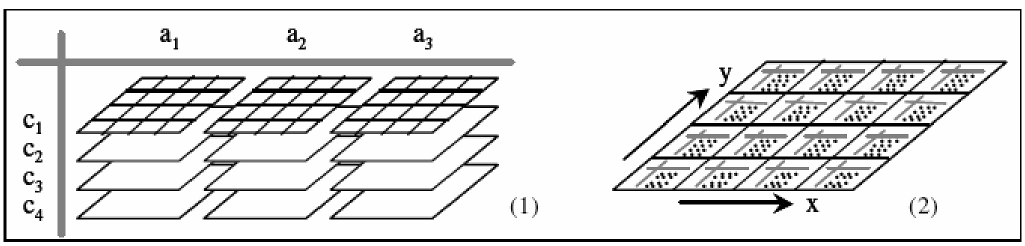

Figure 11: Two interpretations of a two-dimensional decision problem (1: table of maps, 2: map of tables).

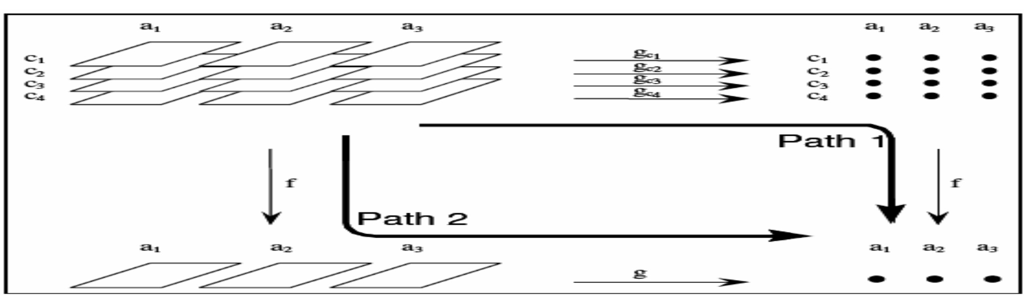

Figure 12: Two paths of spatial multicriteria evaluation.

Importance of SMCE

"SMCE" can play a very important role in the development and application of process or behavioural models, planning models, and evaluation models. Process or behavioural model helps to assess the current state of the system.

Today, sustainability assessment of a resource is one of the very critical issues in the management science. There is a great interest to assess for example sustainability of agricultural development, sustainability of forest management, sustainability of the cities amongst others. "SMCE" can also be applied in the evaluation and planning model. This allows for the assessment and multiple criteria evaluation of several options or alternatives in order to help understand their impacts, pros and cons, their related trade-offs and the overall attractiveness of each option or alternatives. Here the alternatives have specified locations (boundaries) and their performances on each criterion can be represented by a separate map (more than one dimensional table of maps) (Anselin & Getis, 1992).

This type of analysis is based on the multiple attribute decision analysis technique (Sharifi et al., 2003). In the planning model, it can help formulate or develop alternative options. Here, in the planning process alternatives are formed out of pixels of one map. The types of analysis that are applied here are based on the multiple objective decision analysis technique. In this process, the whole decision space is divided into two sets, mainly the efficient and non-efficient ones, which are then used for proper design of alternatives (Anselin & Getis, 1992). A good example of SMCE application in planning and decision models is site suitability map for residential development.

Summary

This chapter introduced the definition of informal settlement adopted for the study, driving forces for spatial growth, and the concept of modelling and simulation. Regarding urban growth and dynamics, four models were reviewed. The urban growth model describes how to simulate different spatial pattern of an urban system. The informal growth pattern model was specifically useful as it demonstrates how to simulate the driving forces that influence informal settlement growth such as proximity to roads, rivers, and existing informal settlements. Rivers and roads are combined together to simulate the linearity of informal settlement growth pattern; transitional rules demonstrates how to simulate an agent locating close to a cell occupied by an agent of the same income group. The peripherization model describes how agents behaviours have been simulated in urban agent based models, and how interactions between agents (people) and with their spatial environment could be simulated. The economic disparity model gives an understanding of how economic variables such as the price of land and income disparities among inhabitants of a city are simulated in agent-based models. The spatial multicriteria evaluation presents the ideological or building blocks for a site suitability map development.

CHAPTER THREE

METHODOLOGY

Introduction

This chapter introduces the study area and the research approach used in the study. Subsequently the data acquisition materials and methods are discussed. The SMCE approach, ethical issues, and challenges to the study are presented respectively.

The study area

Shama, the capital of the newly developed Shama district is located on Latitude $5^{o}0''0'N$ and Longitude $1^{o}39''0'W$, it covers an area of 215 square kilometres. The topography of the area varies from sandy coastline in the south to low-lying areas interspersed with ridges and hills (with altitudes ranging from 30 – 60 meters) in the north. The coastline has many bays with serious erosion problems.

The landscape of the area is characterised by muddy lagoons and swampy marshlands because of the undulating topography of the area. The major drainage system of the area is the Pra River and its tributaries within Shama are susceptible to flooding. The vegetation of the area is characterised by mangroves along the southern portions of the Pra River particularly in some communities such as Anlo Beach and Yabiw (Figure 13 and Figure 14).

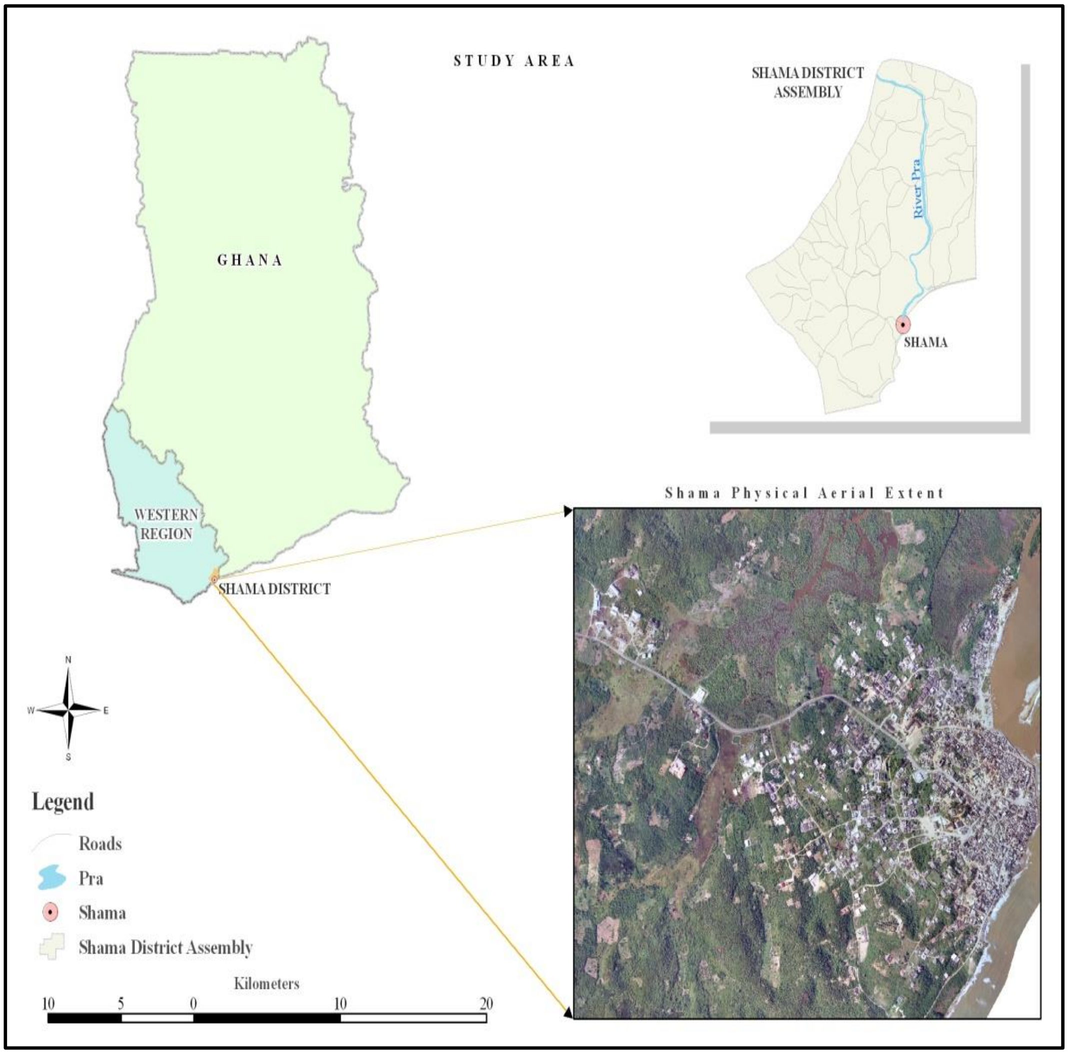

Figure 13: A map of study area (Source: Fieldwork, 2011).

Like other parts of southern Ghana, Shama experiences an equatorial and bio-modal climate conditions with high temperatures ranging from 22^{o}C to 33^{o}C. Precipitation occurs mainly from March to July (70 percent) and between late September and November (30 percent). The dry seasons are short, occurring from August to early September and December through to February.

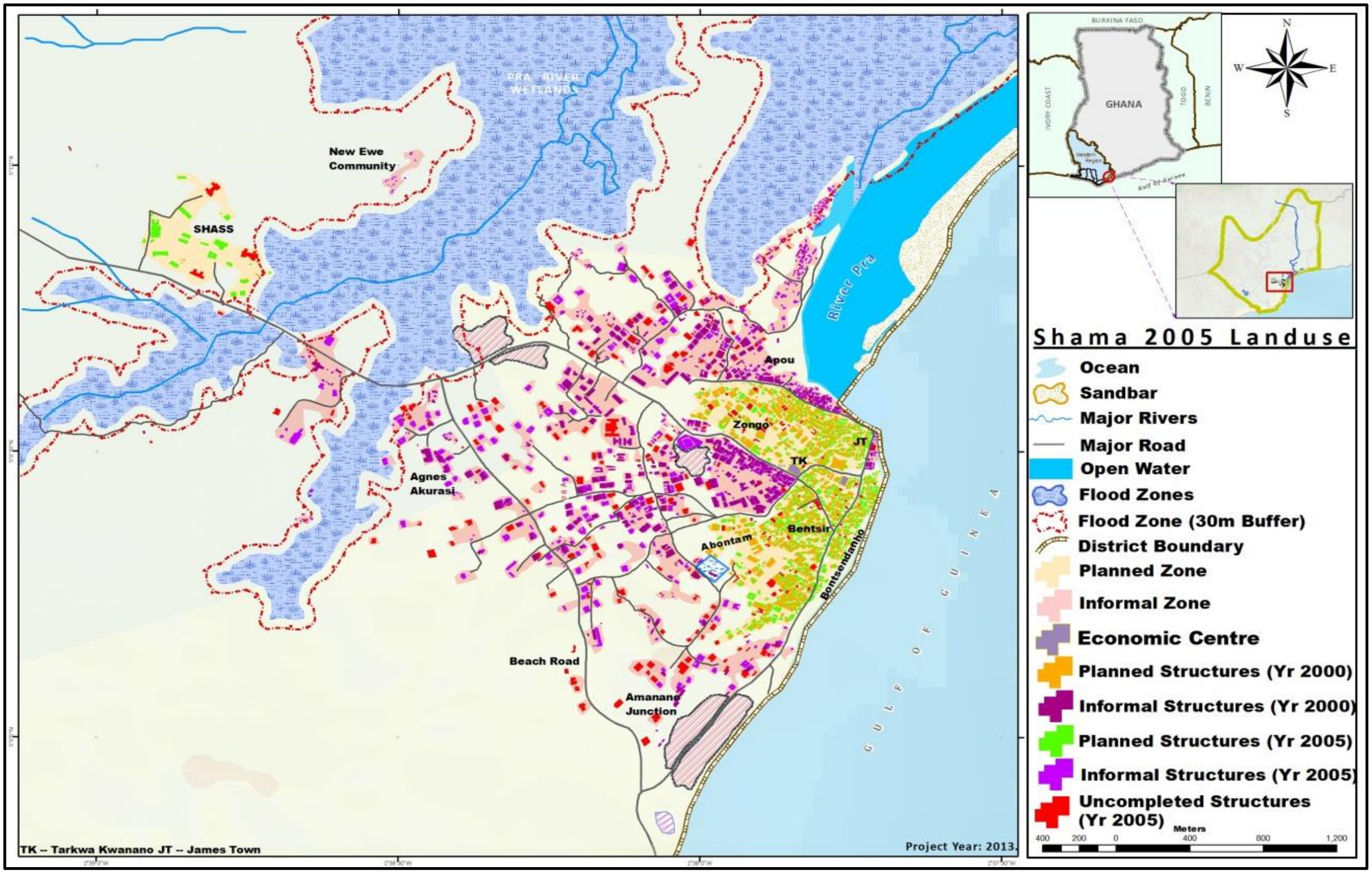

Figure 14: Land use map of Shama (Source: Fieldwork, 2011).

Shama's population as at 1948 was 5,155 people in 1948. It increased to 6,718 people in 1960. According to the 1970 population census, Shama's population increased to 7,739 people with approximately 50 percent increase in 1984 when the population stood at 11,268 people according to the 1984 census result. The 2000 Population and Housing Census conducted indicated that the population had reduced to 9,855 people constituting a 14.13 percent reduction in the size of the population in the 1984 Census (Table 2). Shama was characterised by a growth rate of 3.5 percent as at year 2000 (a figure equivalent to the districts but higher than the regional and national average of 3.2 percent and 2.7 percent respectively).

Table 2: Population growth of Shama and its environs (1948 – 2000).

TOWN	POPULATION SIZE				
	1948	1960	1970	1984	2000
Shama	5155	6718	7739	11268	9855
Inchaban	2641	2575	2797	3524	5486
Yabiw	401	467	383	659	668
Aboadze	3711	3586	3084	4495	9399
	TOTAL HOUSES				
	1948	1960	1970	1984	2000
Shama	-	522	707	677	947
Inchaban	-	337	357	422	765
Yabiw	89	88	79	94	133
Aboadze	-	353	375	297	840
	NO. OF HOUSEHOLDS		HSE. HOLD SIZES		
	2000		2000		
Shama	2297		4.3		
Inchaban	1319		4.2		
Yabiw	176		3.8		
Aboadze	2130		4.4		

(Source: Population and Housing Census, 2000; Ghana Statistical Service, 1960 – 1984).

Justification for choice of study location

Shama, considered as one of the rapidly growing towns in the Shama district (Table 2) has been battling with the growing housing expansion and structural development aimed at accommodating this growth. However, the location of Shama (a coastal town) and an estuary town of the Pra River pose great concern to the nature and extent of settlement expansion.

Against the concerns raised in the aftermath of the floods in 2008, it is appropriate to ascertain the patterns of settlement growth structures in relation to the Pra River, and the individual decision-making abilities of the Shama people regarding development relative to geographic space (Figure 22).

Research design

The study typically adopts an exploratory design aimed at achieving the objectives of the study. The exploratory design goes beyond description by trying to establish causes of phenomenon.

The adoption of an exploratory design is in view of the ability of the design to create a general mental picture of the condition under study. The design for the research specifies sources of data, data collection and preparation, and constraints that may hamper the research and how they could be addressed.

Data and sources

Data used for this study were sought from two main sources namely, secondary and primary. Secondary sources of data used included satellite imagery, topographic maps, and relevant literature on urban growth models.

Given the problem associated with the use of secondary sources, which include data accuracy, primary data collection was also used.

Primary data were collected on locational decision making of individuals, their location factors, land prices, alternate choice of locations, and features they would avoid when choosing a location for residential development.

The methods used to collect data included, satellite/photographic and topographic map interpretations, field observation, and the use of interviews with subject matter expect. The field observation was undertaken to ascertain the true representation of satellite features and for feature inclusion in the case of new development.

However, this action was not exhaustive due to time constraints. Questionnaires were used to obtain locational choices of residents as a means of model validation and to confirm locational preferences and decision making of individuals.

Accidental sampling (a non-probability sampling technique) was used to administer questionnaires to 50 respondents selected from all suburbs within the study location to ensure equity in idea dissemination.

Spatial data acquisition

The aerial photographs of the location obtained for the years 2000 and 2005 respectively constitutes the secondary data for the study. Subsequent data types used includes topographic maps of the study area taken for the period 1974 and 1986.

The data from bands 2, 4, and 5, sensitive to land cover changes, were used (Liu, 2002; Deng, Liu, & Zhao, 2003; Deng, Liu, & Zhao, 2004).

The 2000 panchromatic image obtained from CTK Network Aviation Limited of height 5500ft and scale 1:10,000 was used in addition to the 2005 aerial photograph of the same location for image interpretation and other related GIS analysis (Table 3 and Figure 15).

Table 3: Data acquisition date, sensors, and scale of images sources.

Acquisition Date	Sensor/Camera/Source	Scale/Resolution
11/04/00	PLEOGON A2-SN134662 (CTK Network Aviation Ltd)	1:10,000
01/01/05	PLEOGON A2-SN134662 (CTK Network Aviation Ltd), Ghana Survey Department , Department of Geography and regional Planning.	1:50,000
1974 and 1986	Department of Geography and Regional Planning (DGRP, UCC).	1: 50,000

(Source: Fieldwork, 2011).

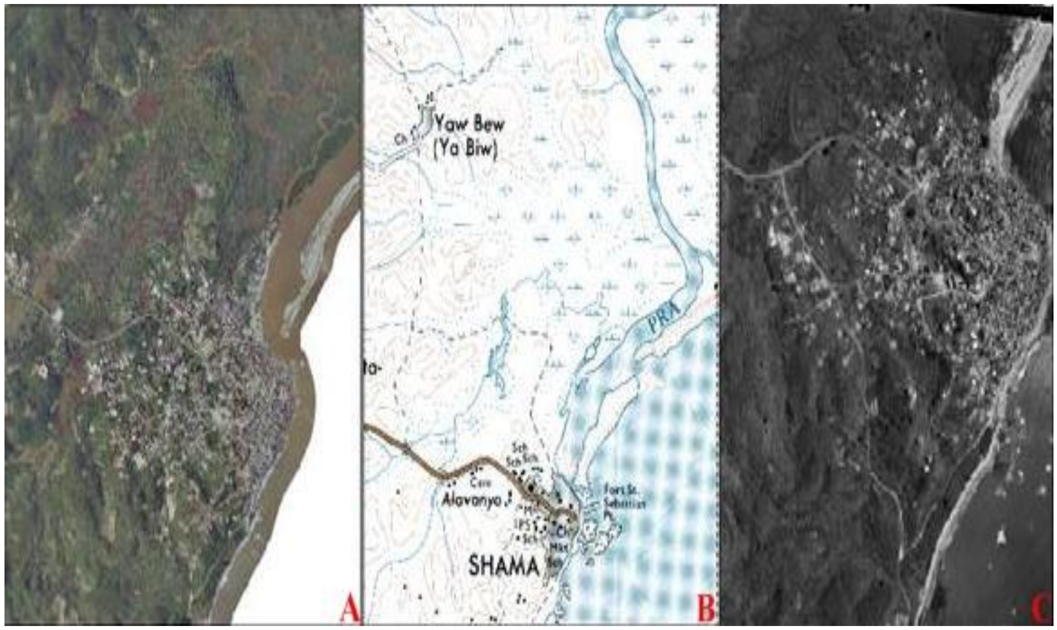

Figure 15: Spatial data acquisition. From Left A: 2005 Satellite Image. Middle (B): 1986 Topographic Sheet; and Right (C): 2000 panchromatic image (Source: Fieldwork, 2011).

The Landsat images were enhanced using the linear contrast stretching and histogram equalization to help identify ground control points in the rectification to a common coordinate system based on 1:100,000 topographic maps of Shama (Deng et al. 2003; Deng et al. 2004). The land cover classification was conducted through visual interpretation and firm knowledge of the area to guarantee the consistency and accuracy of data processing and output.

Data processing

Image georeferencing

In other to integrate these data with other data in GIS, it was necessary to correct and adapt them geometrically, so that they have comparable resolution and projections as other data sets (ILWIS 3.0 User's Guide, pp. 235). Remote sensing data is affected by geometric distortions due to sensor geometry, scanner and platform instabilities, earth rotation and earth curvature. Some of these distortions are corrected by the image supplier, while others can be corrected referencing the image to existing maps.

In view of this, all satellite imageries were georeferenced using ArcGIS 9.3. The 2005 aerial photograph with the Ghana Metre Grid Projection served as the known reference system to which the CTK Network panchromatic satellite image was georeferenced. Satellite images used in the study were resampled by the cubic convolution method and were subsetted to cover the area under investigation (Figure 16).

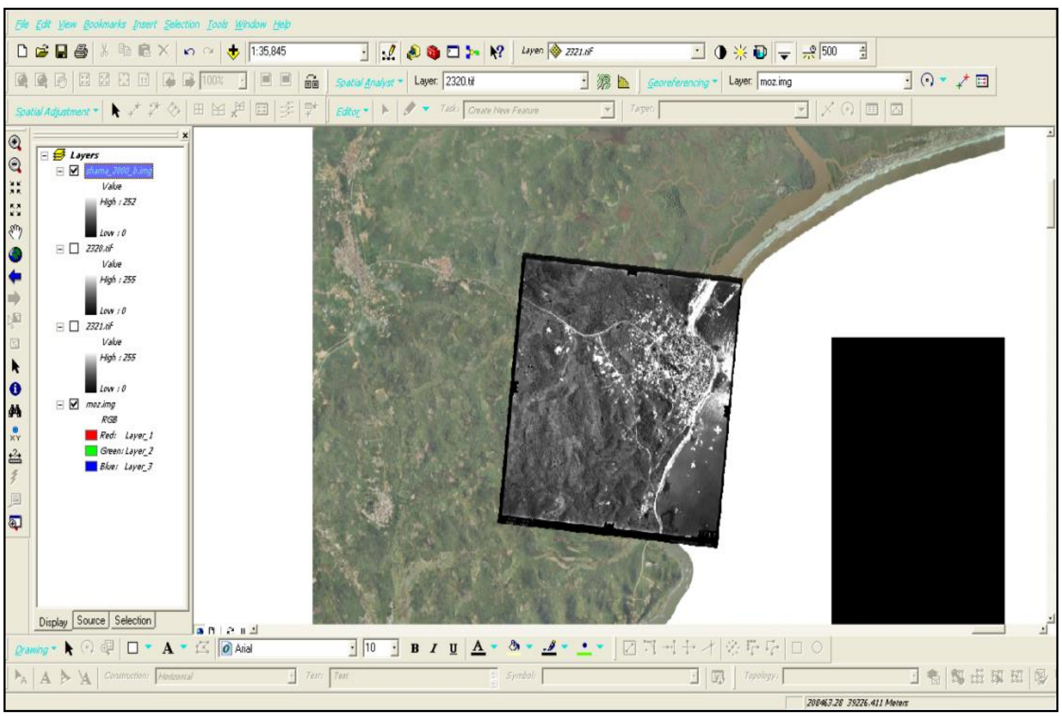

Figure 16: 2000 panchromatic image set at 35% transparency after being georeferenced to the 2005 image (Source: Fieldwork, 2011)**.**

The satellite image was resampled to a resolution of 5m, considered optimal for the discrimination of the built-up areas using the proposed textural approach (Pesaresi, Gerhardinger, & Kayitakire, 2008). The advantages of degrading the spatial resolution of VHR data are faster image processing and for easier data management. A texture-based image processing approach was applied to the 2000 and 2005 satellite data of the study area thus enabling easy extraction of buildings or structures.

Delineating regions of built-up structures and urban growth analysis

A scanned 1:50,000 scale topographic maps provided the reference data for the year 1974. It provided the initial data for extracting features such as rivers (Pra River) flood zone delineation, and marshy area delineation. The raster map (aerial photograph) was projected and topologically corrected.

Feature datasets were created for data organisations. Features such as built-up regions, rivers, flood zones, economic centres, reservoir, and roads were delineated into a common feature dataset. To delineate the built-up areas for the years 2000 and 2005, bands 1, 2, and 3 of the Landsat TM image were assigned to a Red Green Blue (RGB) colour composite display. To enhance the representation of the urban areas, the RGB image was interactively stretched (stretch ranges: R = 110/146, G = 65/96, B = 131/164).

Features on the selected images representing urban classes were manually captured through onscreen digitizing. The efficiency of onscreen digitizing to delineate built-up areas has been shown to work for optical panchromatic images (Pesaresi et al. 2008; Gamba, Pesaresi, Molch, Gerhandinger, & Lisini, 2008). Pesaresi et al. (2008) did show that the GLCM contrast statistic is the most efficient at discriminating between built-up and non-built-up areas. To determine good contrast statistics between building roofs, shadows and background, the input imagery must have a spatial resolution that is equal to or better than the dimensions of the discernable built-up objects.

The result provides structural information on the urban regions; including buildings, open spaces, and roads. The final outputs of delineated features were overlaid on the raster image to inspect the accuracy of feature delineation and masking. Building structures delineated from the 2000 panchromatic image and the 2005 images were overlaid to inspect the extent, pattern, and direction of settlement expansion in the study location (Figure 17).

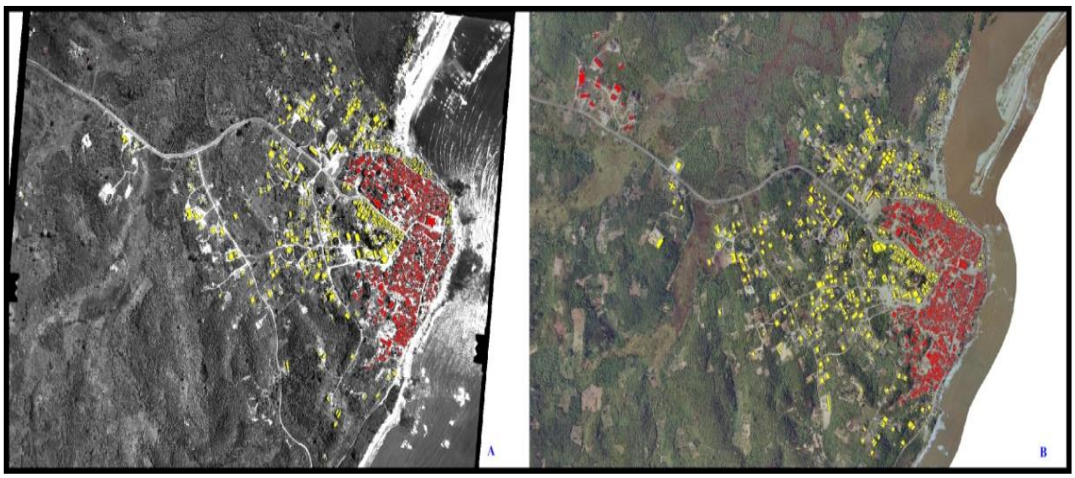

Figure 17: Digitized buildings/structures. Inset A: 2000 panchromatic. Inset B: 2005 satellite images (Source: Fieldwork, 2011)**.**

To analyse the spatial patterns of urban growth, the built-up masks were refined by intersecting road vectors in order to focus on areas originally classified as built-up. A 30metre buffer was created on the digitized flood zones to reflect Ghana’s Legislative Instrument (LI) 30, which disallows housing development located within 30m of an existing water body (river, lake, or the waterway of a river).

Developing a classification scheme

Classification is the process of sorting pixels into a finite number of individual classes, or categories of data based on their data file values. Classified images are commonly used for land cover mapping, agricultural assessments, and resource management. Based on the prior knowledge of the study area and a brief reconnaissance survey coupled with additional information from the District Planner, a classification scheme was developed corresponding to that of Anderson, Hardy, Roach, and Witmer (1976). The classification scheme developed gives a rather broad categorization where the land use and land cover were identified by a single digit. Table 4 depicts the Land use land cover classification scheme adapted from Anderson et al. (1976). A supervised classification using maximum likelihood was performed with a training data developed for the area within the Erdas 9.1 platform (Figure 21).

Table 4: Classification Land use land cover categories.

Code	Land use land cover categories
1	Planned and Informal Settlement
2	Vacant zone / Agricultural
3	Flood zone
4	Educational Centre
5	Economic Centre
6	Others

Source: Adapted from Anderson et al. (1976).

The definition of vacant land (or unsettled land) as used in this research work denotes land without physical structures or any human induced development except probably spots of subsistence farming activities.

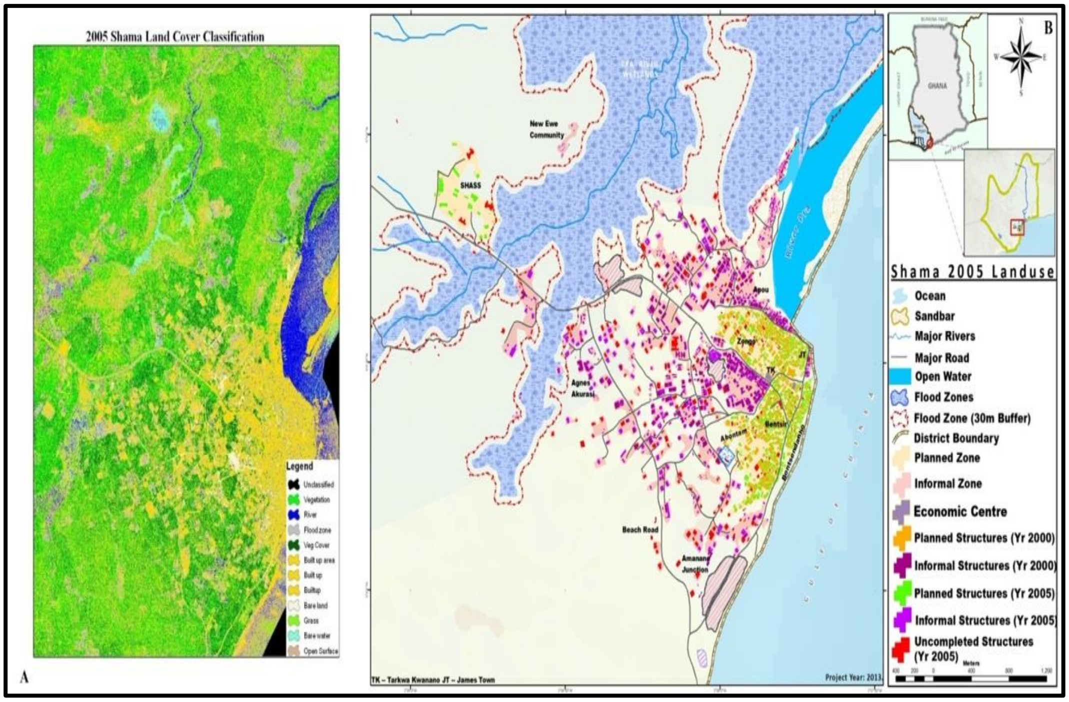

Figure 18: From Left (A) to Right (B): Land cover classification and Land use maps of Shama conducted on 2005 satellite images (Source: Fieldwork, 2011)**.**

The Spatial Multi-Criteria Evaluation (SMCE) process in Ilwis

Despite the historical flooding situations encountered by the residents of the Shama township, they build on available lands given the cost of the land, the ownership of the land, and sometimes the income levels of the individual dweller. This study sort to design a suitability map given some criterion obtained from selected community members as major factors to consider when constructing a house. In view of this, a criteria tree (Figure 19) was developed for selecting areas suitable for residential development.

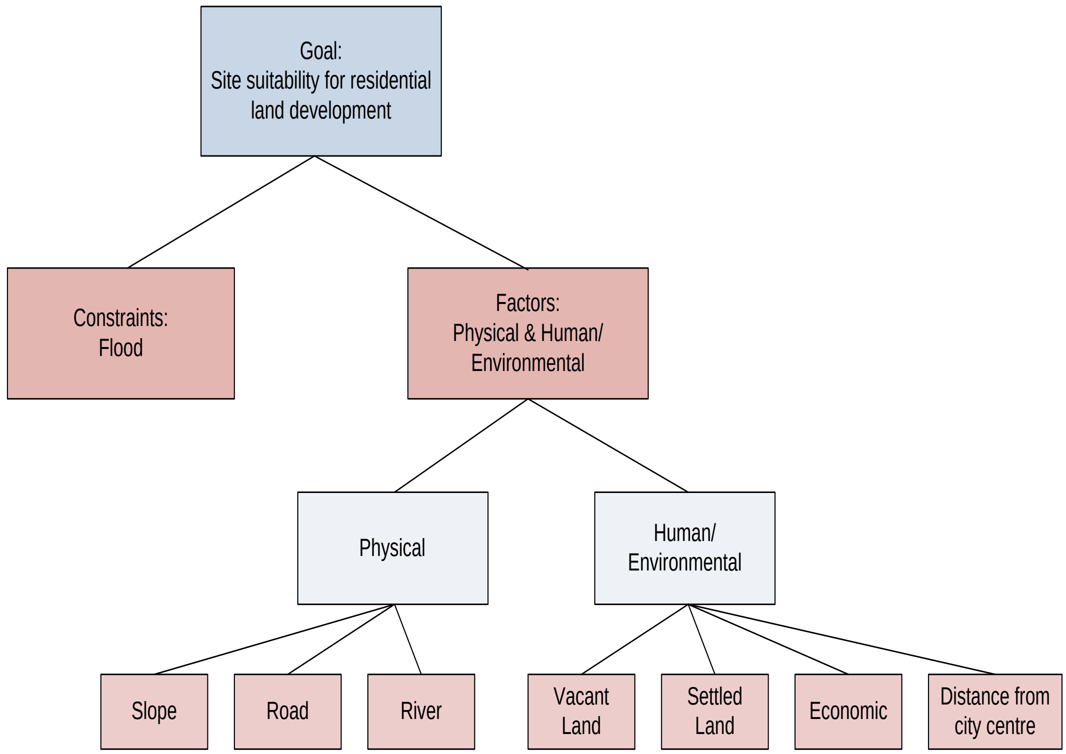

Figure 19: Criteria tree for identifying potential site for residential development (Source: Fieldwork, 2011)**.**

Partial valuation (Standardization)

In Figure 19, a map of a different type represents each criterion, such as a classified map or a value map (example is a slope map). For analysis and decision, the values and classes of all the maps are converted into a common scale, which is called "utility." Utility is a standardized measure of appreciation of the decision maker with respect to a particular criterion, and relates to its value or worth (measured on a scale of zero (0) to one (1)). The utility function in the SMCE platform was adopted as the agent utility function in the modelling design stage of the study.

Different standardization is applied for different type of maps:

1. For “value maps,” standardization is done within Ilwis SMCE by choosing the proper transformation function from a set of linear and non-linear functions. The outcome of the function is always a value between zero (0), and one (1). The function is chosen in such a way that pixels that are highly suitable for settlement have high-standardized values, and unsuitable ones low values. Possible standardization methods for value maps in the developed SMCE module are for example “Maximum,” “Interval” and “Goal”; and

2. For “classified maps,” standardization is done by matching a value between 0 and 1 to each class in the map. This can be done directly, but also by pair wise comparing or rank ordering of the classes.

Weightings

The next step of the SMCE process is weighting each indicator. Weighting is the identification of the relative importance of each indicator. ILWIS’ SMCE module provides support for a number of techniques (direct, pairwise comparison, and rank ordering) that allows elicitation of weights at any level in the criteria tree. The criteria tree designed in the first step enables giving weights to a few factors at a time, as the branches of one group only are compared to each other. Factors are always weighed, but for constraints (floodzone), there is no weight involved, because they simply mask out the areas, which are not interesting.

Suitability assessment and derivation of final suitability map

After partial valuation and identification of the relative importance of each criterion in the site selection process, the next step is to obtain the overall attractiveness (suitability) of each point (pixel) in the map (composite index map) for waste disposal. For this process, ILWIS' SMCE module supports several techniques. The suitability map (Figure 20) indicates the potential sites for residential development and will be used as an input into NetLogo for modelling.

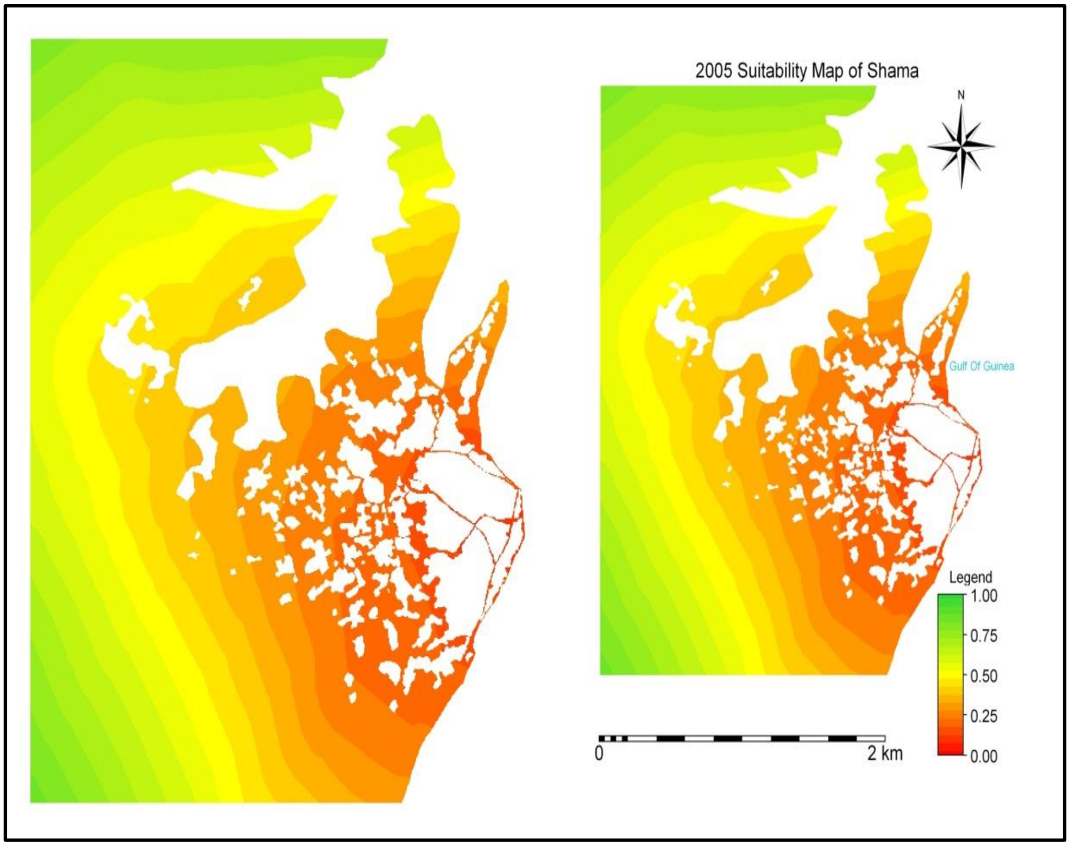

Figure 20: Suitability layers for residential development (Source: Fieldwork, 2011)**.**

With the development of GIS, environmental and natural resource managers increasingly have at their disposal information systems in which data can be manipulated to meet the needs of environmental and natural resource decision making. However, despite the proliferation of GIS software systems and the surge of public interest in the application of the system to resolve the real world problems, the technology is commonly seen as complex, inaccessible, and alienating to the decision makers (Fedra, 1993).

Data analysis and interpretation

Results of the study were presented the use of graphs, maps, and tables. Descriptive statistics was also used to demonstrate settlement growth patterns and the results of the model calibration. The statistical product for service solutions (SPSS) software assisted data entry and analysis. The maps and model outputs are presented with logical interpretations backed with theoretical concepts and literature.

The environment in agent based modelling

In ABMs, the environment is the virtual world within which the agents exist and interact with each other. It may represent social space or geographical space, thereby deemed spatially explicit, simulating some graphical feature of a city (Gilbert, 2008). The environment determines the overall dynamics, combining the effects that influence each agent and applying them generally in discrete time steps.

In particular, in the specific context of simulation the environment is typically responsible for:

1. Reflecting/reifying/managing the structure of the physical/social arrangement of the overall system;
2. Embedding, supporting regulated access to objects and parts of the system that are not modelled as agents;
3. Supporting agent perception and situated action (it must be noted that the agents' interaction should be considered as a particular kind of action);

4. Maintaining internal dynamics (e.g. spontaneous growth of resources, dissipation signals emitted by agents); and
5. Defining/enforcing rules.

Time factor in agent based modelling

In ABM's, time is modelled as discrete time steps in which some or all agents are given an opportunity to act in some way depending on the behavioural rules set during the design (Gilbert, 2008). Agent action during each time step may be sequential asynchronous, random asynchronous, or synchronous, all of which suggest that all agents perform some action within each time step.

Randomness in agent based modelling

Randomness is that feature of the model, which considers the unexpected or unpredictable variation in behaviour of the agents. It is introduced into ABMs to account for random variation or "noise" (Gilbert, 2008). As with other types of models of social phenomena, reality cannot be represented accurately in absolute terms.

Agent interactions

Agents interact within the environment in which they are located and can learn from each other through directly passing messages to each other (as in opinion dynamic models) or by observing other agents. The Environment-Rules-Agent Framework described by Gilbert and Terna (2000) represents a structure within which the behavioural rules for each agent may be written (Figure 21).

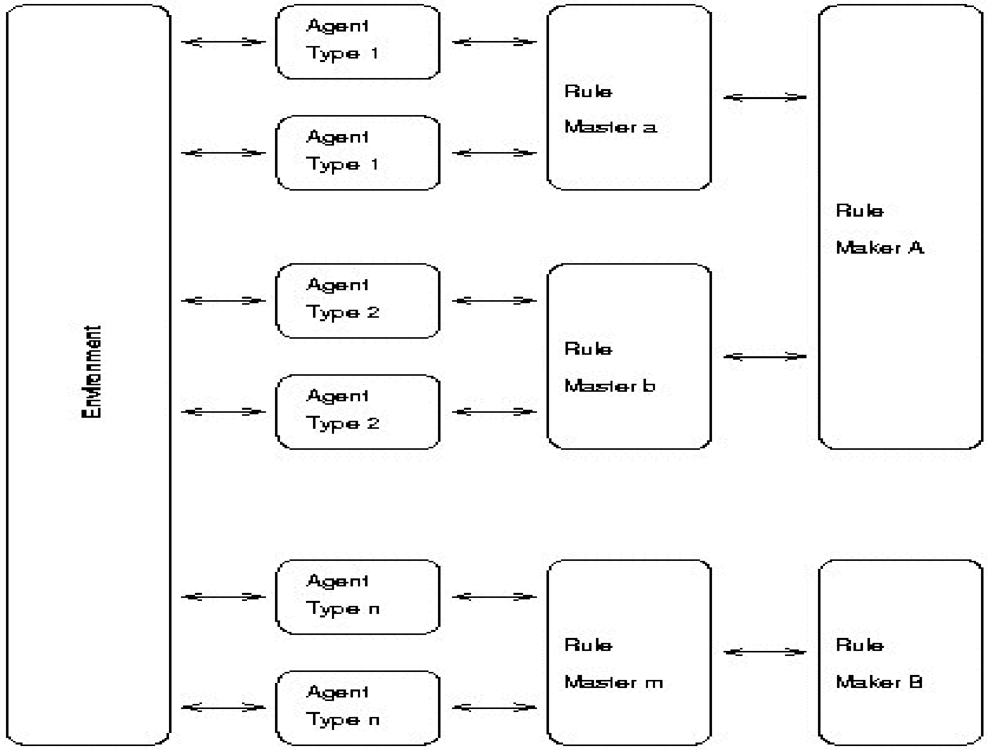

Figure 21: Environment-Rules-Agent-Framework (Gilbert and Terna, 2000).

Bounded rationality

This aspect of rational choice theory has been challenged. As a result, it is proposed that individuals (in this case agents) are modelled as being "boundedly rational", meaning that they are "limited in their cognitive abilities and thus in the degree to which they are able to optimize their utility" (Gilbert, 2008). Bounded rationality is based on the premise that individuals only have certain information available to them and base their decisions on this limited knowledge (Young, 2010).

Learning abilities of agents

Agents have the capacity to gain information (learn) and change their behaviour. Learning can be achieved or modelled in any of three (3) ways: individual by agents' own experience, evolutionary where agents learn because weaker agents die off, or social where agents learn from each other's experiences (Gilbert, 2008).

Calibration and validation of model

Calibration of the model involved checking the parameters in the model (the three income groups, selected driving forces of spatial growth, virtual land price, and population growth rate) to see if they are consistent with relevant description of the model. Calibration of the model was done in NetLogo and validation with subject matter experts. Subject matter expert is an approach similar to the use of third party entities in the independent verification and validation process described by Sargent (2000) (as cited in Young, 2010). The purpose of the validation exercise is twofold: (1) To determine the fitness of the representation of the individual element in the model, and (2) To assess the overall capability of the model. Two different types of SMEs were selected based on individual areas of expertise and experience in growth of informal settlement and agent based modeling, particularly in the area of land-use change modeling.

Subject matter expert ideas relative to the factors under consideration, criteria development, ranking of factors amongst other were obtained with the use of unstructured interview guides and email correspondence. Outcomes of this exercise were used in creating the criteria tree for the spatial multicriteria evaluation and in the development of the model.

Ethical issues

Even though the study did not have serious ethical issues, attempts were made by the researcher to assure respondents of their informed consent along with confidentiality and anonymity of their responses as a way of protecting the right of respondents, and their dedicated support towards a useful outcome of the study.

Challenges to data collection

Major challenges of the study include the cost of acquiring satellite images and time constraint. Subject matter expert interviews were conducted freely but not without frequent postponement of the schedule times and un-replied electronic mails. Furthermore, there was limited cooperation on the part of individual house owners in responding to the questionnaire given them. However, a vivid explanation of the idea behind the study to the understanding of respondents through a face-to-face interaction resolved the challenge.

Summary

This chapter has presented the general methodology aimed at achieving the objectives of the research. Data collection, data processing, data types, and processes involved at deriving a spatial multicriteria evaluation map, agent environment, agent learning and interactive abilities were presented in this chapter.

Primary ethical issues of informed consent, anonymity and confidentiality to respondents are presented.

CHAPTER FOUR

SPATIAL DYNAMICS OF SHAMA

Introduction

In this chapter, patterns of structural growth within geographic space are presented using an exploratory, descriptive, and aerial photo interpretation approaches. Observations of growth patterns are discussed. Developments of structures on areas liable to flooding are also presented.

Spatial growth pattern of settlement in Shama

Spatial growth pattern refers to a regular arrangement for logic ordering of urban structure, process, and system. Camagni et al. (2002) distinguished five types of urban expansion:

1. Infilling (growth that takes place within existing urban area);
2. Extension (growth at the fringes of the city);
3. Linear development (urban development along main transport infrastructures);
4. Sprawl (characterized by new scattered development across the urban area); and
5. Large-scale projects (expansion across the city regardless of existing built-up areas).

This study adopted the five classification schemes to explain urban expansion and patterns of growth in Shama.

Between 1984 and 2000, the national population grew from 12.2 to 18.9 million, corresponding to an annual growth rate of 2.7 percent. During such periods, urban localities were often in focus as places of rapid population growth (Ghana Statistical Service, 2005). Shama assumed an urban status since 1948 because it had over a hundred percent increase in its population from 5,155 persons in 1948 to 11,268 persons in 1984. The total number of houses increased from 522 in 1960 to 677 houses in 1984 (Ghana Statistical Service (GSS), 1960 - 1984). However, the 2000 Population and Housing Census (GSS, 2000) put Shama‘s population at 9855 persons. The question that remains unanswered is where people settled as the population increased, and whether they went through the legal procedures of acquiring the lands for residential development. A related question is how the Shama urban area grew over time and space (Figure 22).

Most of the developed sites are without legal backing (SDA-MDTP, 2010 - 2013). In Ghana, there is no available statistics indicating the sizes of informal settlement. Shama’s informal settlement growth is along major transportation centres, roads and rivers (Figure 23). Groenendijk and Kuffer (2006) argued that informal settlements as in the case of Shama are low-income areas that tend to cluster on marginal lands. Infilling and outward spread, linear development, and spontaneous growth are the consistent spatial urban growth patterns identified in Shama.

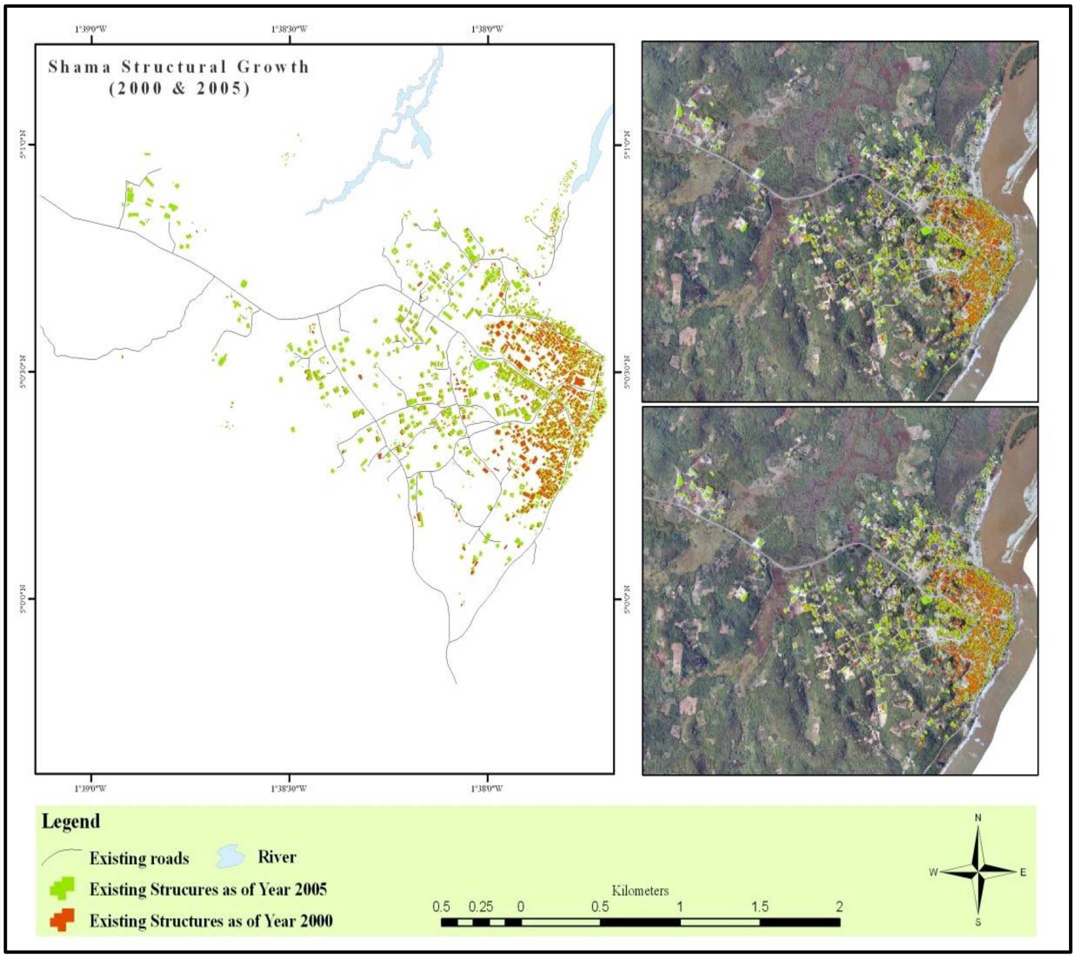

Figure 22: Shama structural growth for year 2000 and 2005 (Source: Fieldwork, 2011)**.**

Linear pattern of spatial growth

Kreibich (2007) through a GIS-based analyses indicated that urban growth in developing countries are informal and are linear in character. In Figure 23, the maps depict settlement are development along major roads in Shama. Figure 23A shows the development of settlement structures along the main road leading to Bontsendanho and James Town. These structures are notably of ancient's architecture and were built decades before the town gained its currents status as the district capital.

Such structures had spread in 2000; and in 2005, this growth continued spreading outwardly from existing settlement. As of 2005, there were growths spreading along the major roads of Shama down through the New Site area. Similar growth of outward spread is as shown in Figure 23B. In 2000 and 2005, growth had existed along the route of Apou further by an outward expansion of structures.

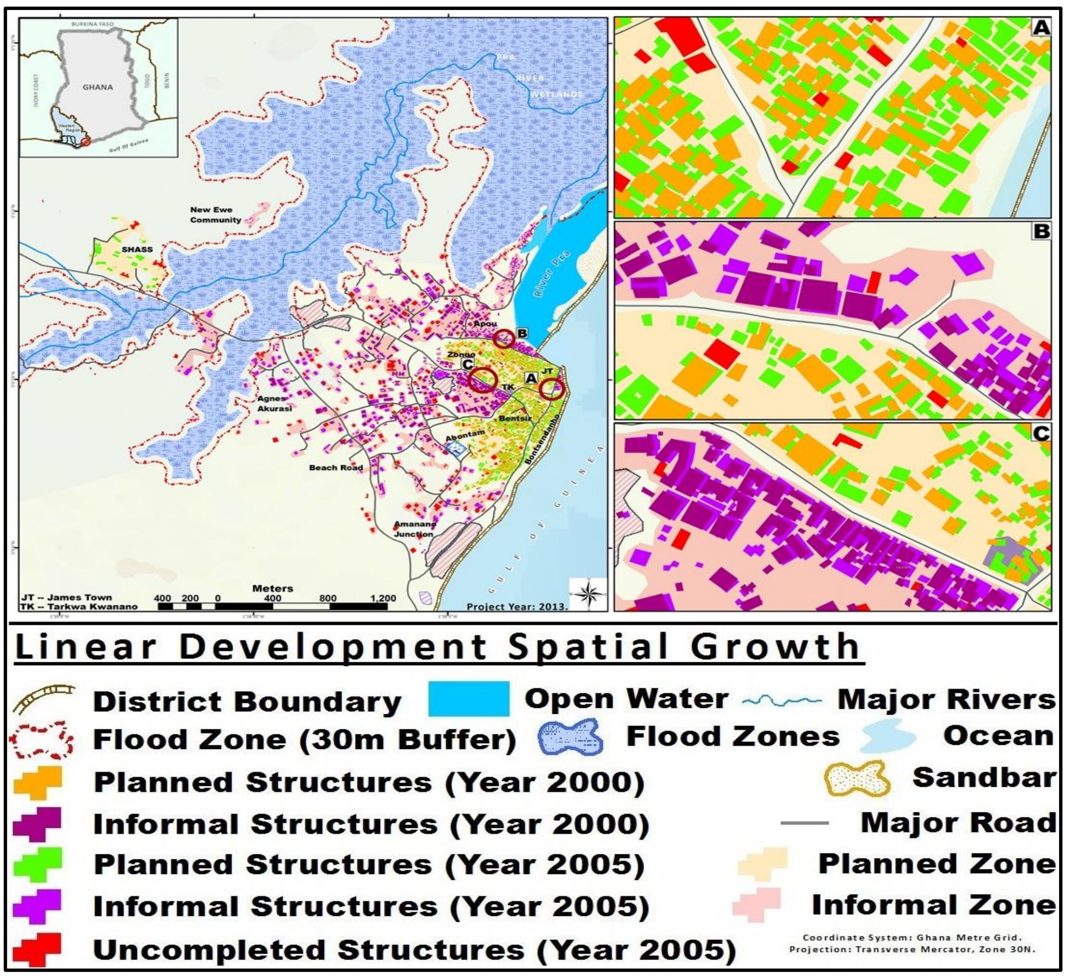

Figure 23: Linear development growth pattern of informal settlement in Shama (Source: Fieldwork, 2011).

Figure 23C shows a perfect example of linear informal settlement growth along a major road, with most of this development taking place in 2000, with further spread in 2005.

Infilling and outward spread pattern of spatial growth

Infilling implies the non-urban area surrounded by urban gradually being converted into an urban entity. Figure 24 shows infilling and outward spread growth of informal structures taking place close to flood zones, along minor roads, within informal settlement and planned settlement areas. The features coloured green in Figure 24A shows infilling pattern of growth within the outskirts of Shama from Awunakwesi towards Adjoakrom. In 2000 (coloured in green), there existed few structures in the Awunakwesi community.

However, the number of structures had increased by filling in the existing structures in 2000 and spreading outwards towards the flood zone as shown in Figure 24A within the same community. It is significant as viewed Figure 24B that some infilling is taking place within existing structures of 2000 within the Zongo community of Shama. This infilling continued in 2005 by filling in the empty spaces provided by the 2000 existing structures. Figure 24C shows another type of infilling taking place in the outskirt of Shama towards the Roman Park area between 2000 and 2005.

This infilling also continues around the waterworks reservoir area and joins the beach road to Aboasi (located southwest of Shama). From Figure 24, it is important to note that infilling and outward spread growth pattern in Shama are influenced by rivers, economic centres and planned residential areas, with these developments taking place in the centre of the town, at an immediate ring outside the central location of town and on its fringes. This type of growth pattern is most noticeable in Abontam, James Town, and the Zongo communities.

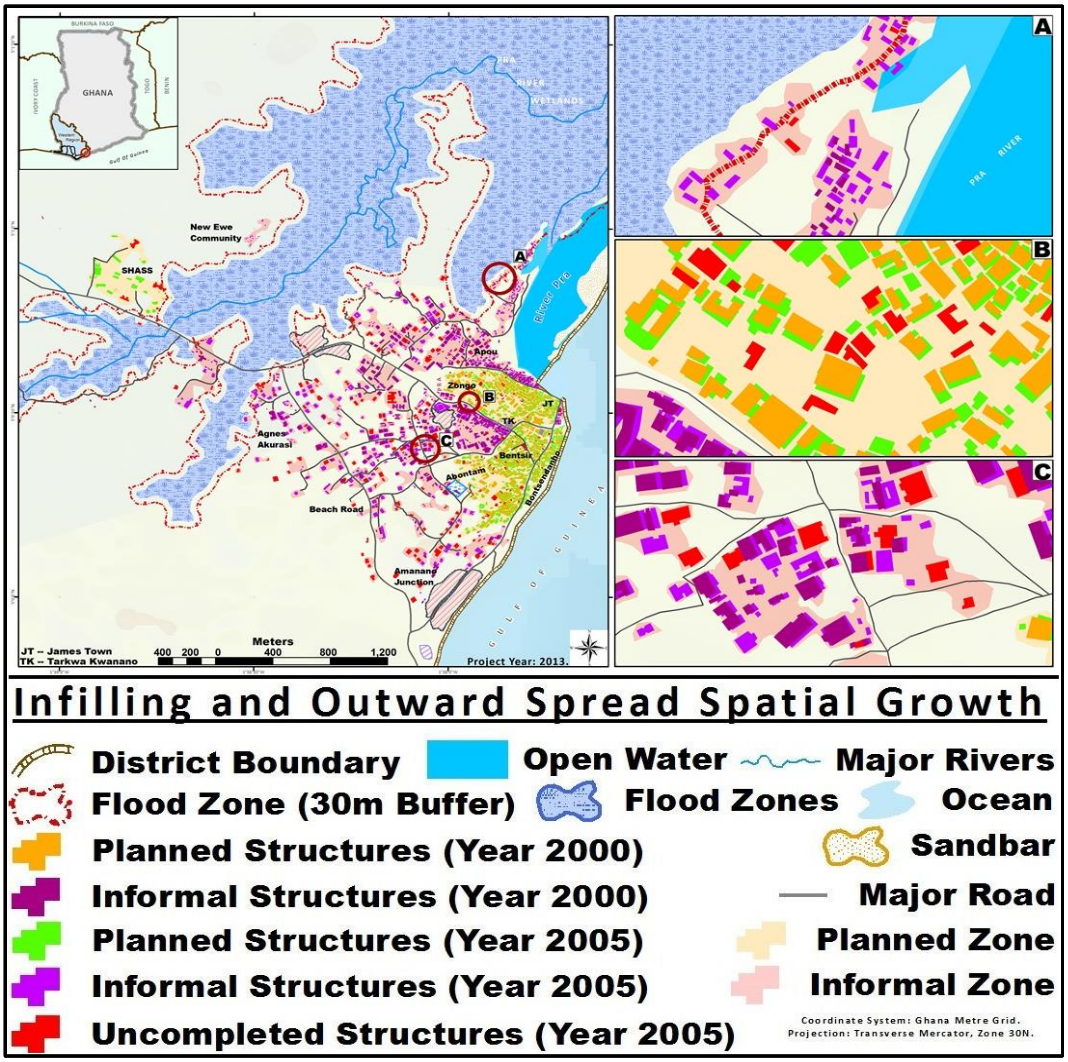

Figure 24: Infilling and outward spread growth pattern of informal settlement in Shama (Source: Fieldwork, 2011)**.**

Spontaneous pattern of spatial growth

In Figure 25, the three (3) inset maps demonstrate spontaneous growth pattern at the fringes of the town, particularly around Beach Road, New Site, Amonano Junction, Integrated Centre for Employable Skills (ICES) and the model school communities respectively. Reference to the map suggests the historical fringes development of Shama since 2000. However, another spontaneous growth that took place in 2005 was the new residential development (predominantly made up of Ewe speaking people) North of Shama Senior High School (SHASS).

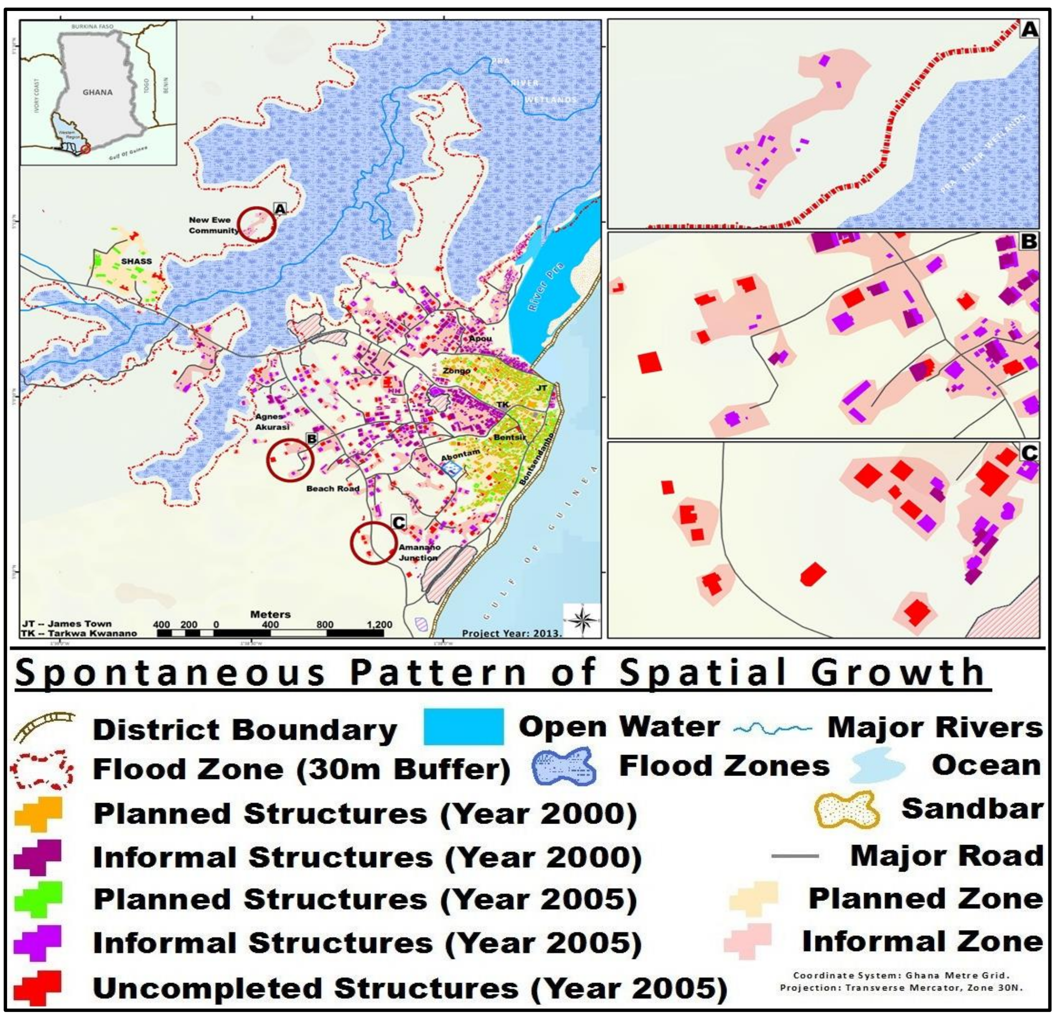

Figure 25: Spontaneous growth pattern of informal settlement in Shama (Source: Fieldwork, 2011)**.**

Based on the spatial growth pattern analyses of the land use map for informal settlements in Shama (2000 – 2005), there is an indication that the three (3) spatial growth patterns (linear development, infilling and outward spread, and spontaneous) exist in Shama. Nevertheless, it is significant to explain the dynamics of these growth patterns. Linear development growth pattern influenced by major roads is the first type of growth pattern of informal settlements that takes place in Shama. This is as followed by infilling and outward spread of new informal settlements from existing formal and informal settlements as shown in Figures 23 and 24 respectively. Subsequently, a new informal settlement in the form of single hamlets and small villages starts sprigging up at the fringes of the town. With time, this phenomenon attracts new settlers resulting in outward expansion.

Road networks and spatial growth pattern

Figure 26 depicts how major roads influences informal settlement development, extending into the fringe of town. Figure 26A represents informal structural development along the main road leading to the main town. Structural growth in 2000 developed linearly along the road with a contrasting outward expansion of existing structures in 2005. The linear development of the informal structures had existed before 2000 and had continued developing both in a linear growth pattern and by expanding outwardly in 2005. Communities that could be said to have been influenced by the existence of roads include Zongo, Bontsendanho amongst others.

Figure 26C present an example of how major roads influences informal structural growth along the beach road, and towards Amonano junction. The development of structures along the coastal route to neighbouring Aboasi indicates an outward spread, and structural development along roads. In the three (3) cases, informal settlements development along major roads is highest in 2000 and 2005 with majority of the roads constructed along the new settlement zones in Shama.

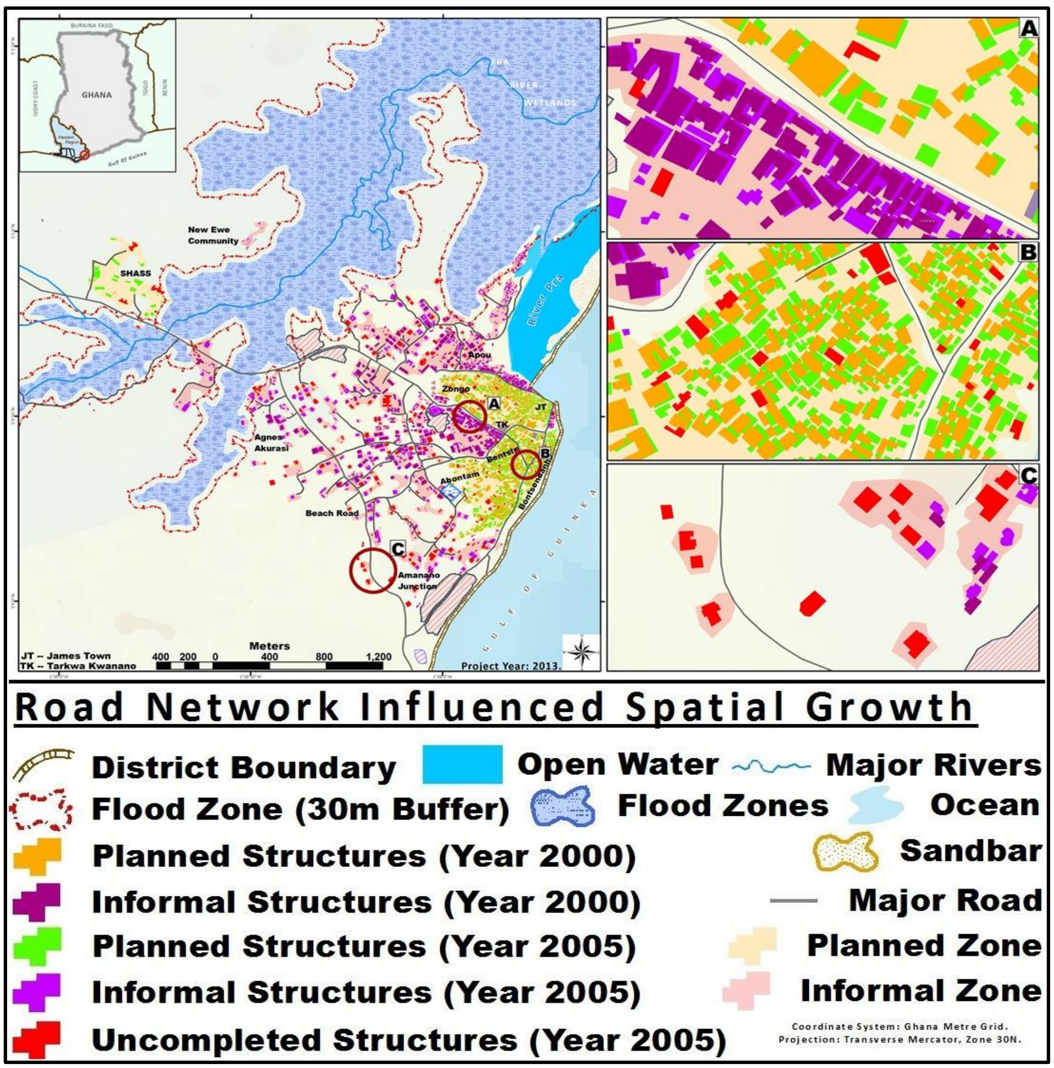

Figure 26: Road network and spatial growth of Shama (2000 - 2005) (Source: Fieldwork, 2011)**.**

Drainage networks and spatial growth pattern

Informal settlements in Shama also develop along coastlines and rivers (particularly along the Pra River and at the estuary). The inhabitants of these areas depend on these water bodies as a source of water supply and as a source of other livelihoods. Hence, in historical context, the rivers and coastlines do have great influence on settlements growth as evident in Figure 27i.

From Figure 27iA, it is evident that new structures have developed have developed to the north east of Shama Senior High School in the year 2005. The area developed into the New Ewe Community was extinct in 2000 but saw some structural growth in 2005. Figure 27iB shows the extended development characteristic of outward spread within Awunakwesi.

Regardless of its existence in 2000, the area saw some outward spread towards the Pra River to the south and the flood zone to the west by way of growth in 2005 filling up the empty spaces close to the river course.

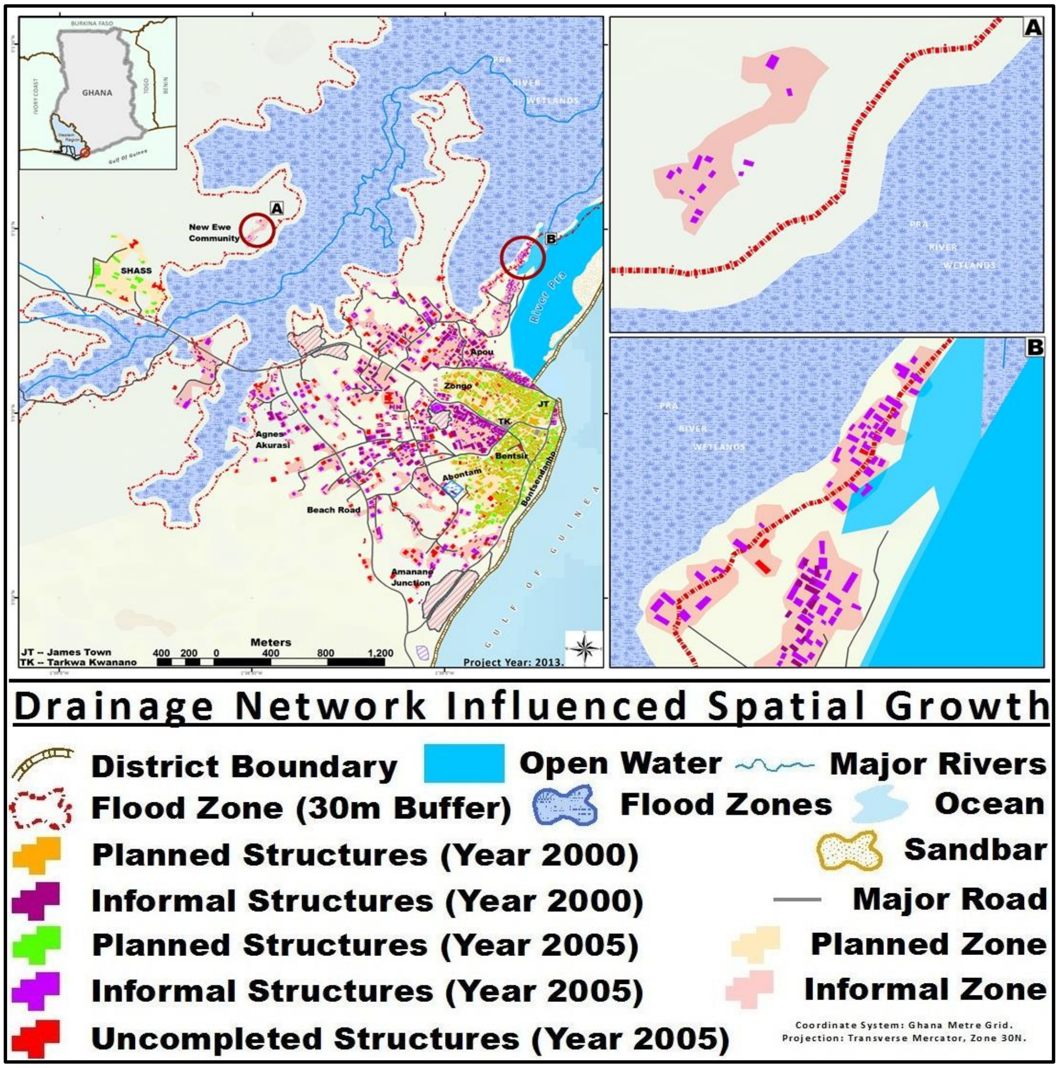

Figure 27i: Drainage networks and spatial growth (2000 - 2005) (Source: Fieldwork, 2011)**.**

Flood prone or swamp areas attract and discourage the development of informal settlements. Figure 27ii demonstrates the distinction between how informal structures develop on swamps and how people try to consciously avoid core swampy areas but end up settling on such hazardous environment.

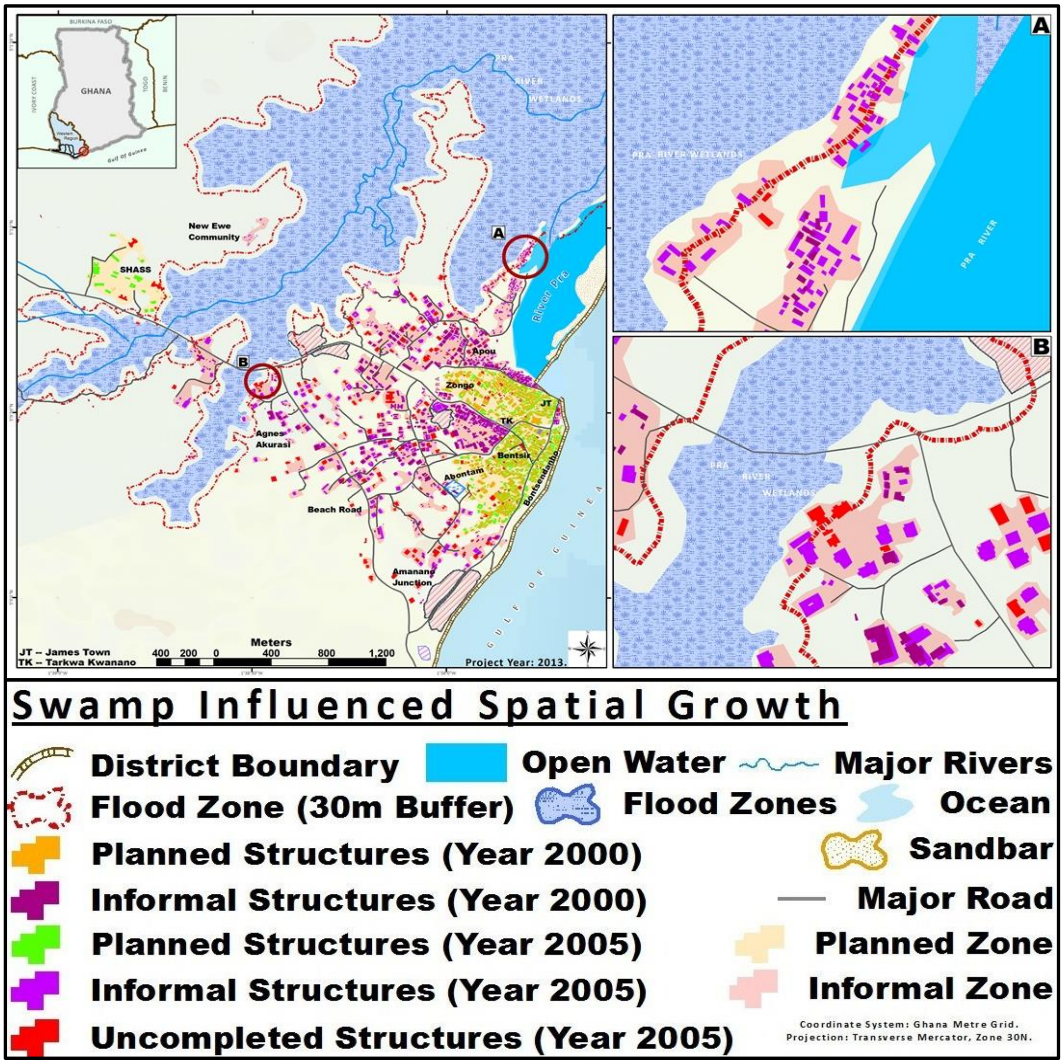

Figure 27ii: Swamp influenced informal settlement growth of Shama (Source: Fieldwork, 2011)**.**

It is evident from Figure 28iiA that current development in 2000 and 2005 is gradually approaching the flood prone zones. It could be concluded that informal settlements develop in swampy areas on the outskirt of the town in the direction towards Adjoakrom with a well noticeable pace and pattern of growth.

Another interesting observation is the development of structures in 2005 influenced by the combined factors of swamp and roads in Agnes Akurasi (Figure 28iiB).

The map visualization has helped the understanding that physical and environmental driving forces influence spatial growth pattern of informal settlements. Of these spatial and environmental factors are: proximity to major roads, proximity to river, proximity to industries, close to planned residential area, proximity to isolated hamlets or villages, swampy areas. However, the model design proposed in this study considers proximity to the economic centres, proximity to major roads and flood zone or swampy areas respectively.

Though proximity to roads and economic centres (as well as the economic capacity of the individual) are the dominant and influential factors in the choice of a residential location, the inclusion of the flood zone (the physical characteristics of the land), makes it more relevant to observe the outcome of the model given these approaches as per the observation of growth in the above classifications.

Economic activities and spatial growth pattern

Another influential factor that suggests the spatial growth pattern of informal settlements in Shama is the commercial activities that take place in the central business district.

Of all the driving forces that make up the economic centres, simple trading of farm produce and selling of fish products have the greatest influence on the growth of informal settlement in Shama.

Inhabitants of these settlements are mainly low-income people who rely on catch from the sea and farm output to ensure their sustenance. Figure 28A shows the influence of commercial centres on informal settlement development.

The lorry station area in Tarkwa Kwanano serving as the hub of commercial activities has resulted in the construction of houses within its immediate environs. Such development had seen its inception even before 2000 and by 2005, as evident in Figure 28B, new development in the form of infilling and outward spread had taken place around the economic centres.

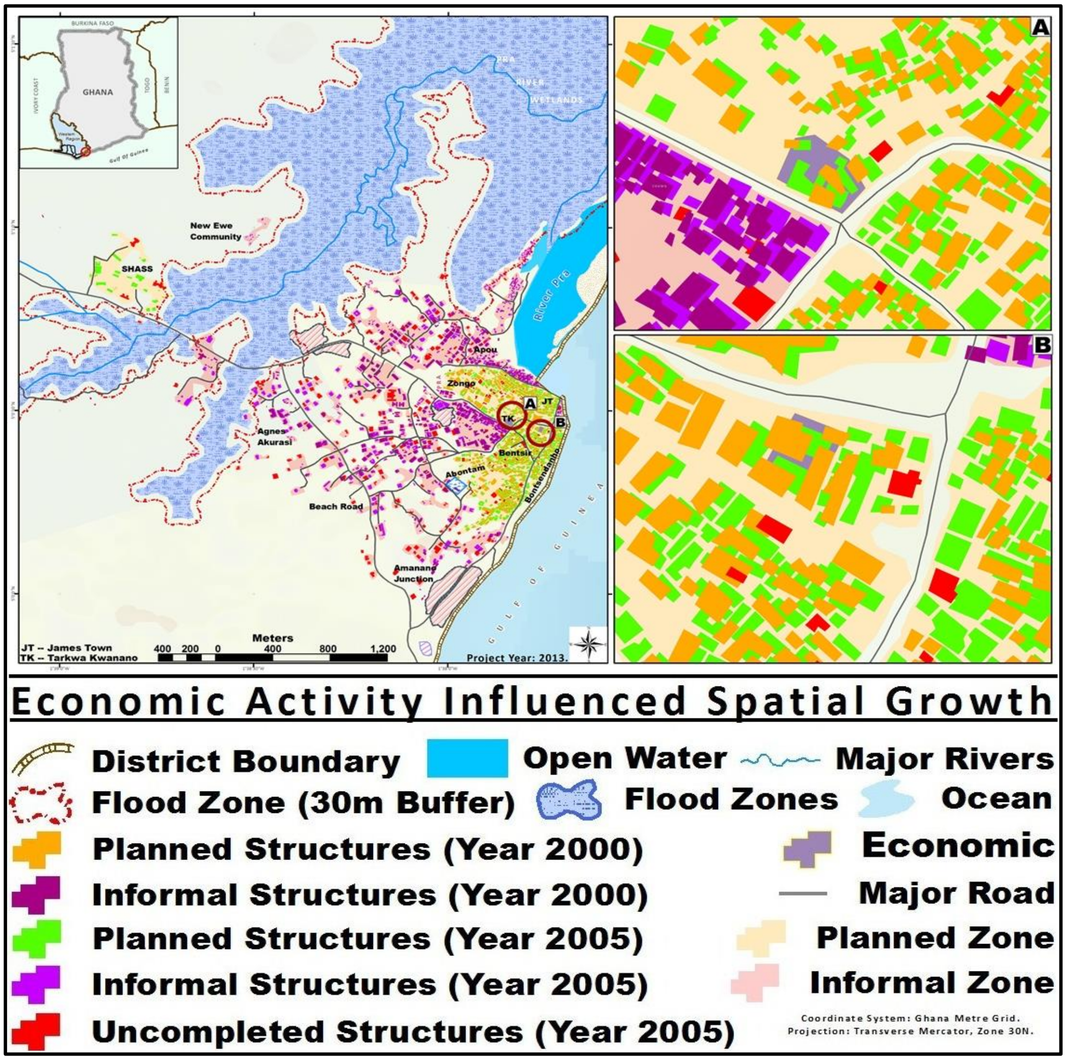

Figure 28: Economic activity and spatial growth (2000 - 2005) (Source: Fieldwork, 2011)**.**

Planned settlement and spatial growth pattern

One factor that attracts informal settlement growth in Shama is the developed formal (planned) settlements. Planned or formal settlement structures are those structures located on land or parcels with legal or valid permit certificate and proper documentation for their citing. Figure 29A displays how formal settlements attract informal settlements growth from 2000 to 2005 as structures start expanding outwardly from planned structures in Apou towards the flood zones to the north. Within the informal settlement is a new development in the form of infilling. In support of this argument, Figure 29B expresses a more characteristic development taking place within the planned areas in 2005 in Bentsir. This historical trend continued between 2000 and 2005 where new informal settlements developed by expanding from existing informal settlements.

Therefore, in 2000 and 2005, there were developments of informal settlement along formal (planned) settlement areas.

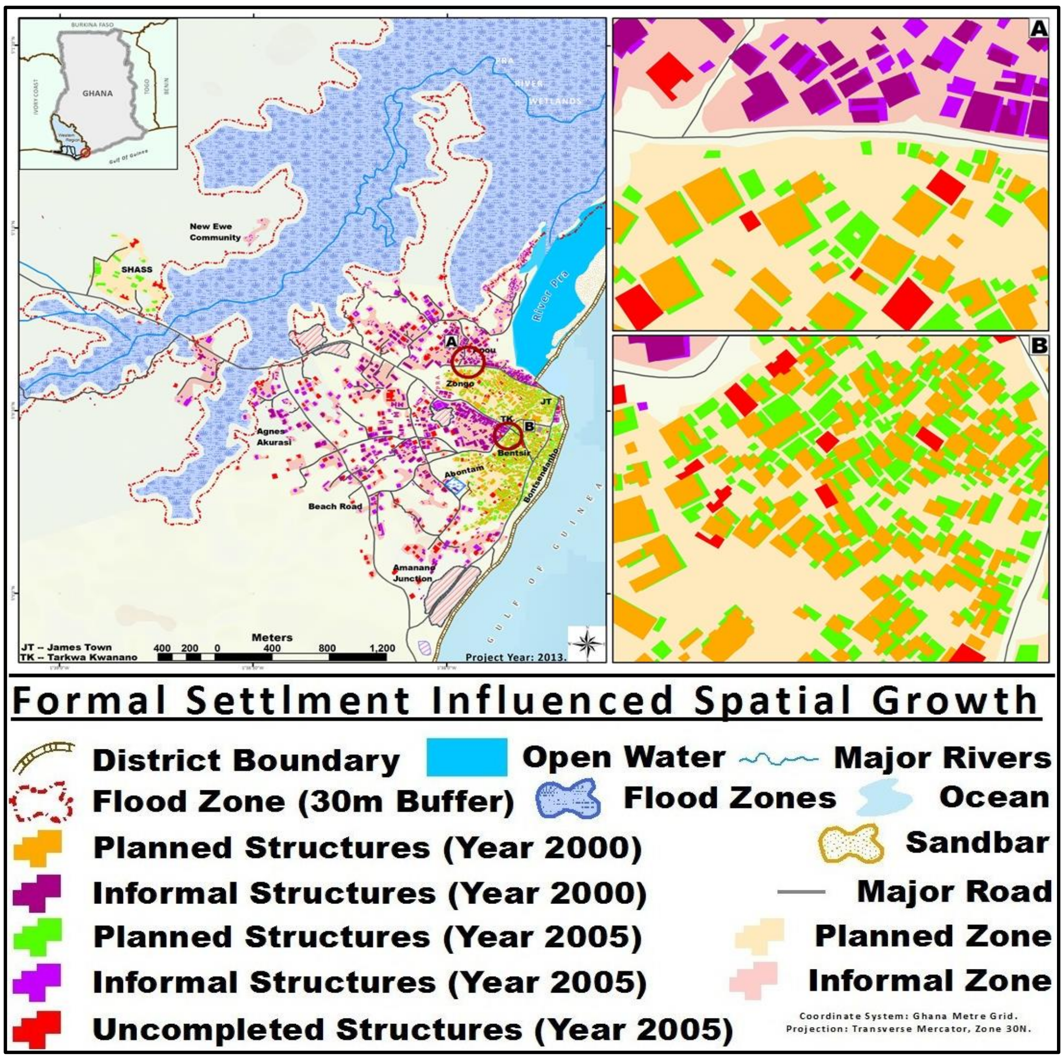

Figure 29: Formal settlement influenced informal settlement growth in Shama (2000 - 2005) (Source: Fieldwork, 2011)**.**

It must be noted that formal settlements do not solely influence informal settlements development, rather a combination with industries; commercial and institutional areas encourages informal settlements growth.

Physically vulnerable structures located within flood prone zones

The effect of unguarded residential development, which could lead to flooding of some settlement, is evident in Figure 30. Given the Ghana Legislation Instrument (LI) 30, which states that houses built must be at least 30 meters away from bank of rivers, a 30m buffer zone proximity function was constructed to help detect buildings, which flout this LI. As indicated earlier, the flood zones digitized from the 1974 topographic sheet informed this procedure. Figure 30 was designed to capture and highlights structural growth taking place within the illegally bounded zone where residential development ought not to be.

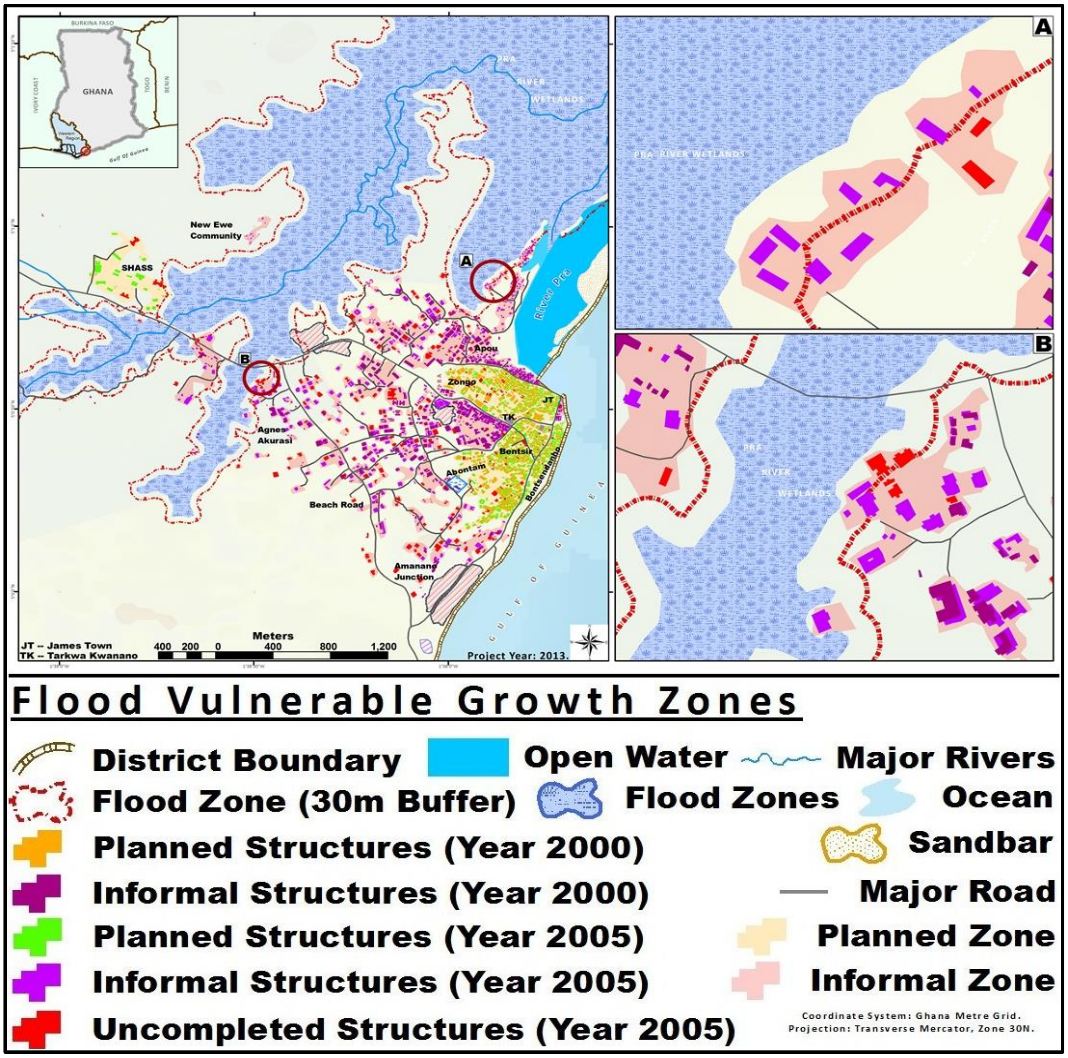

Figure 30: Flood vulnerable zones of Shama (2000 – 2005) (Source: Fieldwork, 2011).

Figure 30 identifies elements that are subjects to risks or vulnerable to flooding. An attempt was be made to analyse the causes for which these elements are at risk. Vulnerability involves both physical and economically susceptible damages relative to inadequate resources needed for its rapid resilience and recovery in the aftermath of a disaster.

Figure 30 showcases that some structures close to Adjoakrom located on the South-eastern side of Shama lies completely within the flood zone. The 30m buffer divides the entire community into about two-thirds its physical extent. This is however alarming, as any further increase in the water level due to sluggish thaw the Pra River at its bend could cause damage to property.

From Figure 30A, the outward spread of Awunakwesi township falls within the 30-meter buffer zone. The outward spread towards the north subjects that part of the community to flood in case of any eventualities. A movement upwards towards Shama new site area also shows some level of development going on within the floodable zones. The onset of such development is evident in the 2005 Aerial Photograph. From Figure 30B, residential developments in 2005 around Agnes Akurasi towards Integrated Centre for Employable Skills (ICES) are situated on potentially floodable areas. These include residential structures located behind Agnes Akurasi.

In 2000, 76 houses (2.3 percent) out of 1,107 buildings were located in the flood zone. In the period between 2000 and 2005 however, 72 new houses were built inside the flood zone. This constitutes 8.2 percent of the new houses (701) built between the period of 2000 and 2005. The 5.9 percent increase in buildings within flood zones is attributed to the outward spread of building patterns.

Summary

In this chapter, three growth patterns were discovered by carrying out a GIS-based aerial photo interpretative analysis on the 2000 to 2005 land use maps of Shama. The three patterns found in this chapter include infilling and outward spread, linear development, and spontaneous growth as propounded by Camagni et al. (2002).

CHAPTER FIVE

INFORMAL SETTLEMENT GROWTH MODEL:

EVIDENCE FROM SHAMA

Introduction

This chapter discusses the adoption of an agent-based model for simulating the spatial growth pattern of informal settlements in Shama (SISGM). The model is based on the locational decision making of inhabitants of the town in connection with the influence of economic, environmental, and physical structures of the coastal town on its spatial growth. It also focuses on the description of structures, which forms part of the conceptual model. This chapter is structured in three parts. The first part presents the logic of the model supported with the field analysis of data collected on 50 respondents. The second part presents the implementation of the model logic using the NetLogo modelling environment. Finally, the verification, validation, and calibration of the model is discussed.

Overview of the Shama informal settlement growth pattern model

The model takes into consideration environmental, economic, and physical components of the area, and the residential locational decision making of residents on the spatial growth pattern of informal settlements in Shama. The principal assumption of the model is that a group of people (agents) search for a location to settle in a town or city. Nevertheless, peoples (agents) ability to settle in the location is determined by their economic power to afford their preferred locations.

The model sought to establish the locational preferences of people (agent) of different economic power.

Household agents in the model are grouped into three (3) economic income statuses namely: high, middle, and low-income earners, this classification is based on the works of Barros (2004). The primary objective of all household agents is to find a location to settle, but their residential locational behaviour or quest is differentiated by the restrictions imposed on their economic power. The high-income agent is able to settle anywhere in the area except from restricted cells or cells occupied by high-income agents. The middle-income agent is able to settle anywhere in the area except from restricted cells, and cells occupied by high and middle-income agents, while low-income agents can only settle on vacant cells.

The eviction rule is applied in this model. The rule is that high-income agents can take over a cell occupied by a middle or low-income agent, while expelling the occupant of the cell in search of a new location. Middle-income agents can only take over a cell occupied by a low-income agent, but low-income agents cannot take over a cell already occupied by any agent.

The agents population is defined in the model according to the total number of household units in the study area informed by the 2000 Population and Housing Census (Table 2); the head of the household represents the household unit in the model (that is the agent). The annual rate of population growth for the study area represents the projected population and a basis for population change in the model. The main population variable considered in defining this population dynamics is migration rate into the town. This change is simulated in the model by introducing new sets of agents into the model at defined time-steps.

The ratio of agents per income group is the percentage of the total number of agents in each of the three economic groups derived from the income divisions of the 2000 Population and Housing Census. Because it is considered in ratio and percentage terms, the total must be 100. At the onset of the simulation, agents are created and settle randomly on existing planned residential and informal settlements designed from the GIS work output, regardless of the income group they belong.

Before an agent settles, it samples different locations. The determinant of an agent settling on a cell depends on the attractiveness of that cell which is a function of the value and price of the cell, the type of agents located in its neighbourhood, and the willingness on the part of the agent to move in search of land. When an agent is unsatisfied with its present location, it searches for a new location by randomly sampling a number of locations (cells) and chooses the most attractive cell. If the sampled cell is an unattractive cell (a cell that does not satisfy the location preference), the household agent continues searching until a more attractive and preferable cell is located.

Upon settling, the price of neighbouring cells and the utility level of the other agent's increases, decreases, or remains the same depending on the income class of the agent. For high-income agents, settling in a location increases the prices of cell and cells in its immediate neighbourhood, the utility value of the agent also increases.

It is assumed that if rich people own land in the same neighbourhood, adjoining locations tend to have high prices. For middle-income agents who settle, however, the price of the cell and its neighbouring cells remains the same but with increased utility value. Low-income agents upon settling on a location cause the price of the location and its adjacent cells to decrease, while their utility value increases (Odunuga, 2009). This suggests why a host of poor household agents settle close to each other which leads to informal or slum development.

The value of plots or land is not only depended on the physical characteristics of a building or its price, but also the built environment or neighbourhood that surrounds that building. Utility and cost are both determining factors affecting the precise location of a potential residential facility (Young, 2010). A house or a potential house owner may make a decision based on the socioeconomic make-up of the neighbourhood. Several models have been developed to show how urban segregation occurs over time concerning income, race or ethnicity amongst other factors (Feitosa, Bao Le, & Vlek, 2009). Socio-economic and socio-cultural characteristics (Table 5) of a neighbourhood have been identified as some factors that influence house owners decisions to settle in a neighbourhood.

Table 5: Neighborhood preferential type by respondents sector of employment (N=50).

	Sector of employment			
Neighbourhood type	Public/Government	Self Employed	Private	Total
Same Occupation	2	6	0	8
Same Religion	0	2	0	2
Same Tribe	3	4	2	9
Same Education	0	2	2	4
Same Income	5	16	6	27
Total	10	30	10	50

Source: Fieldwork, 2011.

Table 5 demonstrates that 27 respondents out of the 50 respondents interviewed prefer neighborhoods with similar income.

The temporal resolution of the model is on monthly time steps. Benenson and Torrens (2004) defined the temporal scale of a standard residential dynamic model to be one month. In view of this, the formula below was derived to calculate the average number of households that developed in the area.

$$tr = \frac{\text{Population}}{N_oH} * 12 \qquad \text{............ eq. 1}$$

Where: tr = temporal resolution; NoH = Number of households;

According to the 2000 Population Census Data (GSS, 2000), 51 households with 79 houses were built in Shama in a period of a month. This provides a perfect basis for adopting the temporal resolution of the model to be in monthly time steps. The model resolution is 140 x 111 torus.

Agents and environment

The Shama informal settlement growth pattern model belongs to the class of bottom-up models developed by adding features to a simple logic, as a way of ensuring that all the components of the model are included in its developmental process. The model is in two (2) major components; agents and environments (Figure 31). While agents in the model represent the components that exhibit certain behaviours and interact in their spatial environment, the environment of the model is a spatially explicit space that exhibits no behaviour nor interacts with other components.

Agents are in-dwellers of the town classified according to their income status such as high (rich), middle (medium), and low (poor) agents. Though the environment as noted earlier did not have any behaviour, its exhibits shadow behaviour of changing its status and price. Land value is static throughout the simulation process, while land price and status of the land in terms of its occupancy is dynamic. The price of land changes given the location of the land whiles the status of land changes with occupancy.

The environment of the model refers to the spatial configuration (landscape) and was divided into four groups: (1) Attractive areas; (2) Less attractive (neutrally defined) areas; (3) Risk prone areas, and (4) Restricted areas. The attractive areas represent locations in planned residential zones, and areas close to major roads and economic centres. Economic, social, and physical factors have been cited as attractive reasons for residential location. Sietchiping (2004), citing Blight and Mbande (1998) underscored favorable factors as industrial areas, market places, and transportation.

Young (2010) attributes location preferences to central business district, proximity to water pumps, and main road. Before the inclusion of the neighbourhood tolerance, the study sought to rank views of respondents relative to their location preferences as illustrated in Table 6. Ranks were undertaken on the very important responses on the Likert scale. The ranking proved planned location and proximity to major roads as the best location for residential development.

Table 6: Location preferences by respondents (N = 50).

Factor	Very important	Important	Somewhat important	Not important	Rank	Total
CBD	23	16	10	0	3	50
Local market	0	27	20	3	9	50
Planned	28	20	2	0	1	50
Main road	25	11	9	5	2	50
Footpaths	1	12	25	12	8	50
School	22	12	9	9	5	50
Clinic	20	16	9	5	4	50
Church/Mosque	2	23	20	5	7	50
Family/ Friends	16	14	13	7	6	50
Tribesmen	0	4	33	13	9	50

Source: Fieldwork, 2011.

The less attractive or neutral areas are locations that are close to rivers, whereas the risk prone areas are locations in flood zones, swamps and on slopes. Restricted areas are locations that discourage structural development.

The results of respondent’s rankings (Table 7) informed the inclusion of less attractive areas in the model.

Table 7: Local constraint to avoid in residential location (N=50).

Factors to avoid	Very important to avoid	Not important to avoid	Rank	Total
High Slopes	43	7	4	50
Floodable Areas	50	0	1	50
Swamp Areas	38	9	5	50
Riverbanks	47	3	2	50
Noisy bars	31	19	6	50
Proximity to the beach	45	5	3	50

Source: Fieldwork, 2011**.**

On a point ranking scale, respondents ranked floodable areas as the most important factor to avoid while looking for plots for residential construction.

It is important to recognise the impact of the social structure as a structural agent in charge of enacting laws and policies that regulate the access to land, sales and registration of land, and the use of both urban and stool lands. The structural agents serve as an umbrella agent that oversees the development of land into residences and as a responsibility, provide the needed social amenities or facilities to areas that develop on legal grounds. Such structural agency is the Town and Country Planning Department (TCPD).

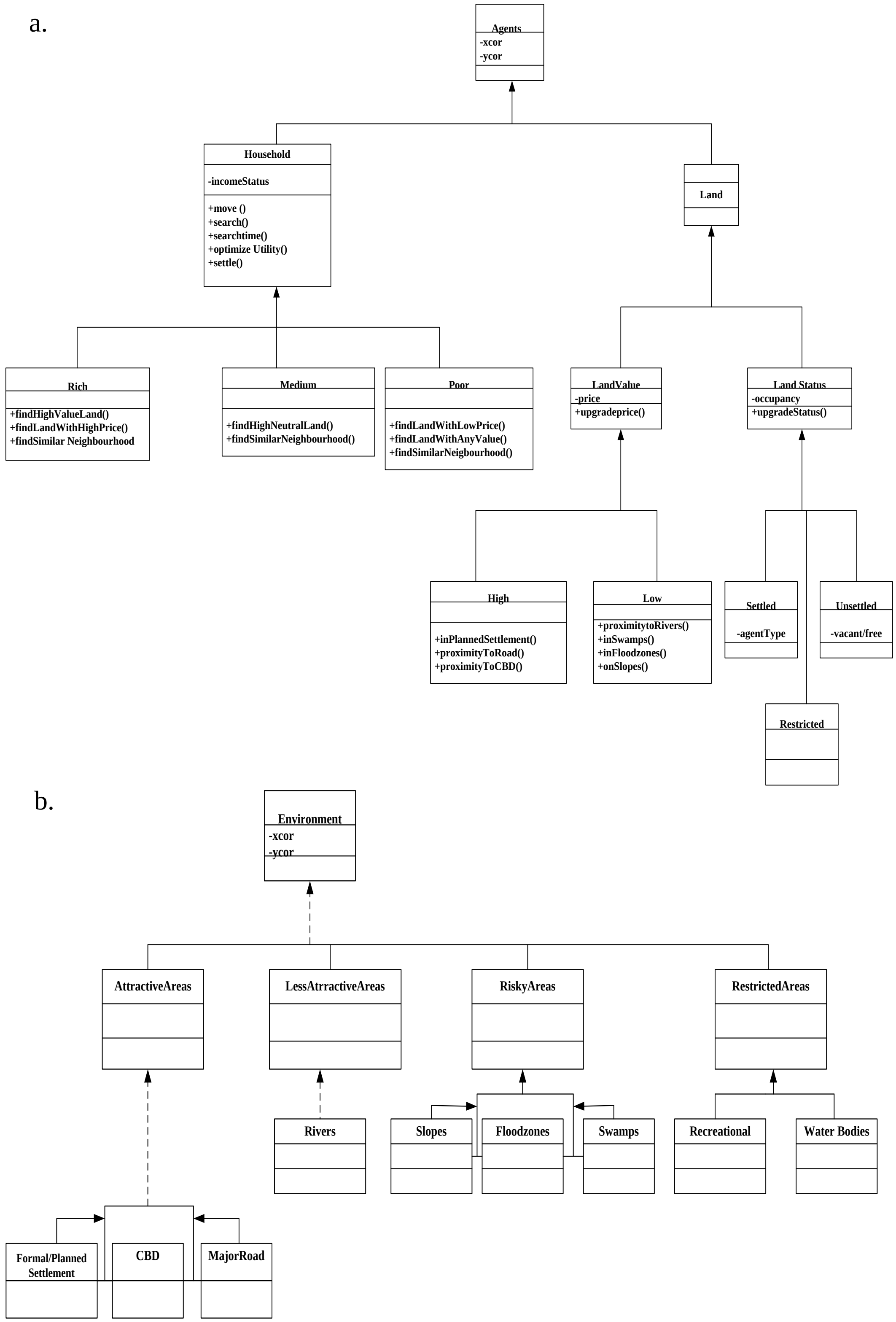

Figure 31: Criteria tree for components of the informal settlement growth pattern model (Source: Fieldwork, 2011)**.**

Model logic

The main behaviour of household agents is to move around in search for a location to settle. Prior to the simulation run, GIS extensions, globals, turtles, patches, and local variables are initialised. At setup, patches for GIS layers (roads, rivers, planned and informal settlement, flood zones, and vacant lands) are created to communicate with agents (Figure 35). Rich, medium, and poor household agents are created, settles (randomly on the model environment without recourse to cell type and cell quality), and assume rules and commands of the model. The population of household agents is determined, and controlled by sliders. At the simulation run, patch utility functions for the agents are set and updated. Household agents interactively locate each other in the process of their movements. Household agent in a bid to locate on preferable locations, searches, evicts, settle, and relocate.

To move, an agent samples a defined number of locations randomly for a location that best optimizes its satisfaction. If no cell optimizes its satisfaction, it waits until the next time step before sampling other sets of locations. The act of waiting connotes the time a household agents investigates and weighs his or her options on lands available to satisfy his or her preferences. It settles there once that cell optimizes its satisfaction; else, it continues sampling new locations until it is satisfied with the new location. The movement of an agent depends on a mechanism termed as the utility function that aids its movement. The utility (satisfaction) level of an agent and its income class influences the agents' movement.

The hedonistic utility function is operationalized to mean that a high-income agent searches for a cell with any value and price (because a rich agent could purchase and develop any land with either a high price and value, or a medium to low price land), located in a neighbourhood of agents of high-income class. With a high-income agent's ability to settle anywhere irrespective of the value and price, they have a high relocation propensity. Relocation is possible for high-income household agents because they could afford plots at different locations, and could travel several distances to the central business districts because they own a means for transportation.

A middle-income agent searches for a cell that has a relative and affordable value, and is located in a neighbourhood occupied by agents of a medium-income class, disregarding the price of such land. Low-income agent searches for a cell that has a low value, low price and is located in a neighbourhood occupied by agents of similar income class. Utility level is affected by land price. For example, if low-income agents settle in the neighbourhood of a high-income agent, land prices decreases causing a decrease in the utility level of the high-income agent. In other words, such lands deter settlers of other income groups because it cast a slur on their hedonistic utility function. The situation could differ if poor agents are located in the heart of an urban centre where prices could be relatively expensive for poor income settlers.

Slum situations in the hub of urban centres will force the other household agents of different income bracket to relocate. Thus, hypothetically, if the number of high- income agents increases in the neighbourhood, the price of land and utility levels of the high-income agent in effect increases.

The willingness to pay for the land in monetary terms is what differentiates the behaviour of agent in the quest to settle in attractive locations (Young, 2010). From earlier discussions, one could infer that the economic power of household agents determines whether an agent will stay at its present location, or relocate. This function introduces eviction rules into the model.

Agent behaviours

Rich household agent behaviour

High-income agent searches for land without recourse to land price, proximity to an economic centre or a major road. This is because a high-income agent has the economic power to afford a car for transportation, and to purchase the necessary building materials for any land irrespective of its location. However, a high-income agent will first survey the environment to avoid restricted areas and then sample available cells for a cell with a high price. If the cell has a high price, the agent will then survey if it is located in an attractive area.

If it is an attractive cell, it will gather information about the neighbourhood occupied by agents of the same income class. If the cell is in a neighbourhood of rich agents, it will then check the status of the cell occupant. If the land is empty, it settles. However, if the status of the land is settled, it checks to see who the occupant of the cell is. If the occupant of the cell is a middle or low-income agent, it evicts the agent and takes over the cell. It evicts either the medium or the poor agents by paying him or her off to assume ownership of the land. This action suggests a relocation of the rich agents. The land on which the rich agents formerly evacuated could be settled by a rich, medium, or a poor agent depending on how much it was leased, or how much the household agent obtained the land based on bargaining or ownership rights. Preferably, a rich agent has the potential to settle on the vacant land. Upon settling on the cell, the price of the cell and its adjacent cells increases. The utility level of the agent increases whiles the status of the cell is updated as settled. However, if none of these conditions is met, the high-income agent starts searching again in the next time step until it finds a location that satisfies its utility.

Medium-income household agent behaviour

Middle-income agents prefer locating close to a major road or an economic centre, but with strong regards to the price of the location. Given the willingness to move, the household agents will first survey if the preferred cell is located in a restricted area, after which it will study if cell satisfies his or her locational preferences. If the cell preferably sought for is not an attractive cell, it checks for its attractiveness. If it is not a less attractive cell, it repeats the search. Hence, if the cell is an attractive or less attractive cell, it checks the status of the cell. If the status of the cell is vacant, it settles on the cell. However, if the status of the cell or land is settled, it checks to see who the occupant of the cell is. If the occupant of the land is a low-income agent, it evicts the agent and settles in the cell. On the contrary, if a high or middle-income agent occupies the cell, the agents continue searching for another location. The eviction is based on the payment of lease or compensation to the poor-income agent who had initially settled on the land. Upon settling in the location, the price of the cell and adjacent cells remain constant, the utility level of the agent increases and the status of the land is upgraded to being settled. However, if the satisfaction level of a location is below the threshold for the agent, the middle-income agent searches again in the next time step by sampling an undefined number of locations.

In case of a relocation, which depicts dissatisfaction with present conditions of a particular location, medium-income agents could sell their land to either a medium-income or a poor-income agent. This could help change their class from medium-income to rich agent. In reality, not-with-standing, some rich agents would purchase lands, develop it for personal use or rent it out to a medium or poor income agent.

Behaviour of a poor-income household agent

From the previous household behavioural accounts, the low-income was characterised by constant evictions, which indirectly increases his or her economic means to also relocate and settle on a more preferred land. This suggests that the poor-income agents' class could change over from the sale of land to either a medium-income or a rich agent. A poor-income agent considers proximity to the central business districts, major roads as preferential locational factors, with little consideration to quality of land. This is because with low-income earnings, poor-income agents cannot afford a means of transportation, hence the nearness to such locations of interest. A low-income agent first checks if the cell is not a restricted cell, and if the price of the cell is low. If the price of the cell is low, it does not matter if the land (cell) is in an attractive, less attractive or a risky cell. It then checks if the cell is in a neighbourhood occupied by agents of the same income class. If the cell is in a similar neighbourhood, the agent then checks the status of the cell. If the status of the land is settled, it searches for other locations but if the status of the cell is vacant, it settles on the cell. On settling on the cell, the price of the cell and adjacent cells decreases, the utility level of the agent increases and the status of the cell is upgraded to being settled.

However, the situation could differ if poor agents are located in the heart of an urban centre where prices relatively could be higher. Notwithstanding, if all these conditions are not met, the low-income agent searches again in the next time step by randomly sampling the defined number of locations. A poor-income agent who is settled on a cell (land) located within the neighbourhood of a rich or medium-income agents with the willingness to relocate could sell his or her plot to a rich or medium-income agent. The willingness to sell the land comes with the willingness to move and relocate, and the dissatisfaction that arises from being settled in the neighbourhood of rich or medium-income agents. Such dissatisfactions could arise from the payment of exorbitant land bills or landownership rents. Notably, some agents could be renter agent. A renter agent is a household agent who occupies a land without making the necessary arrangement for permanent ownership of the land. He or she settles on the land, pays his or her rent of occupancy, and relocates to a new place based on the deadline of the rent agreements.

When the utility level of the agents' decreases to a certain threshold value signifying his or her dissatisfaction with the present's location, the agent vacates its present location and searches for a new location to settle. When an agent of the same income group settles in a land adjacent agent A, it increases the utility value of the agent A.

Shama settlement growth pattern model structure

This segment describes the components of the model in three bodily structures: (1) Physical and environmental; (2) Spatial constraint; and (3) Economic structures. The components of these three outlined structures are shown in Figures 32 and 33 respectively. The first structure focuses on the environmental and physical structures of the city; structure two consists of the environmental and physical structures supplemented with the spatial constraints in the city, and the third structure merges the second structure with the economic components of the urban system.

Structure one: physical and environmental

The model is a spatially explicit model that makes use of a GIS map (with 50m * 50m spatial resolution) as the modelling environment in the simulation. The landscape of the study area constitutes the physical and environment structure, with planned residential and informal settlements, the economic centres, major roads, rivers, and flood zone as its major component.

Physical and environmental factors influence residential locational decision making of the agents and shape the spatial growth pattern of informal settlements in the study area. Figure 32 shows how the value and price of each location in the study area is calculated at the pre-step stages of the model.

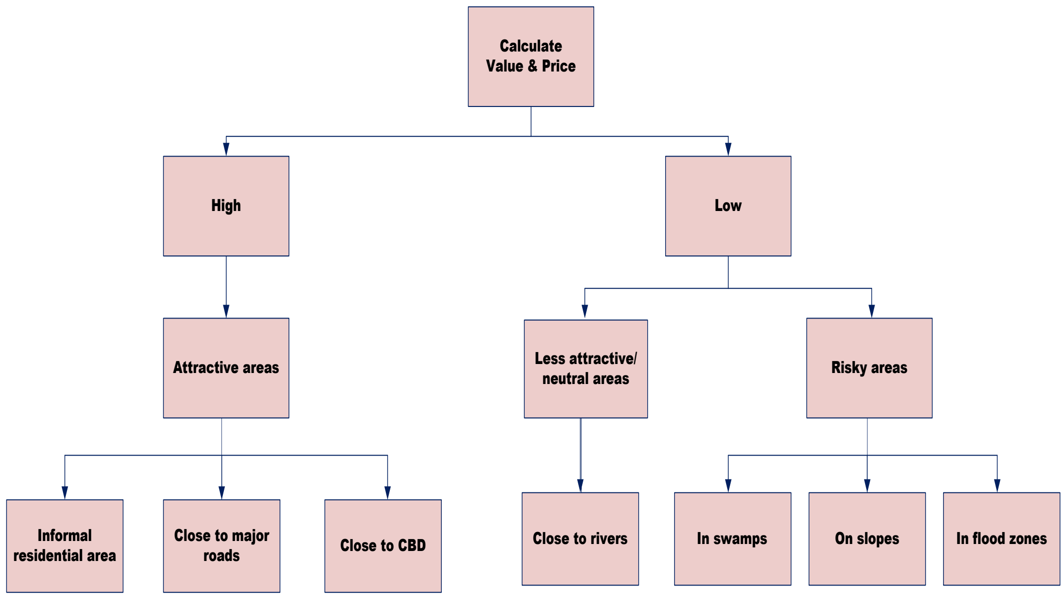

Figure 32: Physical and environmental module (Source: Fieldwork, 2011)**.**

Cells located in planned residential areas, close to the economic centres, and close to major roads attract household agents. Agents in search of a location to settle will first survey its environment for cells located in these three areas. If no suitable location satisfies their utility, they will survey for less attractive cells that are close to attractive areas. This structure was implemented at the pre-step of the simulation in ArcGIS, before being imported into NetLogo as the modeling environment.

Structure two: spatial constraints

Spatial constraints refers to urban features that discourage urbanization or growth in the city (Table 7).

This structure seeks to examine the effects of urban spatial constraints (including general water bodies) on the spatial growth pattern of informal settlements. Agents avoid restricted areas defined in the model as no data layers.

According to Young (2010), paid wage earners would like to avoid practically all biophysical and physical constraints such as flood area, high slope, swamp, riverbank and noisy environment (bars, churches and factories). This is a clear indication that although land with low development capacity is not the first choice for most residents, they are willing to settle there for as long as the land is unlikely to flood.

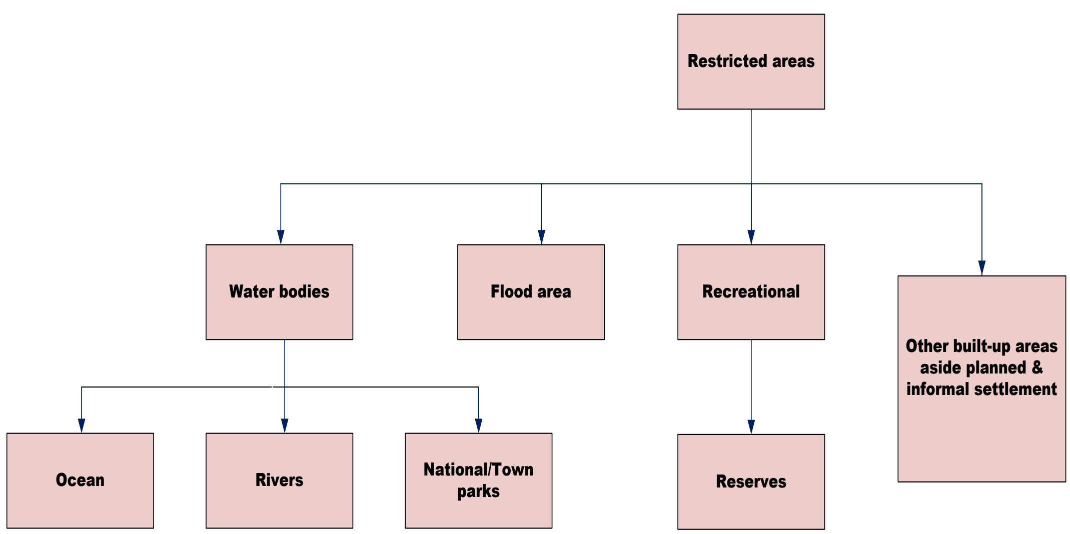

Figure 33: Spatial constraints module (Source: Fieldwork, 2011)**.**

The spatial constraints module is developed by introducing spatial constraints into the physical and environment stucture.

Structure three: economic

The economic structure is a build up of the spatial constraint structure with the objective of examining the effects of physical and environmental factors on the locational decision making of residents. Physical factors such as proximity to amenities, upgrading and land quality will have individual impacts on other factors such as residents' utility and land price, which inturn affects affordability. The locational decision making however is a function of their economic power (income). This structure also simulates the decisions that govern people's potentials and criteria for relocation.

With competition for land in Shama, residents decision to settle on land is defined by the value, price and the status of the land that optimizes their satisfaction. The conceptual framework of the study which summarise the aforemention parameters is presented in Figure 34.

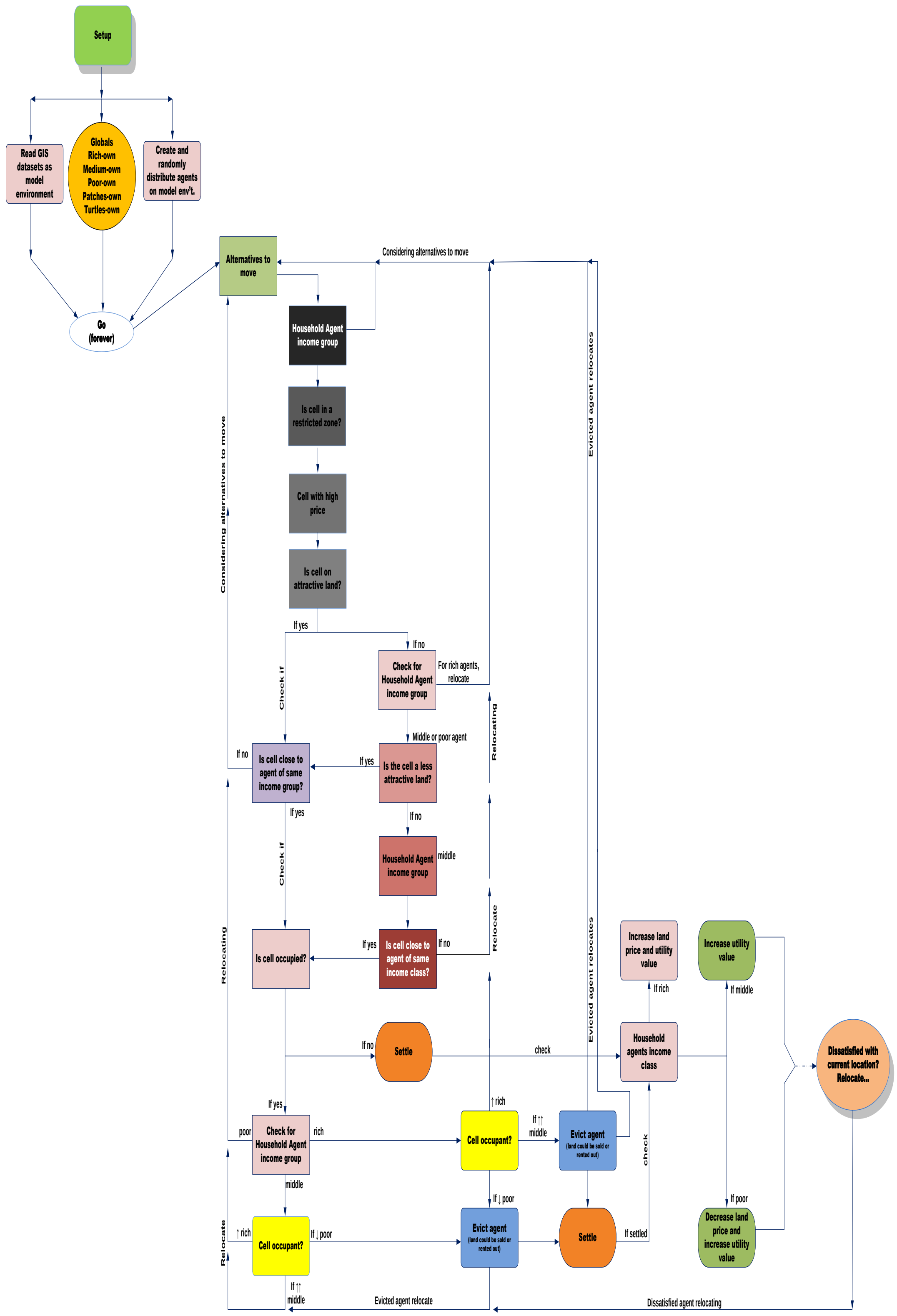

Figure 34: Shama informal settlement growth model (Adapted from Odunuga, 2009)**.**

Model implementation and interpretation for year 2005

The agent-based modelling software, NetLogo was adopted to handle different agent behaviours, attribute and interaction with the spatial environment. Data layers for importation into NetLogo and for creating the residential suitability maps were prepared in ArcGIS. The software allows importing and exporting both vector (ESRI Shapefiles) and raster (Ascii files) data formats. This data is used for defining the model environment and facilitates the development of a spatial model (Figure 35).

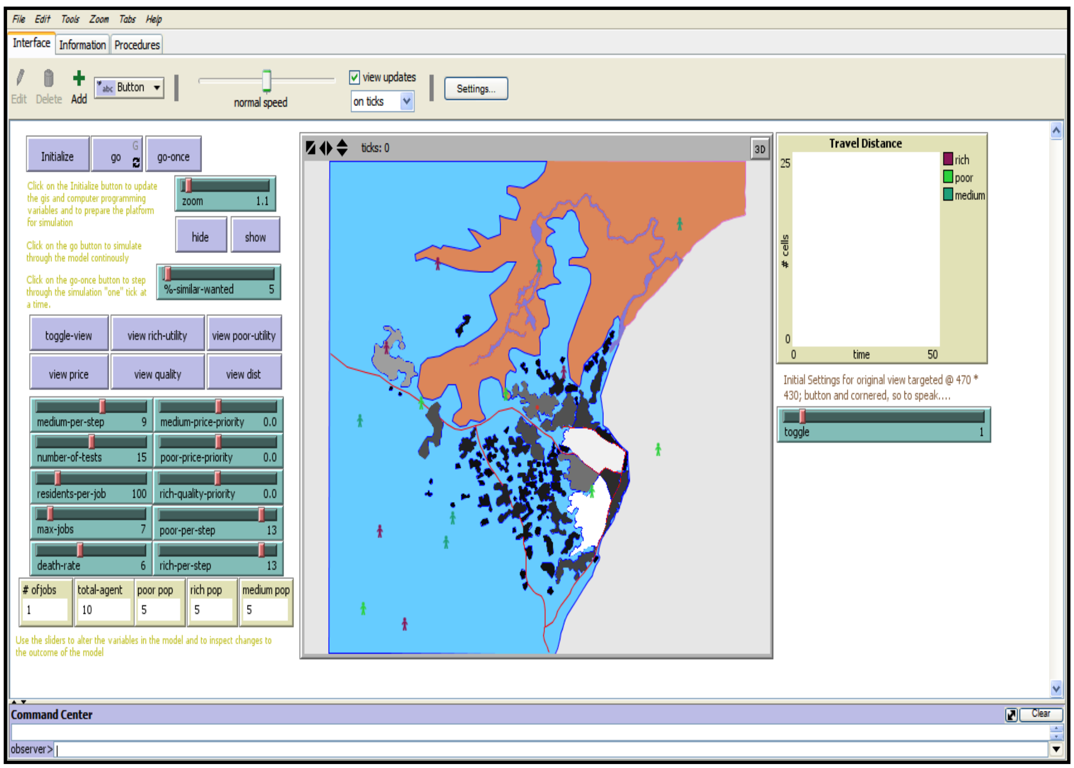

Figure 35: Initial SISGM Environment (Source: Fieldwork, 2011)**.**

Evaluating ABM models

Model evaluation commonly refered to as model verification or validation includes both comparisons of the model outputs with the real world system, and understanding the sensitivity of the model to its internal parameters (Turner, Gardner & O'Neill, 2001).

Verification means building the system correctly, and validation connotes building a correct or most appropriate system (Parker, Manson, Janssen, Hoffmann, & Deadman, 2003).

Verification and calibration approaches

Three checks were performed to ascertain the validity and constructiveness of the computer codes. First, the programmer conducts thorough checks to reveal mistakes (a 'bug') or unwanted errors within the model (Gilbert & Terna, 2000; Crooks, 2007). The second is the subject matter experts (SME) approach aimed at obtaining a better-than-normal expertise or insights into agent based modeling to enable the model concept and computer coding undergo proper scrutiny, corrections, and directions. Comments, and recommendations that resulted from the SME approach was incorporated into the modeling process before the final run of the model.

The third procedure was a verification and calibration approach. This was carried out by defining sets of parameters best explained by the expected outcome of running the model. This procedure tested by expertise reveals that inputs parameters of the model be changed to ascertain their impact or effect on the model behavior.

By way of assessing the performance and behavior of the model, the following hypothesis were developed and tested:

1. The number of sampled lots by agents affect how long an agent locate a new plot to settle;

2. The probability of agents of the same class settling in an area is dependent on how long the agent takes to locate a plot; and

3. The spatial growth pattern of informal settlements (empirical or observed) found in the study area is consistent with pattern captured in the model.

Model verification

Model assessment between total number of sampled areas and agent movement in year 2005.

The total number of sampled areas refers to the total number of locations sampled by each agent at each time step (tick). The total number of sampled areas influenced the degree of fragmentation of spatial patterns formed. In other words, the larger the search area the more fragmented the informal settlements will become. This parameter was tested to see its impact on the general behavior of the model and the resultant spatial pattern formed. In testing the outcome of this parameter, six alterations representing six years (representing 72 ticks) was used as the basis of model analysis.

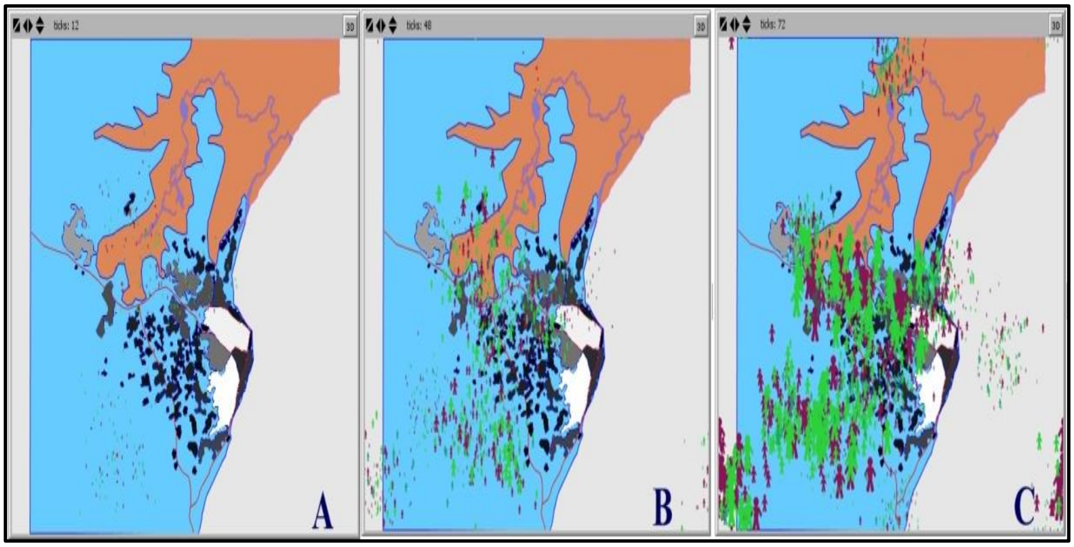

Figure 36: Output of SISGM for year 2005 (Inset A: Iteration One (12 Ticks), iteration two (48 Ticks), Inset Three (72 ticks) (Source: Fieldwork, 2011)**).**

The output of simulation run in Figure 36 depicts that the longer the model is allowed to run, the more fragmented the output would be. The fragmentation informs the pattern of growth. The model slows down when run with many agents, and when a household agent is allowed to sample higher number of locations.

Model assessment between neighborhood density and agent movement

Neighborhood density refers to the total number of similar agents located in the neighbour of a patch (environment). The threshold for neighborhood density was observed to determine the maximum density of agents of similar income accepted by an agent before it settling in a location.

This observation was done by defining different tolerance level for agents of each income group, the calculation for the density is shown below:

Satisfied = Similar-agents >= (%-Tolerance * Total-agents / 100)

Where:

Satisfied = satisfactory level for an agent to settle,

Similar agents = agents of the same income group located on the neighbour of the patch,

Tolerance = 0 – 100, number of agents of different income classes tolerated in the neighborhood,

Total agents = total number of agents located in the neighborhood.

Six (6) iterations (12, 24, 36, 48, 60, and 72 ticks) carried out assisted in ascertaining the neighbourhood density level of the model. At the end of the simulation run, 1283 agents were created; 528 rich agents, 227 medium agents and 528 poor agent. At each time step, a total of 11 agents were introduced into the model, with the number of sampled locations put at 15 and at a 5 percent neighbourhood tolerance level.

The simulation time for each run is 12 ticks, representing a year. A graph representing the general performance of each agent to the model, and their neighbourhood density checks is provided in Figure 37b.

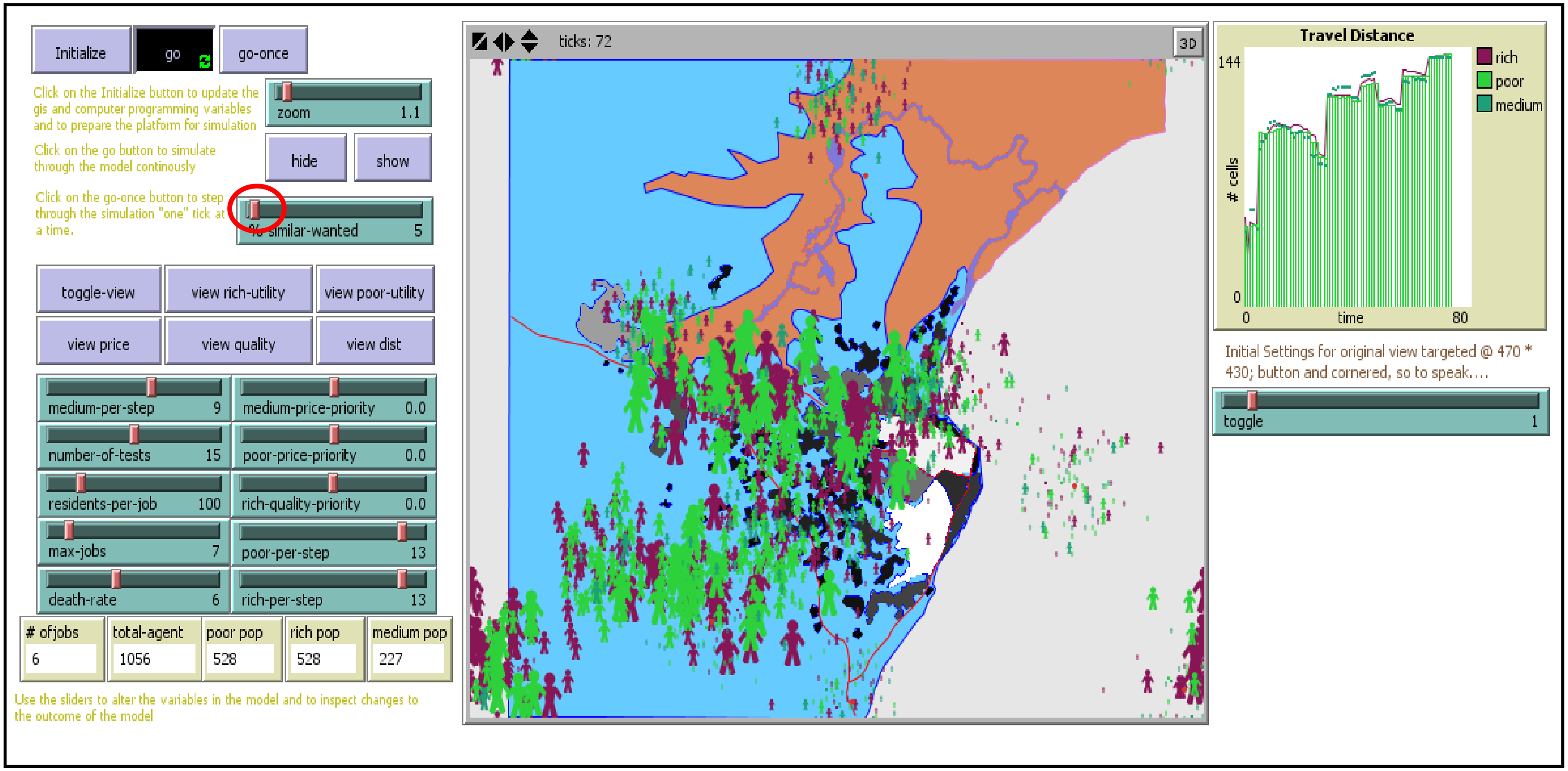

Figure 37a: Agent neighbourhood density and tolerance experiment (Source: Fieldwork, 2011).

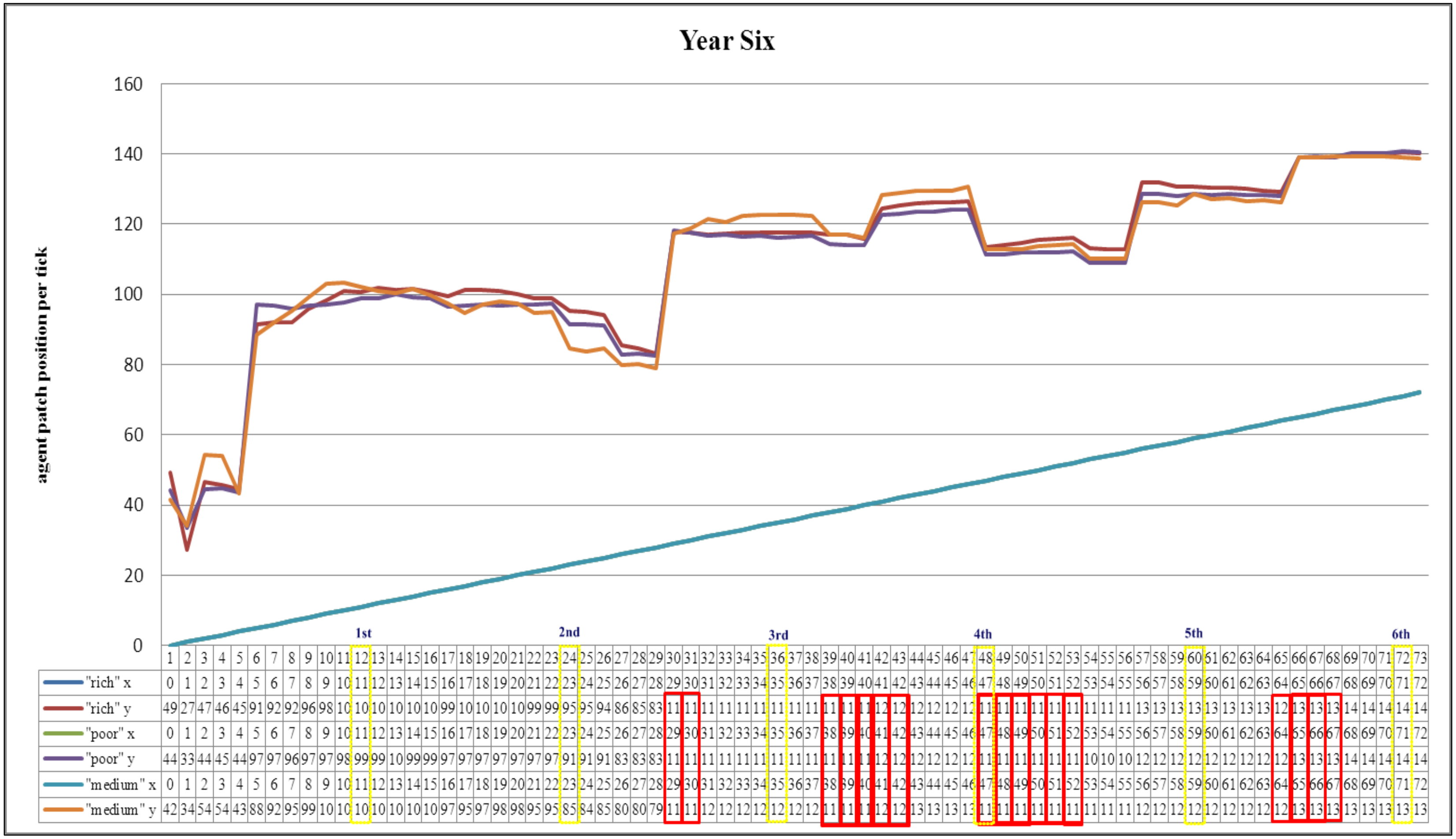

Figure 37b: Composite model iteration graph for year 2005 (Source: Fieldwork, 2011)**.**

Figure 37a depicts the tolerance level of the model used for the entire simulation. In a behind the scene test runs, it was revealed that the lesser the percentage of similar agents tolerated by an agent on its neighborhood, the faster it gets to settle in a location.

However, there exist no significant difference in the number of movements made by agents before settling under any neighborhood tolerance level. Nonetheless, a greater tolerance level will extend the simulation run.

Figure 37b presents a composite graph output of the final simulation run (year six) with yellow strips representing the iteration times and red strips representing the neighbourhood density levels of agents. The distribution of red strips in the third, fourth, fifth, and final iterations suggest the proximate locations of agent of similar characteristics. It also confirms that the longer the model is allowed to run (highlighted under 4th, 5th, and 6th iterations), the more evident the neighbourhood tolerance level of agent are represented. Another interesting phenonenon is the location of dissimilar agent on neighbourhood of patches. However, Figure 37b further suggests the overriding power of rich agent under their utility level functions.

The probability of agents of the same class settling in an area (satisfaction) is dependent on how long the agents takes to locate a plot.

In recognising that agents are introduced, relocated, and die off the model, the first and last iterations suggests the location of similar or dissimilar agents on a patch.

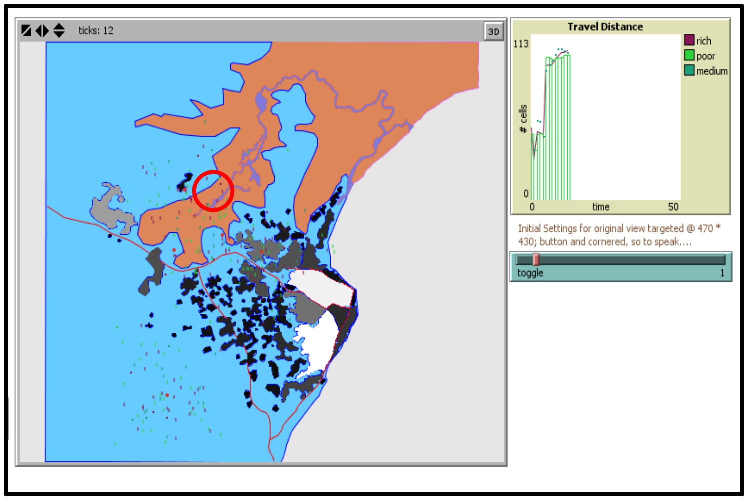

Figure 38a: Agents neighbourhood satisfaction from first iteration (12 ticks) (Source: Fieldwork, 2011)**.**

From Figure 38a representing the first iteration, poor agents (enclosed in the red ring) seemingly settle proximate to each other. This however is the first iteration and as such little could be said of the probability of similar agent settling on proximate cells.

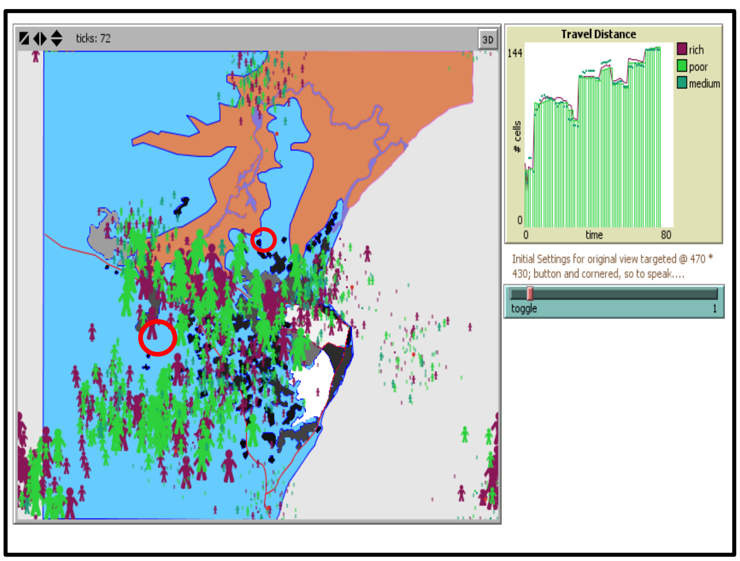

Figure 38b: Agents neighbourhood satisfaction from last iteration (72 ticks) (Source: Fieldwork, 2011)**.**

However, in the final iteration (Figure 38b), the probability of similar agents settling together on proximate cells or locations is more appreciated. The rings in the model output suggest the settlement of rich and poor agents in locations proximate to each other.

The Figures 37b, 38a, and 38b respectively confirms the hypothesis that the longer it takes an agent to locate a plot or the longer it takes the model to run, the higher the probability of settling close to agents of similar characteristics. Satisfaction of agents is achieved when the model is allowed to run for a series of iterations.

Calibration of the 2005 informal settlement growth pattern model

Research makes available different types and methods for model calibrations. Amongs them includes history-friendly approach (which uses empirical data to establish initial parameters and conditions), the indirect calibration approach (uses a combination of facts and empirical data to model), and empirical modeling approaches which uses facts, empirical data and inference procedure to calibrate and verify a model (Fagiolo, Moneta, & Windrum, 2005; Garcia, Rummel, & Hauser, 2007).

The study utilizes both empirical and history-friendly approaches. The history-friendly approach was employed to attempt matching the growth pattern of informal settlements identified in the study area with the model output. This exercise was undertaken in direct linkage with the hypothesis developed earlier in this chapter.

Comparison of observed (reality) growth pattern verses interpolated (model) patterns in 2005.

It is clear that models are mainly meant to represent complex reality, and their inherent characteristics is highly tied to uncertainty. In comparing growth patterns of the 2005 empirical data to the model outputs of the same year, two (2) patterns; road influenced or linear development and spontenous development as postulated by Camagni et al. (2002) were consistent in the simulation output (Figure 39a and Figure 39b). nonetheless, the comparison has revealed some similarities in the trend of spatial development.

The fourth objective of this study was to ascertain the growth pattern of structures in space as described by Camagni et al. (2002). Two of the growth patterns postulated by Camagni et al. (2002) has been consistent in the output. Road influenced or linear development and spontaneous patterns of development were identified.

The inverted rectangular shape highlighted in Figure 39a illustrates a road influenced or linear development pattern of growth.

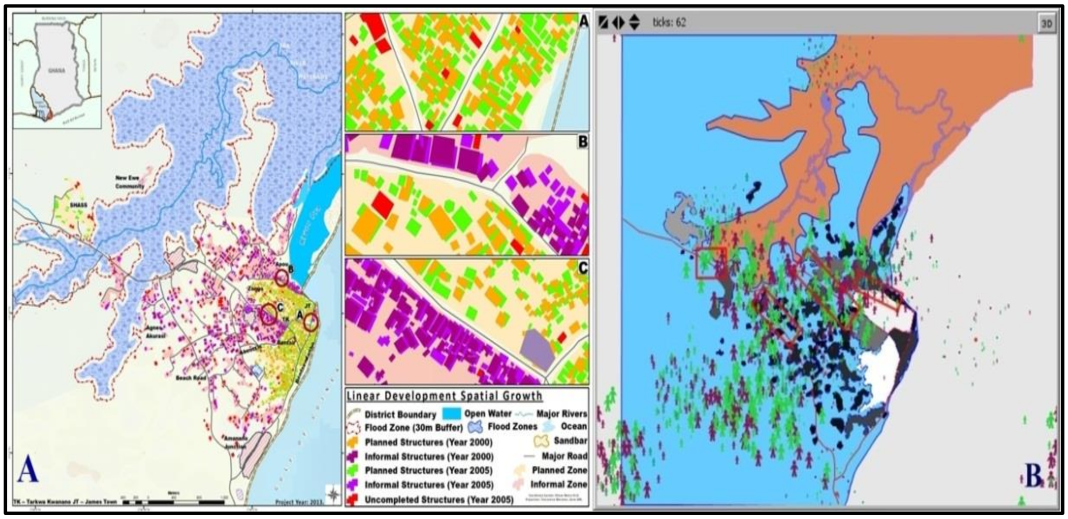

Figure 39a: Linear or road influenced development output comparison in the year 2005 (Inset A: Empirical/Observed Linear Growth; Inset B: Modelled Linear Growth) (Source: Fieldwork, 2011)**.**

The highlighted regions in Figure 39b illustrates spontaneous pattern of development. This output could be described as outward spread development pattern by other researchers.

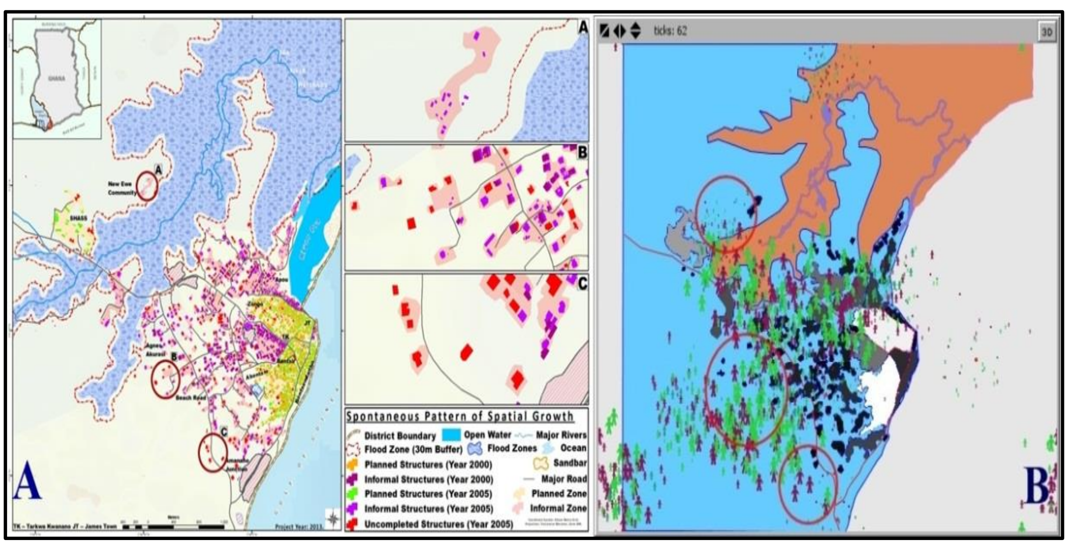

Figure 39b: Spontaneous growth pattern output comparison in the year 2005 (Inset A: Empirical Spontaneous Growth; B: Modelled Spontaneous Growth) (Source: Fieldwork, 2011)**.**

Similarities or otherwise of growth patterns between model output and empirical data.

The discussion in the previous section provides a more clarified assessment on the findings of the study. Empirically, the three most leading patterns of development were the linear or road influenced, outward spread, and spontaneous patterns of development. The model outcome suggests two of these empirical findings; linear and spontaneous development patterns (Figure 39a and Figure 39b).

Anomalies in model iterations

The model environment does not include undefined boundaries outside the area of interest. However, at some point in the simulation, growth or development sprung on such undefined zones. For example, areas highlighted in red rings from Figure 40 depicts spatial development taking place in the ocean.

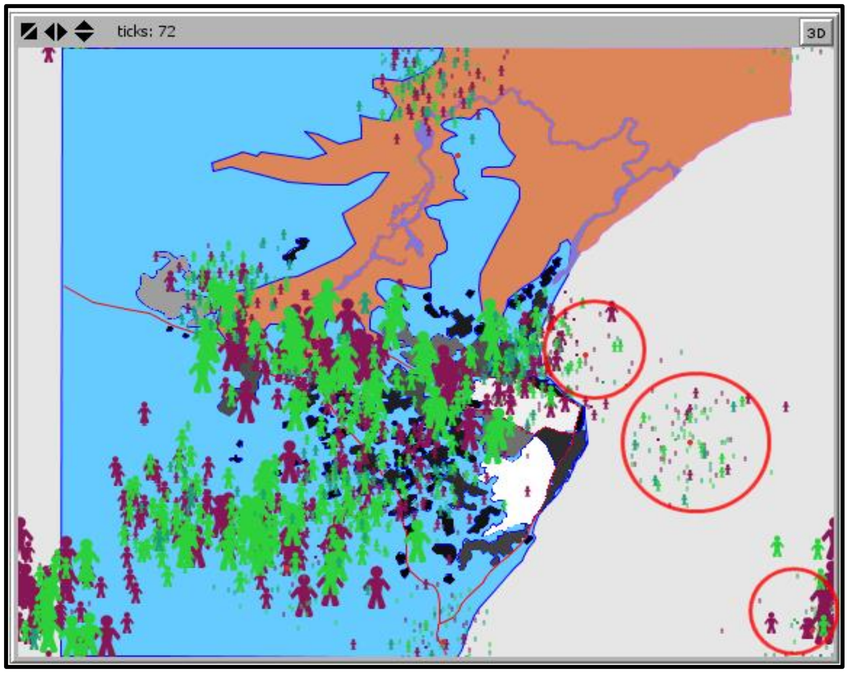

Figure 40: Model output anomalies (Source: Fieldwork, 2011)**.**

Unintended model outcomes.

Other untargeted outcomes were identified during and after the final simulation run. For instance, though behaviours were independently defined for all levels of income agents, their quest to settle in space was without recourse to the location of a plot or who the class of their neigbours were. In classical cases, informal structures located on unapproved lands is characterised by structures of rich, middle, and the poor income agents. In another instance, floodable areas defined in the model were occupied at the end of simulation by agent irrespective of their income groupings. Relatedly, vacant lands were being utilized for land development at the expense of planned zones.

In this respect, a working spatial plan needs to be developed and enforced to bring sanity into how structures are placed or located, and what structures to place where (in relation to space). This will act as a key instrument investors and individuals could adhere to in the quest for spatial development.

Implication of proposed model for actual urban planning process

The proposed model, in this research, can inform the actual planning practice in its endeavor to create a more efficient city amid rapid urbanization. It provides information on the key driving forces of informal structural expansion and densification. In line with it, future probable areas of informal settlement expansion can be detected. Such models are recommended for spatial decision making process and policy development in urban planning and to detect future informal structural expansion zones (Sietchiping, 2005).

The proposed model unfolds significant driving forces for settlement expansion that differs considerably from what development, economic, and physical planners consider in their planning process, and the interventions that comes with it. In essence, this will help planning authorities prioritize, and devise ways to treat various issues concerning each phenomenon and the areas which needs timely intervention. It will help authorities to be decisive on land and space utilization, and need for buffer zones or setback zones to restrict unwanted development. Additional potential is the management of informalization of the system. It provides the need for rezoning of already settled parcels to incorporate existing uses, and better define the path for a well-defined land use to improve living conditions of the people. The model also binds authorities to consider organizing community dialogue sessions to incorporate citizenry concerns into the planning process, and to provide grounded public education on the building regulations to prohibit the development of floodable areas.

Notwithstanding all the challenges in conceiving, designing and implementation of residential growth models, Sietchiping (2005) argues it is dynamic modeling and simulation approach that would bear better informed policies and facilitate the decision support process.

Summary

This chapter provided the analysis to a preliminary study (driving forces for spatial growth) which provided the basis for the development of the conceptual and simulation models respectively. A detailed discussion of the simulation results proceeded given a series of iterations by way of model calibration, verification, and validation. Spontaneous growth and linear development were identified in the model output as consistent with empirically observed data.

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

This study investigated the key driving forces of spatial growth with its resultant patterns of growth, and attempt to model the observed patterns of growth using an agent-based modeling approach in Shama, Ghana. This chapter presents the summary, conclusions, and recommendations of the study.

Summary

Main findings

1. **To identify the driving forces that influences location decision-making of household agent and the spatial growth of settlements in Shama.**

Micro level behavior pertaining to housing construction was analyzed mainly using qualitative and quantitative data attained from a preliminary household survey. The main elements covered under this research objective were socio-economic triggers of housing construction, factors that contribute to location decision-making, biophysical constraints which negatively affect location choice, and the preferred socioeconomic structure of neighborhoods. The main trigger of housing construction according to 58 percent of respondents was to accommodate the family. Relative to sources of funding for building constructing, 69 percent of respondents indicated they self-financed their buildings construction.

Major factors that attract households to particular locations were established to be the proximity to planned locations (and available social amenities and utilities), the central business districts, school, main road, and proximity to a medical centre (clinic). Preferential factors for building location include security, non-floodable zones, and distance to the market. Avoidance areas (known as constraints) in location decision-making were flood-prone areas (ranked in the highest order as a very important area to avoid), riverbanks, proximity to the beach, high slopes, noisy bars and swamp areas. The main characteristics of neighborhoods that respondents found attractive were neighborhoods with similar income (54 percent), and to a lesser extent similar type of occupation, education, religion. In relation to the cause of flooding, unplanned settlement structures (76 percent) were identified as the major cause with little regards to the topography of the land. Despite respondent's experiences on flooding, some highlighted the issue of expensive land prices and current unfavorable economic positions as reasons for their inability to relocate. Others had no choice of relocating away from those floodable zones.

2. **To describe the spatial growth pattern of settlements on areas liable to flooding in different areas of Shama.**

The 2005 spatial pattern of informal settlements simulated reveals interesting points particularly in relation to growth of settlement on areas liable to flooding. Road influenced development, infilling and outward spread and linear development growth patterns were adequately captured as part of the aerial photo interpretation. Spontaneous settlements were found to be the major settlement pattern, elongated unto areas liable to flooding. Spontaneous development patterns along communities located to the North of Shama Senior High School (SHASS), around ICES and the model school, and beach road new site communities superimposed with the 30metre buffer of the flood zone in the study area evidently revealed structures located within a hazardous floodable zone.

The outcome of the preliminary household data collection provides an understanding from a socio-economic point of view the driving forces necessitating spatial development. This included the present expensive cost of land ownership in the area possibly due to the inception of the oil industry, current unfavorable economic conditions, lack of options to move despite their current experiences of flooding and the need to relocate. The observed spontaneous development has elongated unto floodable zones of Shama with the potential of causing destructive impact during the rainfall seasons.

This led to the development of a proposed residential suitability map designed with the aid of SMCE model. The map displays potential site for residential development in a color ramp ranging from one (1) and zero (0) aimed at influencing spatial planning and decision-making in Shama. It is envisioned that this suitability map could assist authorities to know where to place what relative to space, and to properly plan the limited space engulfed by sudden pressure.

3. To ascertain the interoperability of GIS and NetLogo platform.

Current release versions of NetLogo has GIS extensions to enable model builders import GIS datasets (shapefiles and raster’s) as model environment, and export model output in GIS raster format to aid analysis and output discussions.

Despite the challenges this extension has on beginners of NetLogo, it is a current development worthy of commendation, and requires thorough practice and skills to favor its adoption and use.

4. **To develop a conceptual model incorporated with the driving forces of spatial growth patterns of settlements and locational behavior of agents of three income groups.**

To achieve the major objective of developing an agent based modeling to simulate the spatial growth pattern of informal settlement; the study considered approaches aimed at identifying driving forces influencing spatial growth of settlement. The explored driving forces for spatial development informed the development of the conceptual model and the resultant SISGM. Conclusions and findings drawn from the simulation run are presented below.

The research confirms the possibility to create a spatially explicit settlement growth model using modern techniques within the agent based modeling framework. Time constraints coupled with data unavailability hindered the inclusion of all driving forces (obtained on the field) into the model for implementation in NetLogo. Though this might seem negative, it could be seen as a basic streamline for the models adaptation and use by other growing and emerging cities in developing countries. In support of this, it is envisioned, that the model provides optimism for modeling within a larger spatial context.

According to Macal and North (2006) it is typical for successful projects to begin small using one or more of the desktop agent based modeling and simulation (ABMS) tools for it to grow into the large-scale ABMS toolkits in stages.

Notwithstanding, it is relevant to consider the inclusion of other driving forces (discussed in the next session) in helping to move the model closer to reality.

The provision of global parameters allows any user to visualize physical and spatial results of modeling and to explore the outcomes of the model under different conditions and parameters. In this context, the model serves mainly as a visualization and explorative tool.

The simulation results revealed that the model runs faster when few similar agents are tolerated in the agents' neighborhood. The model output revealed that the longer the model is left to run, the denser it is for agents of the same characteristics to settle in the same locality (proving the satisfaction of agent). Major patterns observed in the model output and consistent with empirical data are the spontaneous and linear or road influenced spatial development patterns inspired by the classification of settlement patterns according to Camagni et al. (2002). Other unintended revelations of the model displayed agents settling on floodable areas irrespective of their income class. Other agents as well settled outside the planned zones of the model environment confirming the expensive lots prices within the planned settlement zones.

Model relevance and utilization

The resultant computer model of this research has been able to contribute to the understanding of spatial growth patterns dynamics, the factors, and decision-making processes, which influence these growth related patterns. In another development, agent-based simulation proved to be a suitable technique to explore urbanization issues at the conceptual level, and allowed spatial patterns, dynamics, and social issues to be handled within the same conceptual and modeling framework.

This computer model demonstrates a spatial planning support tool. Various scenarios could be built if empirical data in the form of census data are included in the model to predict spatial growth. Several explorations of varying simulation outcomes could be achieved by adjusting the global parameters of the model. This feature may allow decision makers to test the effects of either potential policies targeted at rural or urban residents or potential spatial planning instruments within the urban environment. For example, with the assistance of the proposed residential suitability map, physical planning officers could exercise restraints when granting permits to investors or individual developers on lands located within unsuitable zones (areas liable to flooding). Moreover, the model contributes to a clearer argument and a more transparent decision process, which helps in establishing far-reaching investment decisions. With the unfolding driving forces causing spatial development, and the observed and modeled pattern of spatial growth, planning authorities and decision makers could devise ways of regulating the use of geographic space to conform to existing planning schemes and land use plans. Planning authorities and decision makers will learn to also project their plans and schemes to include the driving forces of house owners and potential landowners. The model also presents the visualization effects of developing or improving infrastructure in the settlement being modeled.

To date and likely in the future, the proliferation of settlement on areas liable to flooding has not been given the necessary facelift it deserves due to a legal abstraction and administrative barriers to land development. Thus, many people responsible do not see any need for action concerning informal settlement proliferation on areas with poor soil percolating properties. By this means, SISGM plays an important role by calling attention to the topic and sensitizing public and public partnered representatives to the already existing need for action. This also concerns the domain of upcoming land market, land use conflicts and uncoordinated actors including current influx of industrial, agricultural, and residential development needs on the break of the oil find along the coast of the Western region of Ghana. Being prepared for such trends could provide a crucial competitive advantage. Furthermore, the project results give rise to future research targeted at modeling informal settlement growth and spatial planning. Notwithstanding all the challenges in conceiving, designing and implementation of settlement growth models, Sietchiping (2005) argues it is dynamic modelling and simulation approach that would bear better-informed policies and facilitate the decision support process.

Conclusions

With a manifested settlement expansion notably on areas liable to flooding, this research sought to identify the driving forces of spatial growth, and to simulate spatial growth patterns. The study uncovered that the major factors for household location preferences included the proximity to planned settlement areas and the central business district. Non-preferred zones for development largely were floodable zones. In another account, household’s reason to construct a residential structure was to accommodate his or her family. Spontaneous settlement development patterns were the major characteristics of growth patterns. A residential suitability map was developed to inform future development granted that about 70 structures were found to be located within the 30m buffer zone off the water-course sanctioned for development by the legislative instrument (LI) 30. The major objective of developing an agent-based model to simulate the spatial growth of informal settlements in Shama was linked with the achievement of other specific objectives, which informed the development of the model's conceptual framework and the development of GIS data layers for importation into NetLogo. At the initial modeling development phase, an ensuing procedural step of verification, calibration, and validation (of the conceptual model and the computer-based model) took place. Model output such as spontaneous development patterns was found to be consistent with empirical data.

Recommendations

A number of options for future work emerged. Additional empirical data is needed to improve the current model, particularly during its development and validation stages. The following data and accompanying discussions were found to be important in this process:

- Land agent: Understanding further the impact of intermediaries (land agents) in the acquisition and sales of land will help in better defining the final agents' behaviour and decision making in the model;
- Data on land price: Availability of data on land price will help in deriving an understandable driving force for agents' behaviour;

- Spatial distribution of income groups: The implementation of the model with the actual spatial income distribution of the city's inhabitants will have substantial impacts on making the model more realistic and more spatially explicit and distributed. This could also lead to the inclusion of the neighbourhood tolerance parameter in the model, because in reality segregation patterns based on income differentiation exist in most cities particularly in developing countries.

  The spatial income data could serve as a validation tool for the spatial pattern of each income groups as captured by the model:

1. Data on the topography of the study area: Accurate digital elevation models of the area out of which slope data could be derived was unavailable for incorporation into the model. Slope data should be included in the future development of the model as it serves as an equally important factor for land development by way of residential development;
2. Detailed and updated land use map of the study area: This will provide an adequate and useful analysis of the current influences of urban components leading to the growth of informal settlement and a comparative basis for future modelling outcomes;
3. Census data on income distribution and annual population growth should be incorporated in the model; and
4. Special codes written to prevent agent movement on obstructive cells (along the ocean and outside the models area of interest).

The model concept does not consider the mortality rate of the population. This variable is absent mainly due to the unavailable data from the Birth and Death

Department of the District, as well as the Population and Demographic data. Mortality rate can be incorporated by specifying its stochastic effect on the model. For example, if the rate is 2.9 percent, then there is a 0.0029 probability that a household member will die off at each time step. A slider to determine the mortality rate could be defined and incorporated.

Furthermore, the concept of natural or anthropogenic disaster occurrences such as flooding was not incorporated into the model. Though it was revealed in the driving forces as one of the major factors, the rationale for its exclusion is the lack of data on the rate of disaster occurrences. The CBD of the study area was not modeled as a factor both in calculating utility and as determinants for agents' behavior and rules within the model build up because there are different CBD located in different localities within the study area. Considered as one of the major forces for housing development within existing literature, the CBD must be considered an attractive factor for agent utility calculation. Other factor obtained on the field but not considered includes proximity to schools, clinics, family, and friends. Future expansion of the model should incorporate these factors to observe the behavior of the model over time.

In view of the models relevance to planning, it is recommended that bye-laws be developed by the district planning authorities (development and physical planners, works engineers,) to protect land utilization and to restrict development on floodable areas. Once developed, there should be community dialogues sessions organized to better educate the citizenry on these bye-laws, and many other existing regulations that bind spatial development. It is relevant to consider the bottom-up approach to planning where citizenries (land owners and local community) are considered as major stakeholders in the planning process, with their views and inputs well integrated in the planning process thenceforward.

Summary

The quest for an increased understanding of urban spatial phenomena in cities of the Third World is essential in order to provide a basis for future planning (spatial, development, and economic) actions and policies. The approach outlined in this study has taken a step in this direction, bringing a new perspective to an old debilitating problem. This study provides evidence that urban modeling tools can provide an appropriate basis for research in Sub-Saharan Africa’s urban processes and dynamics, and in effect makes clear the need to approach the problem by relating individual decision-making exploits for which emergent dynamic results are evident through urban modeling.

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Appendices
Appendix 1: Questionnaire Instrument.

The following questions are targeted at obtaining information on respondent's location decision behaviour and best alternatives for obtaining land for development. Your participation will be helpful in aid of completing this academic exercise.

Demographic characteristics

1. Sex
   Male ☐ Female ☐
2. Age
   Below 20yrs ☐ 21-25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐
   41-45 ☐ 46-50 ☐ 51-55 ☐ 56-60 ☐ Above 60^{+} ☐
3. Marital Status
   Married ☐ Divorced ☐ Single ☐ Separated/Divorced ☐
4. Religion
   Christian ☐ Islam ☐ African Traditional ☐ Others, specify...................

Personal Details

1. Which sector are you employed?
   Public/Government ☐ Private ☐ Self Employed ☐
   Not Employed ☐

2. Level of Education
   Primary School ☐ Junior High School ☐ Senior High School ☐
   Tertiary ☐ Vocational Training ☐

3. On the Average, how much money does your entire household earn per month (in GH¢)
   ....
   ....

4. Could you give an estimate of how much money you spend on food, security, clothing, utility bills, and other items in a month?
   ....
   ....

5. Were you a tenant somewhere else before settling or building in this area?
   Yes ☐ No ☐

6. If Yes in Q.5, please indicate where you used to live.
....
....
7. Why did you decide to construct the house in this area?
Accommodate family ☐ Provide rooms for rent ☐ Provide own working space ☐ Love for the scenery/environment ☐ Better access to employment ☐
8. How many family members do you have in your household?
No of Children.................... No of Adults (over 18yrs) .... No. of Adults' Employed...................

9. How many rooms has your building?
Bedrooms...............Kitchen.............Bathroom/Toilet/Washrooms..........Store Rooms.................... Living room............. Office...................... Study.............................Other........................

10. How many tenants do you have in your building?
................persons

11. From whom did you obtain information about the land on which your building is situated?
From a family member ☐ Land belongs to my family ☐ Friend ☐
Sales Agent ☐ Advertisement in the Media ☐

12. How much did you pay for the plot(s) of land your building is situated?
GH¢..
13. To whom did you pay these monies?
....
....
14. Which year did you purchase this plots?
....
15. Were you given any documents to suggest the ownership and full right to the land?
Yes ☐ No ☐
16. If Yes, which document were you given? Please give reasons
....
....
....

17. If No to Q15, why weren't you given any document? Please give reasons.
....
....
....

18. Did you seek advice on this area before purchasing the plot of land?
Yes ☐ No ☐

19. If Yes, from whom did you sort advice and what advice did you receive?
....
....

20. If No, give reasons for not seeking advice on the area?
....
....
....

21. Did you register your plot of land after purchasing your plots of land?
Yes ☐ No ☐

22. Was your plot of land inspected before you were allowed to build on the land?
Yes ☐ No ☐

23. Which year did you build on this plot of land?
....

24. What was your source of finance for putting up this building?
....
....
....

25. Were there buildings in this area before you settled here?
Yes ☐ No ☐

26. Apart from putting your building on the plot of land, what other use do you have on your plot of land?
....
....
....
....

Location Choice/Factors

27. Were you able to get the location you wanted when you bought this plot?
Yes ☐ No ☐

28. If No, what is it about the location you do not like?
....
....
....

29. Which other area/location in Shama would you have preferred to live, and why?
.... Reason ....
....
....

30. What best factor would you have considered in terms of choosing a place or plot of land for your building?
....
....
....

31. Please indicate the importance of each of the following listed below where choosing a plot of land to build on.

Feature	Very Important	Important	Somewhat Important	Not Important
CBD				
Industrial Area				
Local Market				
Planned Area				
Main Road				
Footpath				
School				
Clinic/dispensary				
Bus route				
Water Pump				
Mosque/church				
Family/friends				
Tribesmen				
Other………				
Other……….				

32. a. Please indicate which of the following factors you will avoid when choosing a plot of land to build on.

Feature	Very Important to Avoid	Important to Avoid	Somewhat important to Avoid	Not Important
High Slope				
Flood Area				
Swamp				
Riverbank				
Good Temperature				
Noisy bars				
Factories				
Other................				
Other................				

31b. Please indicates amongst the following factors, the factors that are experienced in your area currently.

Feature	Very Important to Avoid	Important to Avoid	Somewhat important to Avoid	Not Important
High Slope				
Flood Area				
Swamp				
Riverbank				
Noisy bars				
Factories				
Other...........				
Other...........				

33. When you were looking for a place to build, what kind of neighbourhood did you look for?
People who have same occupation ▢ Same religion ▢ Same tribe ▢
Same education ▢ Same income ▢

34. How did you know this was a good place to live/settle?
....
....
....

35. Was there any person who assisted you to gain or select this plot?
Yes ▢ No ▢

36. If Yes in Q35, please indicate who it was and the nature of the assistance offered you?
....
....
....
....

37. If you were given some financial assistance of GH¢100,000.00p assistance to spend this month, how much would you save for building construction?
....
....
....
....

38. If you would construct a new building, where would you construct it?
In this same settlement ▢ Another plot in this same settlement ▢
Another settlement ▢

39. What would be your reason for constructing a new building in another settlement?
....
....
....
....

Past and Present Experiences of Flooding

40. Have you experienced flooding in your area ever since you lived here?
Yes ▢ No ▢

....
....

41. Which year did you first experience flooding in the area, and give a brief account of the flooding?
....
....

42. Which year did you last experience flooding in the area?
....
....

43. In your opinion, what do you think are the causes of flooding in your area?
....
....
....
....

44. How were you affected by the floodwaters?
....
....
....
....

45. Do you still have plans of living in the area irrespective of the past flooding event?
Yes ☐ No ☐

46. Justify your choice in Q.45
Yes, because:
....
....
....
....
No, because:
....
....
....
Thank You!!!

Appendix 2: Shama Informal Settlement Growth Model code in NetLogo

```
extensions [ gis ]
globals [ flood-dataset road-dataset settled-dataset river-dataset vacant-dataset
counter view-mode min-poor-util max-poor-util min-rich-util max-rich-util path ]
breed [ river-label river-labels ]
breed [ road-label road-labels ]
breed [ vacant-label vacant-labels ]
breed [ flood-label flood-labels ]
breed [ rich a-rich ]
breed [ poor a-poor ]
breed [ medium a-medium ]
breed [ jobs job ] ;; jobs are places of employment or commercial enterprises
which hold many people.......

rich-own [ utilityr ]
poor-own [ utilityp ]
medium-own [ utilitym ]
jobs-own [ utility ]
turtles-own [ similar-agents other-agents satisfied? total-agents ]
patches-own [ settled quality price sddist
similar-agents2 other-agents2 satisfied?2 total-agents2
similar-agents3 other-agents3 satisfied?3 total-agents3
similar-agents4 other-agents4 satisfied?4 total-agents4  ]


;;;;;;;;;;;;;;;;;;; Initialization Stage ;;;;;;;;;;;;;;;;
to setup
clear-turtles
clear-patches
clear-drawing
clear-output
ask patches [ set pcolor white - 1 ]

set road-dataset gis:load-dataset "Shama/road.shp"
set vacant-dataset gis:load-dataset "Shama/vacant.shp"
set flood-dataset gis:load-dataset "Shama/flood.shp"
set river-dataset gis:load-dataset "Shama/river.shp"
set settled-dataset gis:load-dataset "Shama/settled.asc"

gis:set-world-envelope (gis:envelope-union-of (gis:envelope-of flood-dataset)
  (gis:envelope-of settled-dataset)
  (gis:envelope-of river-dataset)
  (gis:envelope-of road-dataset)
```

```
  (gis:envelope-of vacant-dataset))
display-settled
draw-world

setup-jobs
setup-patches
setup-rich
setup-poor
setup-medium
;ask patches [ update-patch-color ]
reset-ticks
clear-plot
end

;-----------------------gis procedure ------------------------;

to display-settled
gis:paint settled-dataset 0
end

to setup-world-envelope
let world (gis:envelope-of vacant-dataset) ;; [ minimum-x maximum-x minimum-y
maximum-y ]
if zoom != 1 [
let x0 (item 0 world + item 1 world) / 2          let y0 (item 2 world + item 3 world) /
2
let W0 zoom * (item 0 world - item 1 world) / 2   let H0 zoom * (item 2 world -
item 3 world) / 2
set world (list (x0 - W0) (x0 + W0) (y0 - H0) (y0 + H0))
  ]
gis:set-world-envelope (world)
end

to draw-world
gis:set-drawing-color [220 134  89]    gis:fill flood-dataset 0
gis:set-drawing-color [222 111 214]    gis:draw flood-dataset 1
gis:set-drawing-color [102 204 255]    gis:fill vacant-dataset 0
gis:set-drawing-color [  0   0 255]    gis:draw vacant-dataset 1
;gis:set-drawing-color [255 204 102]   gis:fill settled-dataset 0
;gis:set-drawing-color [255 255 102]   gis:draw settled-dataset 1
gis:set-drawing-color [255   0   0]    gis:draw road-dataset 1
```

```
gis:set-drawing-color [255  24  12]    gis:draw river-dataset 0
gis:set-drawing-color [129 120 218]    gis:fill river-dataset 1
gis:paint settled-dataset 0
end

;;------------------------ agents setup -----------------------;;

to setup-jobs
create-jobs 1
ask jobs
  [
setcolor red
set shape "circle"
set size 2
  ]
end

to setup-patches
ask patches [
set quality 40
set price 40
  ]
ask patches
  [
setsddist min [distance myself] of jobs
  ]
end
to setup-rich
create-rich 5
ask rich
  [
setcolor 124
set shape "person"
set size 6
let radius 10
setxy ( ( radius / 2 ) - random-float ( radius * 1.0 ) ) ( ( radius / 2 ) - random-float (
radius * 1.0 ) )
raise-price
raise-value
  ]
```

```
ask rich [ setxy random-pxcor random-pycor ]
end

to setup-poor
create-poor 5
ask poor
  [
setcolor 65
set shape "person"
set size 6
let radius 10
setxy ( ( radius / 2 ) - random-float ( radius * 1.0 ) ) ( ( radius / 2 ) - random-float (
radius * 1.0 ) )
decrease-price
decrease-value
  ]
ask poor [ setxy random-pxcor random-pycor ]
end

to setup-medium
create-medium 5
ask medium
  [
setcolor 75
set shape "person"
set size 6
let radius 10
setxy ( ( radius / 2 ) - random-float ( radius * 1.0 ) ) ( ( radius / 2 ) - random-float (
radius * 1.0 ) )
decrease-price
decrease-value
  ]
ask medium [ setxy random-pxcor random-pycor ]
end
to decrease-value
ask patch-here [ set quality ( quality * 0.95 ) ]
ask patches in-radius 1 [ set quality ( quality * 0.96 ) ]
ask patches in-radius 2 [ set quality ( quality * 0.97 ) ]
ask patches in-radius 3 [ set quality ( quality * 0.98 ) ]
ask patches in-radius 4 [ set quality ( quality * 0.99 )
if (quality < 1) [ set quality 1]
  ]
end
to raise-price
```

```
ask patch-here [ set price ( price * 1.05 ) ]
ask patches in-radius 1 [ set price ( price * 1.04 ) ]
ask patches in-radius 2 [ set price ( price * 1.03 ) ]
ask patches in-radius 3 [ set price ( price * 1.02 ) ]
ask patches in-radius 4 [ set price ( price * 1.01 )
if price > 100 [ set price 100 ] ]
end
to raise-value
ask patch-here [ set quality ( quality * 1.05 ) ]
ask patches in-radius 1 [ set quality ( quality * 1.04 ) ]
ask patches in-radius 2 [ set quality ( quality * 1.03 ) ]
ask patches in-radius 3 [ set quality ( quality * 1.02 ) ]
ask patches in-radius 4 [ set quality ( quality * 1.01 )
if quality > 100 [ set quality 100 ]
  ]
end
to decrease-price
ask patch-here [ set price ( price * 0.95 ) ]
ask patches in-radius 1 [ set price ( price * 0.96 ) ]
ask patches in-radius 2 [ set price ( price * 0.97 ) ]
ask patches in-radius 3 [ set price ( price * 0.98 ) ]
ask patches in-radius 4 [ set price ( price * 0.99 )
if (price < 1) [ set price 1]
  ]
end
;;;;;;;;;;;;;;;;;; Runtime Procedures ;;;;;;;;;;;;;;;;;;

to go
locate-poor
locate-rich
locate-medium
if counter > residents-per-job
  [
locate-service
set counter 0
  ]
if count (rich) >= 20 [kill-rich]
if count (poor) >= 20 [kill-poor]
if count (medium) >= 20 [kill-medium]
if count (jobs) >= max-jobs [kill-service]
update-view
do-plotting
if ticks = 11 or ticks = 23 or ticks = 35 or ticks = 47 or ticks = 59 or ticks = 71 [
toggle-view ]
```

```
if ticks = 12 [ export-world "year one.csv"
export-plot "Travel Distance" "yearone.csv"
                export-view  "yearone.png"
export-interface "yearone1.png" ]
if ticks = 24 [ export-world "year two"
export-plot "Travel Distance" "year two.csv"
export-view "yeartwo.png"
export-interface "yeartwo1.png"]

if ticks = 36 [ export-world "year three"
export-plot "Travel Distance" "year three.csv"
export-view "yearthree.png"
export-interface "yearthree1.png"]

if ticks = 48 [ export-world "year four"
export-plot "Travel Distance" "year four.csv"
export-view "yearfour.png"
export-interface "yearfour1.png"]

if ticks = 62 [ export-world "year five"
export-plot "Travel Distance" "year five.csv"
export-view "yearfive.png"
export-interface "yearfive1.png" ]

if ticks = 72 [ export-world "year six"
export-plot "Travel Distance" "year six.csv"
export-view "yearsix.png"
export-interface "yearsix1.png" ]
if ticks = 73 [ stop ]
tick
end

to locate-poor
set counter ( counter + poor-per-step )
create-poor poor-per-step
  [
setcolor 65
set shape "person"
evaluate-poor
decrease-value
decrease-price
```

```
  ]
end
to locate-medium
set counter ( counter + medium-per-step )
create-medium medium-per-step
  [
setcolor 75
set shape "person"
evaluate-medium
decrease-value
decrease-price
  ]
end

to locate-rich
set counter ( counter + rich-per-step )
create-rich rich-per-step
  [
setcolor 124
set shape "person"
evaluate-rich
raise-price
raise-value
  ]
end

to update-prich
set similar-agents2 count (turtles-on neighbors) with [color = 124 ]
set other-agents2 count (turtles-on neighbors) with [color = 65 or color = 75]
set total-agents2 similar-agents2 + other-agents2
set satisfied?2 similar-agents2 >= ( %-similar-wanted * total-agents2 / 100 )
end

to update-pmedium
set similar-agents3 count (turtles-on neighbors) with [color = 75 ]
set other-agents3 count (turtles-on neighbors) with [color = 124 or color = 65]
set total-agents3 similar-agents3 + other-agents3
set satisfied?3 similar-agents3 >= ( %-similar-wanted * total-agents3 / 100 )
end
to update-ppoor
set similar-agents4 count (turtles-on neighbors) with [color = 65 ]
```

```
set other-agents4 count (turtles-on neighbors) with [color = 75 or color = 124]
set total-agents4 similar-agents4 + other-agents4
set satisfied?4 similar-agents4 >= ( %-similar-wanted * total-agents4 / 100 )
end

to update-rich
;; check the neighborhood of the patch for similar agents
set similar-agents count (turtles-on neighbors) with [color = [color] of myself]
set other-agents count (turtles-on neighbors) with [color = 75 or color = 65]
set total-agents similar-agents + other-agents
set satisfied? similar-agents>= ( %-similar-wanted * total-agents / 100 )
end
to update-medium
;; check the neighborhood of the patch for similar agents
set similar-agents count (turtles-on neighbors) with [color = [color] of myself]
set other-agents count (turtles-on neighbors) with [color = 124 or color = 65]
set total-agents similar-agents + other-agents
set satisfied? similar-agents>= ( %-similar-wanted * total-agents / 100 )
end
to update-poor
;; check the neighborhood of the patch for similar agents
set similar-agents count (turtles-on neighbors) with [color = [color] of myself]
set other-agents count (turtles-on neighbors) with [color = 75 or color = 124]
set total-agents similar-agents + other-agents
set satisfied? similar-agents>= ( %-similar-wanted * total-agents / 100 )
end
to evaluate-poor
let candidate-patches n-of number-of-tests patches
set candidate-patches candidate-patches with [ not any? turtles-here ]
if (not any? candidate-patches)
[ stop ]

;; we use a hedonistic utility function for our agents, shown below
;; basically, poor people are looking for inexpensive real estate, close to jobs
let best-candidate max-one-of candidate-patches
[ patch-utility-for-poor ]
move-to best-candidate
setutilityp [ patch-utility-for-poor ] of best-candidate
end
to-report patch-utility-for-poor
```

```
   report ( ( 1 / (sddist / 100 + 0.1) ) ^ ( 1 - poor-price-priority ) ) * ( ( 1 / price ) ^ (
1 + poor-price-priority ) )
end
to evaluate-medium
let candidate-patches n-of number-of-tests patches
set candidate-patches candidate-patches with [ not any? turtles-here ]
if (not any? candidate-patches)
[ stop ]
;; we use a hedonistic utility function for our agents, shown below
;; basically, rich people are looking for good quality real estate, close to jobs
let best-candidate max-one-of candidate-patches
[ patch-utility-for-medium ]
move-to best-candidate
setutilitym [ patch-utility-for-medium ] of best-candidate
end

to-report patch-utility-for-medium
   report ( ( 1 / (sddist / 100 + 0.1) ) ^ ( 1 - medium-price-priority ) ) * ( ( 1 / price )
^ ( 1 + medium-price-priority ) )
end

to evaluate-rich
let candidate-patches n-of number-of-tests patches
set candidate-patches candidate-patches with [ not any? turtles-here ]
if (not any? candidate-patches)
[ stop ]
;; we use a hedonistic utility function for the household agents, shown below
  ;; basically, rich people are looking for good quality lands irrespective of where
its located but preferably close to jobs
let best-candidate max-one-of candidate-patches
[ patch-utility-for-rich ]
move-to best-candidate
setutilityr [ patch-utility-for-rich ] of best-candidate
end
to-report patch-utility-for-rich
  report ( ( 1 / (sddist + 0.1) ) ^ ( 1 - rich-quality-priority ) ) * ( quality ^ ( 1 + rich-
quality-priority) )
end
```

```
to kill-poor
repeat ( death-rate )
  [
;always kill the person that's been around the longest
ask min-one-of poor [who]
[ die ]
  ]
end

to kill-medium
repeat ( death-rate )
  [
;always kill the person that's been around the longest
ask min-one-of medium [who]
[ die ]
  ]
end

to kill-rich
repeat ( death-rate)
  [
;always kill the person that's been around the longest
ask min-one-of rich [who]
[ die ]
  ]
end

to kill-service
  ; always kill the oldest job
ask min-one-of jobs [who]
[ die ]
ask patches
[ setsddist min [distance myself + .01] of jobs ]
end
to locate-service
let empty-patches patches with [ not any? turtles-here ]
if any? empty-patches
  [
ask one-of empty-patches
    [
sprout-jobs 1
```

```
    [
setcolor red
set shape "circle"
set size 2
evaluate-job
    ]
  ]
ask patches
[ setsddist min [distance myself + .01] of jobs ]
 ]
end

to evaluate-job
let candidate-patches n-of number-of-tests patches
set candidate-patches candidate-patches with [ not any? turtles-here ]
if (not any? candidate-patches)
[ stop ]

let best-candidate max-one-of candidate-patches [ price ]
move-to best-candidate
set utility [ price ] of best-candidate
end
;;;;;;;;;;;;;;;;; Visualization Procedures ;;;;;;;;;;;;;;;;;;;;;;;
to update-view
if (view-mode = "poor-utility" or view-mode = "rich-utility")
 [
let poor-util-list [ patch-utility-for-poor ] of patches
set min-poor-util min poor-util-list
set max-poor-util max poor-util-list

let rich-util-list [ patch-utility-for-rich ] of patches
set min-rich-util min rich-util-list
set max-rich-util max rich-util-list
 ]
end
to toggle-view
if toggle = 1 [
ask rich
[ set size size * 2 ]
ask poor
[ set size size * 2 ]
```

```
ask medium
[ set size size * 2 ]
  ]
end
;;;;;;;;;;;;;;;;;;;;;; Plotting Procedure ;;;;;;;;;;;;;;;;;;;;;
to do-plotting
letrtotal 0
letptotal 0
let step 0
letrtime 0
letptime 0
set-current-plot "Travel Distance"
setrtotal 0
setrtime 0
setptotal 0
setptime 0
set-current-plot-pen "rich"
plot median [ max [distance myself] of jobs ] of rich
set-current-plot-pen "medium"
plot median [ max [distance myself] of jobs ] of medium
set-current-plot-pen "poor"
plot median [ max [distance myself] of jobs ] of poor
end
```