Modelling Spatiotemporal Urban Growth of Adama Town using CA-SLEUTH Model

By

Sintayehu Haile Damu

A Thesis Submitted to

The Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's

In Geomatics Engineering (Specialization in Geoinformatics Engineering)

Office of Graduate Studies (OPS)

Adama Science and Technology University

Adama

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Sintayehu Haile Damu

Advisor Daniel Alemayehu (PhD)

Co-Advisor Dejene Tesema (PhD Candidate)

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Board of Examiners Approval

We, the undersigned, members of the Board of Examiners of the final open defense paper by Sintayehu Haile Damu have read and evaluated his thesis entitled: Modelling Spatiotemporal Urban Growth of Adama Town using CA - SLEUTH models and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Geoinformatics.

______________________	______________________	______________________
Advisor	Signature	Date
______________________	______________________	______________________
Co-Advisor	Signature	Date
______________________	______________________	______________________
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DECLARATION

I, SINTAYEHU HAILE DAMU hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university and all sources of material used in this thesis have been properly acknowledged.

Candidate:

Name: SINTAYEHU HAILE DAMU

Signature: ________________

This MSc Thesis has been submitted for examination with our approval as thesis advisor/co-advisor.

Advisor

Name: ____

Signature: _____________________________

Date of submission: _______________________________

Co-Advisor

Name: ____

Signature: _____________________________

Date of submission: _______________________________

ACKNOWLEDGEMENT

First, I would like to thank my God in the name of his son Jesus Christ for his mercy on me and graces of strength I am endowed to complete my MSc thesis. I would like to present my heartfelt gratitude and special thanks to my Advisor Daniel Alemayehu (PhD) for his professional guidance through out of my work.

I am deeply thankful to my CO- Advisor Mr Dejene Tesama, for his persistent help in all the steps of the thesis, from title selection to writing the final report. His way of teaching, continuous guidance, feedbacks, advices and encouragements have been truly exceptional, learnable and motivation to write the best thesis in its current form.

I never forget to thank my family and friends for their unpaid caretaking and advices.

Finally, I am thankful to Adama Sciences and Technology University for providing the sponsorship towards my further study.

May God bless you all and give peace to your heart!

Sintayehu Haile Damu

October 2019

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LIST OF ACRONYMS

ASTU	Adama sciences and technology university
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CA	Cellular Automata
CAD	Computer Aided design
CSA	Central Statistical Agency of Ethiopia
DEM	Digital Elevation Model
ETH	Ethiopia
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
EMA	Ethiopia Mapping Authority
ERA	Ethiopia Road Authority
ERDAS	Earth Resource Data Analysis System
GCP	Ground Control Point
GIS	Geographic Information System
GIF	Graphics Interchange Format
GPS	Global Positioning System
IBM SPSS	International Business Machines Corporation Statistical Package for the Social Sciences
LULC	Land Use Land Cover
MSS	Multispectral Scanner System
NA	Not Available
SLUETH	Slope Land use Urbanization Exclusion Transportation Hill shade
OLI	Operational Land Imager
TM	Thematic Mapper
UN	United Nations
RS	Remote Sensing

ABSTRACT

The pace of urbanization is rapidly accelerating in developing countries, and the Town *planners require spatial and scientific criteria for policy formulation. CA-SLEUTH model are one of the strongest tools for modeling urban spatial growth, owing to their structure, simplicity, and possibility of evaluation. The objective of this study to analyze the spatiotemporal urban land use, land cover dynamics and to model using CASLEUTH the simulations, urban land use, land cover and the prediction future urban expansions based on three urban spatial growth scenarios (i.e. Aggravated, business as usual, & restricted). The current study was conducted by analyzing urban land use land cover change statistics of Adama Town for understanding the temporal urban land use, land cover dynamics for the year 1990 to 2019; The simulation and prediction of urban land use land cover were conducted using CA-SLEUTH Source Code. The outcomes of the current study are changes of urban spatial growth for three decades (1990 to 2019). Accordingly, the simulation results on the growth of urban areas with respect to its coverage inside the boundary of Adama Town reported to be Built-up area during 1990–2000 as 7.4 Sq. Km to 134.1 % and 2000–2010 at 41.4. sq.km, with a 139 % rate 2010-2019 of growth of built-up area increased by 30%. Validation of urban land uses land cover map were assessed for the year 1990, 2000, 2010, and 2019 and stated to be 91.67%, 85.71%, 91.67%, and 83.3% respectively. The results of prediction for urban spatial growth scenarios restricted, business as usual, and aggravated predicted for the year 2019 to 2040 as 53.84 km*^{2} *(0%), 90.2 km*^{2} *(45.2 %), and 101 km*^{2} *(29.1%) respectively. The current study confirms that the CA - SLEUTH Model is an efficient model for simulating and predicting urban spatial growth different growth scenarios (i.e. Restricted, business as usual and aggravated). Therefore, CA-SLEUTH Model can be potentially recommended to used for Cities like Adama for updating, urban dynamics and supervising the actual growth with proposed plan or scenarios to avoid nonconforming problem.*

Key Words*: Urban Spatial Growth, Spatio-Temporal, CA-SLEUTH Model, Prediction, Adama Town*

CHAPTER ONE

1. Introduction

1.1. Background of the study

The term urbanization refers to the process of a changing population from rural to urban. Urban growth is a global phenomenon, it is a cause for and an effect as well, of various ecological and socioeconomic processes that take place in both natural and human environments Urbanization has been occurring in human history under various forms and is an inherent process of human evolution, both physical and cultural. In a social point of view, it could be describe as a spatially referenced tradeoff between different types of human needs and expectations. For the first time in human history, more than 50% of the global population live in urban areas while urban population growth rates are increasing. What increases even faster is the urban society's need in space, services, facilities and energy. Considering the above, it is crucial that the urban growth phenomenon is studied and comprehend in order to be directed towards controlled and sustainable patterns and scales of evolution. (Candau, 2010)

It is essential to have a clear vision of sustainable urbanization patterns in order to be able to design policies with a significant impact towards sustainability. Such knowledge is necessary for the optimal use of space, services, facilities and energy, which will lead to maximizing the benefits of urban population while minimizing both economic and environmental cost.

A model is a simplified and hence a more comprehensible conceptualization of a real phenomenon or process. To model is to subtract by reality until the final concept is simple, but also retains its realism. Nevertheless, simplifying is not simple, especially when it comes to complex phenomena where there lies great inherent spatial, temporal and decision-making heterogeneity, this is a result of socioeconomic and ecological heterogeneity itself (Firew, 2010).

Urban growth has been even more difficult to model, since not only it evolves in time, but also spreads in space in both continuous and discontinuous ways. That means that apart from the difficulties of studying a spatial phenomenon, when studying urban growth, be come across first-seen qualitative interactions, of which are lack the ground to model in a mathematical way. That is because our knowledge, either empirical or data-driven, is merely describing the part of the urban growth dynamics that have already occurred and have been observe rather than the urban growth dynamics in general. (Nissar, M, & Nuzhat, 2016).

Urban growth evolves in areas where it has already occurred (vertical expansion) and also extends its borders continuously by sprawling or occurs in segregated areas (horizontal expansion). Moreover, its underlying patterns of evolution are evolving in time as well. This means that even if a clear vision of the patterns occurred is acquired it can only be used under certain assumptions of relative stasis. (SHAFEEQ, 2015).The models should not consider as calculators; their scope is not only to provide estimations of the future status but also knowledge of the phenomenon. The knowledge derived from a model is as much important as the model's consistency to the real world; knowledge that is meant to be communicated. To resolve these issues, the researcher designed a modeling structure that may use Spatio-temporal rules, deterministic or stochastic, empirical, data-driven or both. Such a model allows the user to overcome the limitations of the available data by using exogenous knowledge adapted to the model by empirical similarity patterns, providing thus better fit to the real process. The knowledge of this model is expressed in common language describing simple relations with linguistic terms that provides a conceptualization of the phenomenon and an information flow closer the human conceptualization and makes the model friendly and easy to use, especially to the non-expert users. Urban is still an interesting topic to discuss whether government or public studies. As the economy grows in cities, more people are coming there to try to find their luck. According to (National Health Mission, 2013) many people wanted to improve their social class hoping to vertical mobility, so they came to cities. Instead of vertical mobility, most of them only receive horizontal mobility (e.g., Farmer becomes labored.) of course, the rapid growth of people coming to cities becomes a problem especially to government deciding policies. Government tries to make some policies to regulate the number of urbanizations. (arde, 2004).

Urban modeling is an important tool for designing efficient policy. Here in present a methodological framework for urban modeling, which attempts to access the multi-level urban growth dynamics and express them in linguistic terms. The suggested framework incorporates a set of CA- SLUETH systems, each one of which focuses on different aspects of the urban growth dynamics, while the systems' structure and connection provides a workflow closer to the human conceptualization of the phenomenon (Dietzel & Clarke, 2007).

1.2. Statement of the Problem

Urban growth is one of the biggest challenges for human kinds in the twenty century. This growth is still almost exponential and saturation may be reached, the rapid ,development makes sustainable urban growth more difficult Land consumption for urbanization if it is not control this vast pried of urbanization and the urban expansion can be make the following major problems: Disorder developments of urban often leads a series of classic symptoms such as loss of and fragmentation of natural resources, environmental pollution, residential crowding and traffic congestion (Batty, 2009). As per the mentioned global facts, a better and scientific understanding of spatial dynamics of urban growth and evaluating the impacts of urban growth on the environment are imperative and of great importance to manage resources and provide services in these rapidly changing environments.

As per the previous unpublished studies and report conducted by Adama Municipality, indicate that information related to Adama Town urban expansion is not enough to explain the growth of the Town from the out datedness, inadequacy single planning period and incompleteness point of view. As confirmed by a research questionnaire in Appendix1. Moreover, lack of frequent decadal urban Spatiotemporal Growth of Adama Town major challenges for urban planners and administrators that could lead to difficulty for decision makers, unsustainable growth, and development unconformity challenges(Bulti, 2017).

The long year historical urban spatial growth is not available in the respective years that shows the spatial as well as descriptive data about the study areas the historical urban spatial growth helps to understand the growth circles of the area. This study used a multiple scenarios based approaches research rather than single approach in ordered to overcome the identified problems related to urban spatial growth, the current study is designed to model the urban dynamics of the Town. This may require advanced spatial techniques supported by the land use planners and policy makers involving shifting of emphasis from basic geographic data handling into manipulation modeling and analysis to solve the real problems.

1.3. General and Specific Objectives

1.3.1. General Objectives

To model the historical spatial expansion and predict the future possible behavior of the urban spatial growth in Adama Town using CA-SLEUTH Model

1.3.2. Specific Objectives

- To simulate land use change from 1990 to 2019
- To predict urban spatial growth of the Town based on Aggravated, Business as usual and restricted growth scenarios in 2040.
- To identify one-growth scenarios from three generated growth scenarios for Sustainable Urban Growth Management.

1.4. Research Questions

This paper answers the following research questions with Corresponding to the problem statement,

- What are the possible simulated urban spatial expansion of Adama Town 1990 to 2019?
- How to predict the expansion patterns of the Town from 2019 to 2040 under aggravated business as usual and restricted growth scenarios?
- What are the appropriate management strategies based on the simulated and predict growth scenarios?

1.5. Significance of the Study

The significance or advantage of this research can be Benefit three different groups, namely: Individuals, Government, and Society.

- ➢ Individuals in this study are helpful for individuals who want to do more analysis on urban modeling and one may get his own research ideas from this paper. This means this study is useful for educational purpose for modeling urban spatial growth and the urban expansion.
- ➢ Government The study also helps the Adama Town Administration to take action on the Master plan of the Town to protect from Disorder developments such as fragmentation of natural resources, environmental pollution, and residential crowding and traffic congestion.

- Society Further, society will be benefited if the government takes policy action plan on areas of the Town that are most probably affected by spatial expansion. This enables them in preserving their social life and protecting their families and economy from damage. Saving number of people that are in the current development area has great importance for the society by protecting everyone from disturbance.

1.6. Delimitation/Scope

The Geographical scope of this study is Adama Town, where urban growth is prone in the areas, which cover 313.0422-km2and shape area with the current new Administrative boundary. This study is limited to Adama Town urban spatial growths that are focuses main two issues.

The first issues are to simulate the spatial expansion of the Town based on CA-SLEUTH Model simulations for the past three decades from derived satellite data from the year 1990.The second issues is to predict the expansion patterns of the Town from 2019 to 2040 under aggravated business as usual and restricted growth scenarios.

1.7. Operational Definitions

CITY: A large settlement, bigger than a town

GIS: A Geographic Information System (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data.

Models: are simplifications of reality

Modeling: mathematical representation of real-world behaviors by equation, formula graphs is a situation that poses a level of threat to life, health, property, or the environment.

Urban models: are thus essentially computer simulations of the way cities function which translate theory into a form that is testable and applicable without experimentation on the real thing

Remote Sensing: Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on-site observations

SLEUTH Model: A CA-based urban growth model coupled with a land-cover-change model

Spatio-Temporal: is space and time together (having both spatial extension and temporal duration)

Town: .A settlement an area with residential districts, shops and amenities, and its own local government, especially one larger than a village and smaller than a Town

Urban: An urban area is a human settlement with high population density and infrastructure of the built environment.

Urban growth: evolves in areas where it has already occurred (vertical expansion) and also extends its borders continuously by sprawling or occurs in segregated areas (horizontal expansion).

1.8. Limitation

In this study, the following are limitations.

Lack of high resolution satellite data

There is no much Empirical study on urban growth modeling in the study area (published).

1.9. Organization of the Thesis

Background of the study, the research problem, objectives, scope and limitation of the study are the main body incorporated in the first chapter just discussed Chapter two consists of the review of related literature. Chapter three consists of Methodology of the study. Chapter four consists of finding and discussion of the research and the fifth chapter gives conclusions and recommendations.

CHAPTER TWO

2. Literature Review

In this part, the study examined same important Definition and theoretical bases for urban spatial growth, CA SLUETH model and related Empirical research are reviewed.

2.1. Theoretical Literature Review

In developing countries, rapid growth of urban population is one of the major challenges for governments and planning agencies. According to United Nations Department of Economic and Social Affairs report, 54% (3.9 billion people) of the world population are located in urban areas and it is expected to attain 6.3 billion in 2050, with closely 90% of the future urban population increase in developing world cities (United Nations & Affairs, n.d.).

2.1.1. Introduction to Urban Studies

If delineating urban areas is a difficult task, classifying different types of urban land use is even more so. A mixture of diverse material and land use classes, such as buildings, commercial infrastructures, transportation networks, and parks, characterizes the urban environment. Because they are combinations of spectrally distinct land cover types, mixed pixels in urban areas are frequently misclassified as other land-cover classes. Similarly, the definition of an "urban" spectral class will usually incorporate pixels of other non-urban classes. Such spectral heterogeneity severely limits the applicability of standard classification techniques, where it is assumed that the study area is comprised by a number of unique and internally homogeneous classes. Many authors(Walsh & Leonard, 2014) have discussed in detail the issues associated with spatial and temporal requirements for urban studies.

2.2. Classification of Urban Areas

2.2.1. Urbanization at worldwide level

In the past few decades, urbanization and urban growth have accelerated worldwide. Within two Decades, the population of cities has doubled or even tripled. At the beginning of the nineteenth Century only about 3 percent of the world's population lived in urban places [Lug hood and Hay, 1977]. In 1970s and 1990s, the proportion rose to 37 percent and 45 percent respectively. This proportion is expected to pass 50 percent by 2005 and it is expected that by the year 2030, the proportion will rise to more than 60 percent (UN-Habitat, Nations, & Assembly, 2017) 76 percent of the population has already lived in urban places and "people and jobs are moving out away from the big cities to smaller towns.

2.2.2. Africa’s Urban

In most parts of the world, urbanization has been accompanied by industrialization and economic development, as increases in productivity in manufacturing and services benefited from the proximity and concentration of activities and inputs. In Africa, data for 2011 confirm the relation between per capita income and urbanization levels However, Africa’s urbanization is occurring at lower levels of income and with far less investment in infrastructure. These trends suggest serious problems in coping with the challenges of rapid urbanization, notably accommodating a larger population and ensuring a favorable business environment (Freire, Lall, & Leipziger, n.d.).

2.2.3. Urbanization in Ethiopia

Ethiopia is one of the least urbanized countries in Africa; only 20 per cent of the population resides in cities. Over the next twenty years, urbanization will double. The government plans to transform Ethiopia into a middle-income country by 2025 and industrialization has been prioritized to promote economic growth and job creation Like most African countries, in Ethiopia large-scale urbanization is a fairly recent phenomenon. However, the history of town dwelling in the country extends back to the Axumite Kingdoms of the 4th century, when Axum, the first political, commercial and religious center in the north of the country, was established. Despite this long urban history, however, Ethiopia remains one of the least urbanized countries of Sub-Saharan Africa. (UN-Habitat et al., 2017) Prior to the 20th century, the establishment and growth of the Ethiopian cities are said to be in response to indigenous political, religious, economic as well as military strategic requirements. Despite its failure to build well-organized and large size urban settlements, the constant shifting of the locations of the capital cities of the empire during this period had accounted for the establishment and growth of a number of towns particularly in northern Ethiopia. For instance, Axum, Lalibela, and Gondar – founded in the 4$^{-th11\ th}$ and 17th century, respectively are some of the urban centers that served as capitals of the nation. In addition to these government administration centers, there were also indigenous and historically significant towns in the south and east, such as Harar and Jimma.

Ethiopia is the second most populous country in Africa next to Nigeria with a population estimated at 99.39 million in 2015 from which 19.4% live in urban and peri-urban areas (CSA, 2016). Between 2007 and 2015 nineteen million people were added to the population. The population size is growing by 2.9 percent per year and is expected to nearly double in less than 33 years to around 185 million in 2050 (Efrem & Tesfaunegn, 2017). The country is one of the lowest urban dwellers residences compared to Sub - Saharan standards of a percentage of the total population residing in cities and urban settings, despite indications display a rapid rate of urbanization in the pace at which people are relocating to urban centers.

Projection made by the Ministry of Urban Development and Housing indicates that, the number of urban population by 2025 is expected to reach between 30-35 million (27 to 30% of a total population). By 2037, the urban population will be 42.2 million (40% of the total population). This means that the urban population of Ethiopia will increase between 2015 and 2037 by as much as 39 million, and that the urban population expansion accounts for around 75% of the total population increase of over 50 million during this period. Date back to the country level of urbanization, it was about 5% in the 1950s, and 10% in the 1970s and by 1984 was about 13%, and reached 19% in 2014 having grown by 6% between 1984 and 2013and this reflects an average increase of 2% per decade(Pieper & Hakalin, 2018).

2.3. Factors Proliferating Urban Expansion

There are various and interrelated factors responsible for the expansion of Adama town. Among them rapid population growth is the major. However, there are also other important factors contribute to the expansion of the town. According to

Rapid urbanization is basically derived from migration from villages to towns, urban expansion to peri- urban areas and the natural growth of urban inhabitants. There are various and interrelated factors responsible for the expansion of town. Among them rapid population growth is the major. According to (Efrem & Tesfaunegn, 2017).

2.3.1. Migration

Migration considered as major factor to urban growth dynamics in Ethiopia and has significant contribution to the country's urban population. The population migration in Ethiopian to urban centers has been rural-urban and urban–urban. Several studies including the report on State of Ethiopian Cities revealed that proportion of migrants in urban centers drastically increased. The proportion of migrants in the urban population which was above40% and more than 73% of the urban migrants were from rural areas (CSA, 2008), indicating increasingly general level of rural-urban migration Better employment opportunities and basic social services are attracting rural migrants to the urban areas.

2.3.2. Urban Expansions

As demand for land increased over time, urban centers have been physically expanding their boundaries to surrounding rural and peri-urban areas by including additional land where people did base their lives in agriculture. Most commercial and manufacturing expansions were guided by the urban expansion planning where as many of the residential settlements were due to urban sprawl from inner cities and informal settlement with people living at outskirts in a built or rented housing occupations. Commercial activities, infrastructures and services in expansion areas attracts people who were originally agrarian to gradually transform their living styles to urban settings and these causes spatial expansion as well as urban population increments to overall count. Accordingly, Factors proliferating Urban Expansion are summarized in below to Adama town.

- Surrounded by Agricultural productive weredas
- Transport facility,
- Commercial center
- Proximity to capital city.
- Center of recreation and tourist attraction
- Location or steepness of slope

2.4. Modeling and simulation

Perspective Modelling & Simulation has the following concept. Modelling is the process of representing a model, which includes its construction and working. This model is similar to a real system, which helps the analyst predict the effect of changes to the system. Simulation of a system is the operation of a model in terms of time or space, which helps analyze the performance of an existing or a proposed system. In this tutorial, we will discuss the concept and classification of Modelling & Simulation, their architecture, application areas, and other key ideas. Definitions of Modelling and Simulation of categories were given by(Singh, 2010)as follows

Modelling is the process of representing a model, which includes its construction and working. This model is similar to a real system, which helps the analyst predict the effect of changes to the system. In other words, modelling is creating a model, which represents a system including their properties. It is an act of building a model.

Simulation of a system is the operation of a model in terms of time or space, which helps analyze the performance of an existing or a proposed system. In other words, simulation is the process of using a model to study the performance of a system. It is an act of using a model for simulating the manipulation of a model in such a way that it operates in time or space to summarize it.

Advantages of simulation

New policies, operating procedures, information flows and son on can be explored without disrupting the ongoing operation of the real system. New hardware designs, physical layouts, transportation systems and… can be tested without committing resources for their acquisition. Time can be compressed or expanded to allow for a speedup or slow-down of the phenomenon (clock is self-control). Insight can be obtained about the interaction of variables and important variables in the performance. Bottleneck analysis can be performed to discover where work in process, the system is delayed. A simulation study can help in understanding how the system operates. "What if" questions can be answered?

Disadvantages of simulation

Model building requires special training. Vendors of simulation software have been actively developing packages that contain models that only need input (templates). Simulation results can be difficult to interpret. Simulation modeling and analysis can be time consuming and expensive. Many simulation software have outs.

2.4.1. **Overview of CA-SLEUTH Model**

The name SLEUTH was derived from the simple image input requirements of the models: **S**lope, **L**and cover, **E**xclusion, **U**rbanization, **T**ransportation, and **H**ill shade SLEUTH which based on Cellular Automat that was written in C programming language is a model which developed to simulate cities under the influence of urban change Dynamics. SLEUTH model that has developed as Unix-based, open source is run with UNIX emulator Cygwin programs in the Windows environment. SLEUTH does not use socioeconomic data and it only uses geographic data of the built environment (Maithani, 2010)

The data set to be need to prepared to run SLEUTH model need to have certain main standards. These basic standards are:

- The entire data set to be used as input must be in 8-bit depth and in ".gif" format.
- The entire data set to be used as input must have the same coordinate system and the same projection
- All data set groups to be used as input must have an equal number of pixels (resolution) (row x column) The entire data set to be used as input must have the naming standards in the model user guide

In the data set groups to be used in the calibration phase, the pixel size should have a ratio of 1/4 to 1/2 - 1 determined for the standards. 6 different data sets which are required to be able to start Urban growth and land cover / land use simulation process in SLEUTH model was produced. Data produced are below:

1. Urban data of at least 4 different cities (1990, 2000, 2010 and 2019)
2. At least two different transportation network-transportation data (1990 and 2010),
3. At least 1 slope (%) data (DEM),
4. At least 1 hills hade data (DEM-Digital Elevation Model)
5. At least 1 exclusion data,
6. At least two different land cover / land use data (2000 and 2010)

SLEUTH model contains four predefined growth rules Spontaneous Growth, New Spreading Center Growth, Edge Growth and Road-influenced Growth. Growth rules are applied separately to each pixel and it is taken into consideration that whether the relevant pixel would be transformed into the urban area or not that. Implementation of growth rules and the system behavior are carried out with five-growth control factor (Dispersion/ Diffusion coefficient, Breed Coefficient, Spread Coefficient, Slope resistance coefficient and Road-gravity Coefficient). The growth control coefficients take full values in the range

0-100.Calibration stage constitutes the first step of SLEUTH model applications. Calibration is the step in which the growth coefficient values to be used in the forward simulation are determined according to the input data of the model. SLEUTH model calibration is performed in three steps: coarse, fine and final, in three different resolutions (Tombuş & Yüksel, 2018).

The model works based on five growth coefficients here is a preview of some of the contemporary urban models based. These models have been studies for understanding the modeling concepts and model frameworks, for this research. Urbanization growth rules are summaries and present in the following.

- Spontaneous Growth models the development of urban settlements in undeveloped areas.
- Diffusive Growth permits the urbanization of isolated cells, which are flat enough to be desirable locations for new urban spreading centers.
- Organic Growth promotes the expansion of established urban cells to their surroundings.
- Road Influenced Growth promotes the urbanization along the transportation network because of increased accessibility.

Table 2.1 Relationship between growth types and growth coefficients

No	Growth types	Controlling coefficients	Summary description
1	Spontaneous	Dispersion	Simulates the random urbanization of land
2	New spreading center	Breed	Simulates establishment of new urban centers
3	Edge	Spread-slope	Simulates old or new urban centers spawn additional growth
4	Road Influenced	Road, gravity dispersion breed, slope	Simulates newly urbanized cell growths along transportation networks

2.4.2. The Role of CA-SLEUTH Model in Urban Planning

Computer modeling is essential for the analysis, and especially for the prediction, of the dynamics of urban growth Rapid progress in remote sensing (RS), geographic information systems technology (GIS) and computer science, has allowed new spatial modeling approaches, such as cellular automata (CA), artificial neural networks statistical models and multi-agent models Using these models, policy makers can analyze different scenarios of urban growth, land use change and evaluate their effects in support of land use planning and policy Among the dynamic models, CA models, originally proposed by Ulam and Von Neumann in the 1940s, are among the most remarkable urban growth models because of their flexibility, simplicity in application, and their close ties to remote sensing data and geographic information systems (GIS provided the theoretical relationship between geographical CA and urban land use change dynamics, a variety of CA models such as SLEUTH (Bihamta, & Gholamalifard, 2015).

The SLEUTH model is a CA-based urban growth model coupled with a land-cover-change model It can project urban growth based on historical trends with urban/non-urban data or with detailed categorized land use data under different developmental conditions pointed out that the parameters derived from calibration of the Sleuth model can be compared among different urban systems, and the interpretation can provide a foundation for understanding the urban growth processes unique to each urban system (its regional DNA).

The parameter values (*i.e.*, an urban DNA) can serve as valuable elements to describe a region's character. The majority of SLEUTH applications have been for urban forecasting, for integrated modeling of urban growth with some other social or physical process model was designed to simulate urban growth and land cover change. Requirements for driving the model: Slope, Land use, Exclusion, Urban extent, Transportation and Hill shade. SLEUTH simulates urban dynamics through four growth rules: spontaneous growth, new spreading center growth, edge (organic) growth and road-influenced growth. Each type of growth is applied sequentially during each cycle, and is controlled by five coefficients, namely diffusion, breed, spread, slope resistance, and road gravity (Hua, et al, ,,2014)

The urban growth rules involve the selection of a location by investigating the spatial properties of the neighboring cells, and urbanizing the cell under consideration based on a set of using land use and urban growth trend. There are four types of growth rules in the model. According to (Jantz,et al,,2004) urbanization is the sum of these growth rules:

2.4.3. Application of SLEUTH at Worldwide level

The key aspects that made SLEUTH a popular land use change model where its open access, availability of source code, and ease of use (Chaudhuri & Clarke, 2013). This part of the paper provides an overview of, first, the general applications of the model in the United States and the rest of the world followed by an overview of studies where the model was coupled with other types of social and physical models. The paper concludes with a review of applications of the model under different scenarios. Figure 2.1 shows the published applications of SLEUTH until 2012.

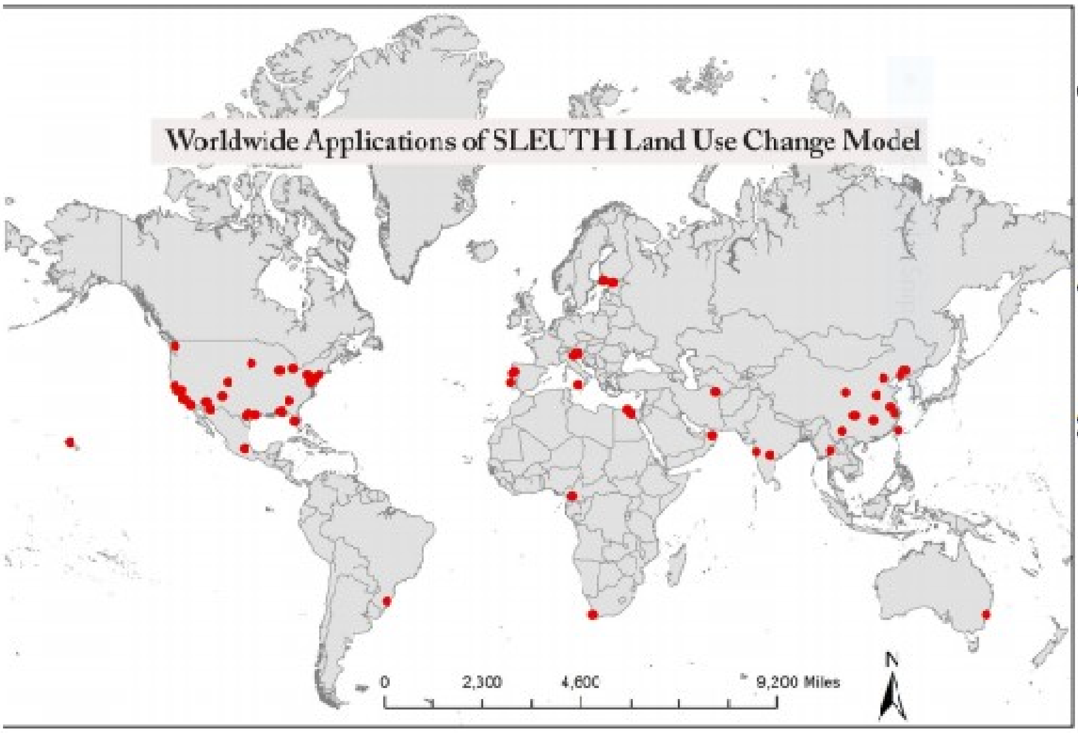


Figure 2.1Worldwide Application of SLEUTH Land Use Change

2.5. Scenario

The use of scenarios to address land-use changes have become useful tools in the assessment of land-use dynamics Several policies and strategies have been formulated by national and regional governments in order to minimize the negative impacts caused by improper urban development's thus exploring scenarios by predicting future urban land use patterns under different ('What If?') conditions can help in the managements of urban change as well as in the developments of alternatives plans before irreversible transformations occur (Mubea, Goetzke, & Menz, 2014).

Scenario- based planning is the testing and application of different scenarios to come up with a plan. It is a powerful way to deal with uncertainties of the future associated with urban growth, and has been a common practice in recent years with technological advancements(Kamruzzaman, & Yigitcanlar, 2017).

The building of scenarios ('What If?') in the context of policy option for regional planning and governance turned out to be very appealing and stimulated the discussions more than graphs and text. The idea of this exercise is to bridge the two communities in order to collaborate around spatial models and produce future land use maps which should have a clear and accepted interpretation, be robust, statistically validated and respond to policy interventions. By using urban growth rate as a driving force, the following scenarios were developed by the researcher for current study areas.

- Aggravated scenarios
- Business as usual scenarios
- Restricted growth scenarios

2.6. Empirical Literature Review

The empirical study of urban spatial growth is accessing from internet sources and same published research few of them have been presented in the following.

(Chaudhuri & Clarke, 2013b) examined The SLEUTH Land Use Change Model: A Review Over the last 15 years, since its first publication, SLEUTH has continuously been explored, modified and applied worldwide by the land use change modeling and planning communities. Over these years, one of the biggest criticisms and yet a strength of SLEUTH is its simplicity, which has led to an increasing number of applications.

(Al-sharif & Pradhan, 2013) investigated the Spatio-temporal Analysis of Urban and Population Growths in Tripoli using Remotely Sensed Data and GIS and GIS has focused on the patterns and extents of change in urban growth of Tripoli metropolitan area from 1984 to 2010,which can be useful in terms of directing the analysis results demonstrated that there is an obvious indication of urban dispersion and urban sprawl for the metropolitan of Tripoli Town, i.e. Sprawl is increasing with time. Consequently, it is not a rule that cities in developing parts of the world become more compact with decreasing population growth rate.

Another study by Silva & Clarke, (2002)Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal important finding from the study calibration experiments is the fact that detailed and exhaustive calibration improves the performance of the SLEUTH model in a significant way. The most interesting finding is the observation of how these two different urban settings constrained the evolution of the three calibration phases in order to adjust the model closer to the reality of each area However, the more rapid closure on results also reflects an urban reality that easily corresponds both to the history of human settlement and to the roots of the computer models of urbanization and land use change that have been applied.

According to Tombuş & Yüksel, (2018) Use of SLEUTH Model in Land Cover/Land Use Change Simulation, Corum Town In this study, they are aimed to forecast for the future with respect to land cover/land use in the year 2040 Turkey, Corum, one of the medium-sized Town to understand much better the urban structure. SLEUTH model which is one of simulation techniques in Cellular automata-based urban growth and land cover/land use change models was used. According to carried out SELUTH simulation results to determine an estimate of year 2040 change, the most changes have occurred in urban areas. According to the study trends of development scenarios, it is estimated that urban structure will increase by 49.3% (1001 ha).

Simulating Urban Growth Using the SLEUTH Model in a Coastal Peri-Urban District in China the study examined that SLEUTH Model Calibration Procedures Based on the calibration data, future urban growth trends were predicted for 2020 assuming three development scenarios: a historical growth scenario (HU), a regional and urban planning scenario (RUP) and an ecologically sustainable scenario (ES) (Hua, Tang, Cui, & Yin, 2014a). The first scenario assumed that growth and development would continue along with historical trends; urban growth was simulated with unchanged current conditions. For this scenario, parks and water were fully excluded from future development The second scenario projected a managed growth in which urban growth was limited using an excluded layer, according to the future development plans for Jimei district and Xiamen Town The RUP scenario reflected a stronger commitment to spatially focused growth and resource protection. Areas excluded from future development, according to Town development plan included In the third scenario, growth was allowed to continue similar to the second scenario with the same excluded layer, The results of the urban future extent predicted by SLEUTH are The historical growth shows that there is no limit to urban expansion. The area of the Town expanded about 78% from 2006 to 2020, reaching98.8 km2. The HU scenario showed the highest urban expansion, leading to the degradation of an overwhelming amount of land and natural resources.

Mueller, Klein, & Hof, (2018) on the article An easy-to-use spatial simulation for urban planning in smaller municipalities analyzed the most spatial simulations require great volumes of data input, intensive data preparation or programming skills. Consequently, high quality spatial simulations are usually not applied in practice in the municipalities of smaller size (< 25,000 citizens). The study indicated that the easy- way to-use tool for smaller urban administrations. A web application was developed which requires a minimum of manual user input for automated data preparation. Gamified elements aim to encourage the user to experience the underlying mechanisms of the system under alternating planning scenarios. These mechanisms are modelled as a combination of spatially implicit and explicit rules which can be derived from dependencies in the data itself. Spatial attractiveness was modelled as a function of accessibility of facilities, ground value, soil sealing, traffic intensity and noise pollution in a multi-variate spatial autoregressive regression analysis.

2.6.1. Related Empirical Studies in Adama Town

Yhdego, (2007) examined the urban expansion of Adama Town for suitable sites for housing. The researcher examined the challenges and opportunities in Town that current efforts to digitize the cities' systems through GIS for effective suitable site selections for housing. The paper evaluated the practice urban expansion and challenges and potential opportunities that can be utilized through urban infrastructure asset management. According to the findings from the article, the main problems affecting infrastructure due to lack of improvement and upgrading condition they examined the consequences on the environment, urban expansion, housing, education and health the study assessed urban expansion of the Adama Town by integrating GIS and Remote Sensing techniques, remote sensing in providing information with regards to suitable sites selections for housing.

Tesema, Negera, & Sori, (2017) studied Evaluating land-use plan using conformance-based approach in Adama Town, The studies have been conducted using the two acknowledged theories they are conformance based approach, which highlights the conformity between physical development and plan's intention; and performance based approach, which focuses on how the plan is consulted in decision making process. Hence selection between the two evaluation approaches depends on one's understanding of spatial planning and the type of plan under study. In the paper, morphological conformity was assessed by comparing physical development with plan's prescription by using land-use land-cover as of 2004, 2014, and maps of proposed land-use plan The results from study Overall, the majority of developments have followed a plan; however, there are nonconforming developments occurring outside of proposed locations mainly in western and eastern parts of the Town are shown. The research examines the extent to which Land-use plan of Adama Town functioned from 2004 to 2014 has guided and controlled all spatial developments during the planning period by measuring the degree to which actual land-use outcomes over a10-year period conform to the Plan intention the studies suggested conforming, nonconforming, and unfulfilled developments are identified during the study period.

Manikandan, (2018) suggested that in Ethiopia, policy makers need to link Spatial and Temporal Dynamics of Urban Sprawl Using Multi- temporal Images and Relative Shannon Entropy Model in Adama, Ethiopia The researcher suggested found out that the rate of urban areas are Remote sensing-based indices in urban areas are generally used to distinguish between different urban land-use features such as built-up, barren land, vegetation and water bodies and extraction of these land use features is very challenging because of high intermixing between classes, especially in urban areas The findings indicated that in a period of 33 years (1984–2017), the built-up area in Adama municipality has increased almost six times (51.3 sq.km) of 1984 (8.80 sq.km), which shows excessive alteration of land use occurring in the area. The results from this study of built-up area change would allow urban planners to understand and evaluate municipal growth for sustainable usage of the urban land system.

(Tesema, 2018) the article harnessing the Success or Failure: Effectiveness of Adama Town Master Plan in Managing Urban Growth and Preserving Green Spaces In this study, the effectiveness of the plan is measured by the level of conformity between plan intention and outcomes nonconformity or significant deviation from original plan design to adjust course to updated information. The paper evaluated the current practice of Master Plan and its implementation According to the findings from the article, the main problems affecting Master Plan implementation is Non-conforming development. The researcher Provides important information on the effectiveness of Adama Town master plan and influencing factors, for its Successfulness.

According to the paper urban built-up area information is required in various applications of land use planning and management (Sinha, Verma, & Ayele, 2016) However, urban built-up area extraction from moderate spatial resolution Landsat time series data is challenging because of significant intra-urban heterogeneity and spectral confusion between other land cover types the paper proposes a technique to extract urban built-up area from time-series data and determines urban area changes between 1984 to 2015. Remote sensing based indices in urban areas are generally used to distinguish different urban land use. Therefore, the results of this study is to show built-up area change would allow urban planners to understand and evaluate municipal growth for sustainable usage of the urban land system.

2.7. Conceptual Framework

In order to prepared urban model same standard data need to be identified that are relevant to a particular study area According to model urban spatial growth satellite data are obtained from open sources in this study the urban simulation and urban prediction were developed to Model of study area By using C^{++} language in Cygwin Environments.

This study summarizes urban spatial growth modelled by using the CA - SLEUTH Model by assigning urban growth type and urban growth control parameters has been assigned to the study area within the CA-SLEUTH Model calibration phase. The result from model calibration has been identified using spatial matching Statistics with original input data the model was generated in the simulation and Scenario based predication. In Simulation Matching Statistics result are analyzed by comparing with current spatial extents of input data to predict future urban spatial growth. The model results can be used as input for ensuring of efficient utilization of land and using as guides for actors involved in urban plan preparation and implementation.

From the analysis of related literature above, the researcher can realize that only a few studies engaged Directly in the analysis of the Spatiotemporal Growth of CA-SLEUTH Model problems in urban growth Limited studies on urban Modelling, governance structure, on the causes and consequences of urban development and urbanization, the role of policies and institutions, urban development choices and development of urban studies have been done by the same authors in the study area. This shows there is a need to investigate area specific challenges through problem solving research.

Most of the findings from the above studies indicated that governance and institutional constraints were critical challenges in the improper urban growth and the handling methods More vividly seen is out datedness, inadequacy and incompleteness failure in urban sectors Causes and consequences of the deficiencies in urban development were examined in little depth from the studies. Option for alternative, sustainable urban growth developments were efficiently investigated in the studies.

Hence, the researcher in integrated Modelling urban Spatio temporal growth of Adama can help fill the gap in such investigation. More articles will be included in the main document to enrich the literature review.

CHAPTER THREE

3. Materials and Methods

3.1. Description of the study Area

3.1.1. Location

Adama is located about 100 km southeast of Addis Ababa along the main road to Harare, enclosing between 8^0 35' 00" to $8^0$36' 00" North latitude and 39^0 11' 57 to "39^0 21' 15" East longitude at an average altitude of 1620m above sea level. East Showa Zone, in which Adama is located, form a part of the mid central plateau physiographist unit.

It is found in a nodal location along main national and regional transport lines from the capital Addis Ababa to other important towns. It is also situated close to natural, recreational Sites such as 'SODARE',' ' BOKU' etc.

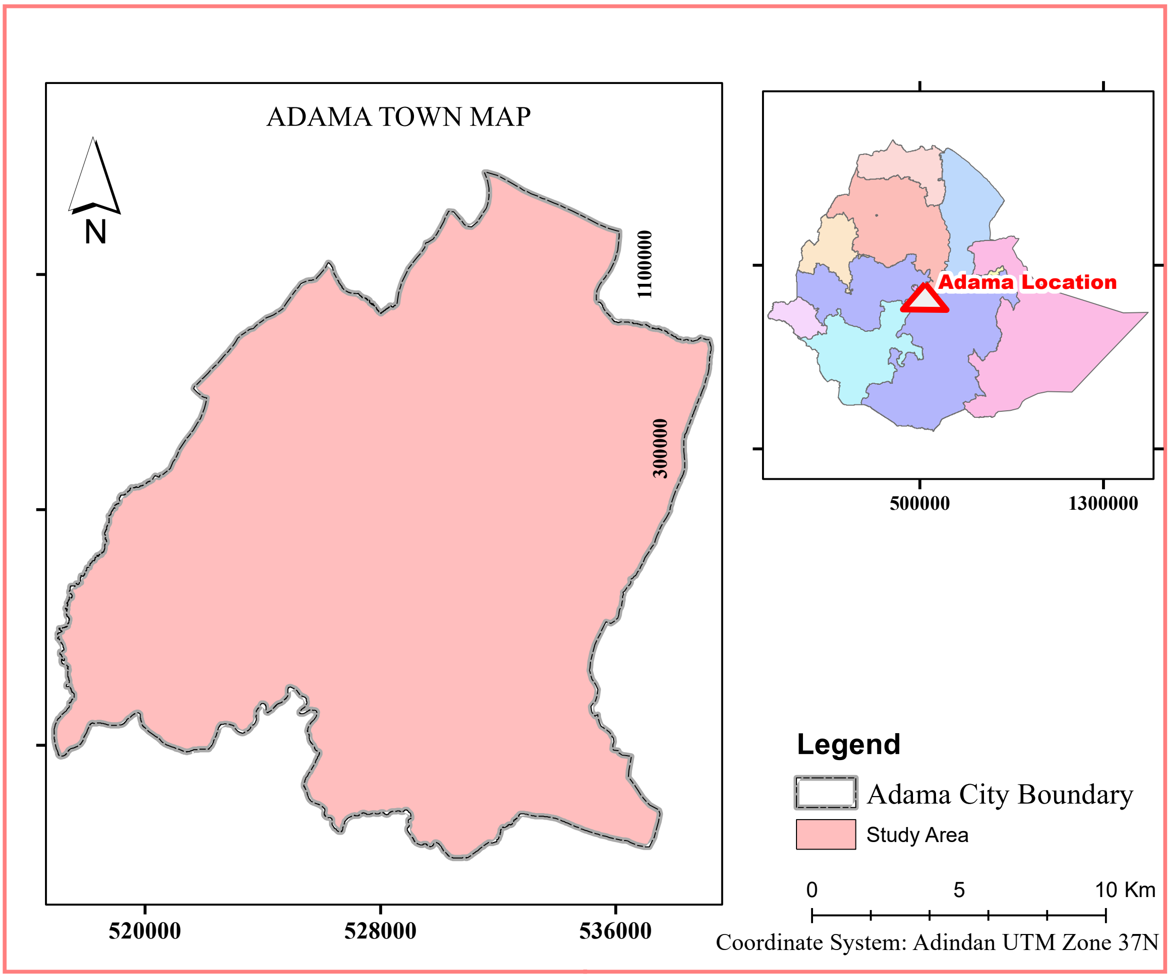


Figure 3.1Location of the study area

3.1.2. Climate

Adama lies in somewhat warm and lower climate, hence, it enjoys hot and dry weather for the greater part of the winter and warm and sunny climate in summer References to its temperature points that Adama has a minimum annual temperature falling between 19^0 and 22^0C. Its yearly minimum rainfall is reported to be 760 mm According to NUPI (1995), the humidity record based on the 39-year period (i.e., 1953-1991), points that, the mean annual precipitation of the Town was 822.5 mm.

3.1.3. Urbanization History of Study Area

The reports from the Adama municipality Adama Town was established almost before 100 years ago even in the late 19th century According to the officers report Ethiopian kingdom had unintentionally contributed for Adama to emerge as a leading center from among its vicinities. This was followed by such measures as establishing a strong base of the Ethiopian Ground Force at Adama. The opening of Addis Ababa to Djibouti railway in 1917 was another impetus for the emergence of Adama as an important commercial center. The beginning of the first settlement of indigenous people to exchange goods and services with the railway workers was the embryo of the process that later brought about the evolution of the area into the focal as an urban area. Further, the Italian occupation was also another important stimulus for Adama to begin playing substantial economic roles in the area According to Adama Town municipality.

3.2. Data collection and Data sources

Here it needs the following major data that have to be collected and used in the process of the analysis. The data for the projects are listed in the following tables.

Table 3.1 Data source

No	Data required	Sources	Data type	Year	Uses	Resolution	Format
1	Satellite image Landsat MSS, TM ETM+, OLI	Classified from satellite image	Secondary data	1990,2000, 2010,2019	LULC	30m	TIFF
2	DEM	Free ASTER	Secondary data	2019	Slope		GRID
3	Aerial Photograph	EMA	Secondary data	2019	Base map	15 cm	TIFF
5	Adama Master plan	Municipality	Secondary data	Recent	Comparison		CAD
6	GPS Survey	GPS Satellite	Primary data	2019	Validation		
7	Road network	Digitized on Satellite image	Secondary data	1990,2000, 2010,2019	Input data		Vector

3.3. Software used

The process of analyzing this research work was passing through some compulsory steps. In order to achieve the objectives of this research the following approaches and Software used are adopted. Arc GIS 10.4.1 ERDAS IMAGINE 2014, IBM SPSS Statistics and CA-SLEUTH Model are widely accepted software and used in recent studies. Arc GIS 10.4.1

Arc GIS 10.4.1 is a software application developed by ESRI for working with maps and geographic information. It is used for creating maps and model, compiling geographic data, analyzing spatial information, sharing geographic information and managing geographic information in a geo-database this method software common for spatial information analysis the study areas . ERDAS IMAGINE 2014 is one of the latest several commercial software products that are designed specifically for the purpose of accessing, interpreting, and analyzing satellite images ERDAS IMAGINE 2014 helped in this study to images processing and manipulating large image files and storing, viewing, updating and analyzing raster and vector datasets. CA-SLEUTH Model to simulate and forecast future urban spatial growth for the study area. Table 3.3 shows the implemented software, lists with their corresponding version and purposes.

Table 3.2 List of Software's and their purpose

No	Software	Purpose
1	CA-SLEUTH model	To simulate and forecast future urban spatial growth
2	Arc GIS 10.4.1	For analyzing spatial information
3	ERDAS IMAGINE 2014	To produce land use land cover
4	IBM SPSS Statistics	Analyzing Statistical data

3.4. Method of Data Analysis

Data analysis approach for this study was used two techniques the first method is simulating urban spatiotemporal dynamics and second is to predict the future situation land use of the Adama Town by comparing Actual urban expansion with simulating urban expansion. Based on these two techniques in this paper will try to analysis and predict of urban dynamics in the study Area with the help of CA-based CA-SLEUTH model. The overall methodology used for examining the research is shown in Figure 3.3 below.

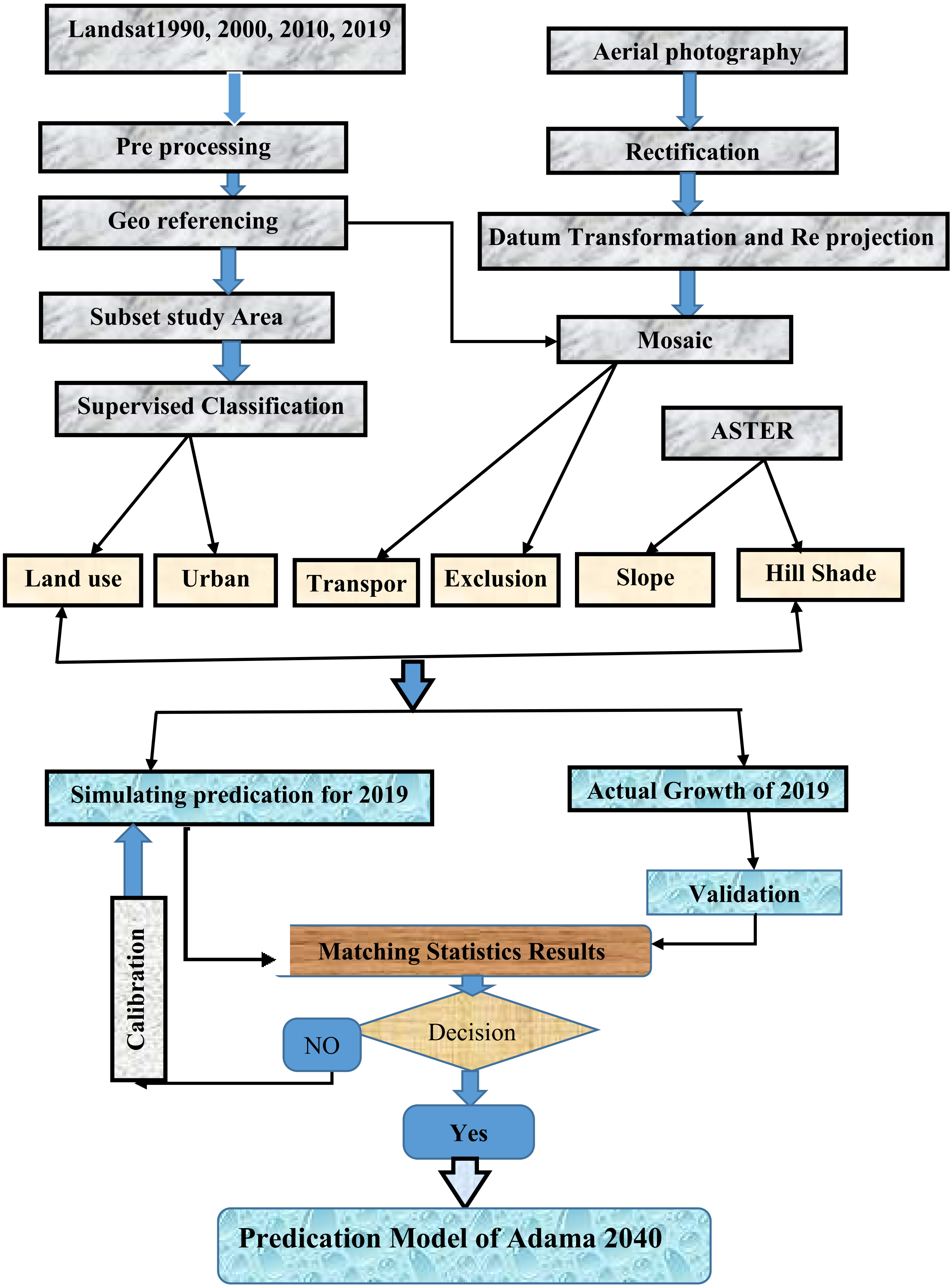


Figure 3.2 Methodology by the Author

CHAPTER FOUR

4. Data Analysis, Results, and Discussion

Data analysis in combination with the results is consequently and clearly provided in this section. The predefined workflow figure 3.2 are applied for urban modelling, Calibrating, and predication, of urban dynamics, respectively to solve the research problem in this paper. Understanding the dynamics of complex urban systems and evaluating the impact of urban growth on the environment involves procedures of modeling and simulation. Cellular Automata (CA) are a modeling procedure which is widely used by researchers of urban growth for predicting future urban extents(Kumar, & Ghamisi, n.d.).

In this research CA-SLEUTH is used to simulate and predict the urban growth in Adama Town, Province SLEUTH is a dynamic, scale independent and future oriented model which can be applied to all regions under different conditions by modifying same initial parameters, it can also use different types of images simultaneously as input data and apply GIS techniques and remote sensing tools to process them.

4.1. Data Analysis and Results

The most important issues for urban planners and administrators are measurements of urban growth and determining the urban requirements that can be accomplished earlier to get ready for future urban demands, rather than waiting for urban expansion will occur or not (Al-sharif & Pradhan, 2013).

The models presented and used in this study can be employed to give guidance to identify and measure the changes likely to happen if the tendency of urban history persists. The data have been collected from primary and secondary data sources. The input dataset for the SLEUTH model is listed below.

4.1.1. SLEUTH Input Dataset Used in the Study

The input dataset for the SLEUTH model is processed and compiled using remote sensing and Geographic information system techniques. SLEUTH requires that all input data must be in the same extent, (30x30), same projection (Adindan_UTM_Zone_37N, EPS Projection: Transverse Mercator and same resolution which is 30 m. Therefore, all data were rectified with an acceptable root mean square error (RMSE) and all the input layers were resampled to 120, 60, and 30-m resolutions corresponding to the coarse, fine, and final resolutions using a nearest neighbor algorithm. Finally, the input dataset has been converted to unsigned 8-bit grayscale GIF format. The input dataset for the CA - SLEUTH Project as listed in the following tabular forms.

SLEUTH requires six different data layers as input for both the simulation and prediction functions. Each layer must be compiled as a grayscale .gif image. If one wishes to model land-use, one is able to input a sixth file, a land-use classification image. For each of these input layers, a pixel value of zero is considered inactive or nonexistent, while all values 0<n>255 are considered active, or existing entities for that theme. Each data, image must be consistent with resolution to ensure that pixels in all layers conform in size and location in model space. For the same reason all raw data images gathered must conform to the same projection before processing and conversion. The model expects grayscale, GIF image files with the file name format as described in below table 4.1.

Table 4.1 SLEUTH input dataset

layers	Year	Format	Naming Format
Slope layer	NA	Raster	ethoroadama.slope.astu.gif
LULC	1990	Raster	ethoroadama.landuse.1990.astu.gif
	2019	Raster	ethoroadama.landuse.2019.astu.gif
Urban Extent	1990	Raster	ethoroadama.urban.1990.astu.gif
	2000	Raster	ethoroadama.urban.2000.astu.gif
	2010	Raster	ethoroadama.urban.2010.astu.gif
	2019	Raster	ethoroadama.urban.2019.astu.gif
Excluded layer	NA	Raster	ethoroadama.excluded.astu.gif
Transportation layer	1990	converted to raster	ethoroadama.roads.1990.astu.gif
	2000	converted to raster	ethoroadama.roads.2000.astu.gif
	2010	converted to raster	ethoroadama.roads.2010.astu.gif
	2019	converted to raster	ethoroadama.roads.2019.astu.gif
Hill shade layer	NA	Raster	ethoroadama.hillshade. astu. gif

4.1.2. Slope layer

The slope is one of the major factors that affect urban expansion the slope of the current study area is shown in figure 4.1. The slope is commonly derived from a digital elevation model (DEM) data having 30m resolutions, which is retrieved from ASTER Cell values are in *percent* Pixel value range: 0–100. Among topographic factors that affect the land use planning, slope is considered for this study Slope map of the urban extents was produced using the Spatial Analyst or 3D-Analysis tools of Arc-GIS. The standardized slope raster layer was further reclassified in two subgroups using standard classification schemes. This classification scheme divides the range of attribute values into equalized sub ranges via manual methods there by allowing us to specify the number of intervals while ArcMap determines where the breaks should be and new values were re-assigned ratings. Figure 4.1.

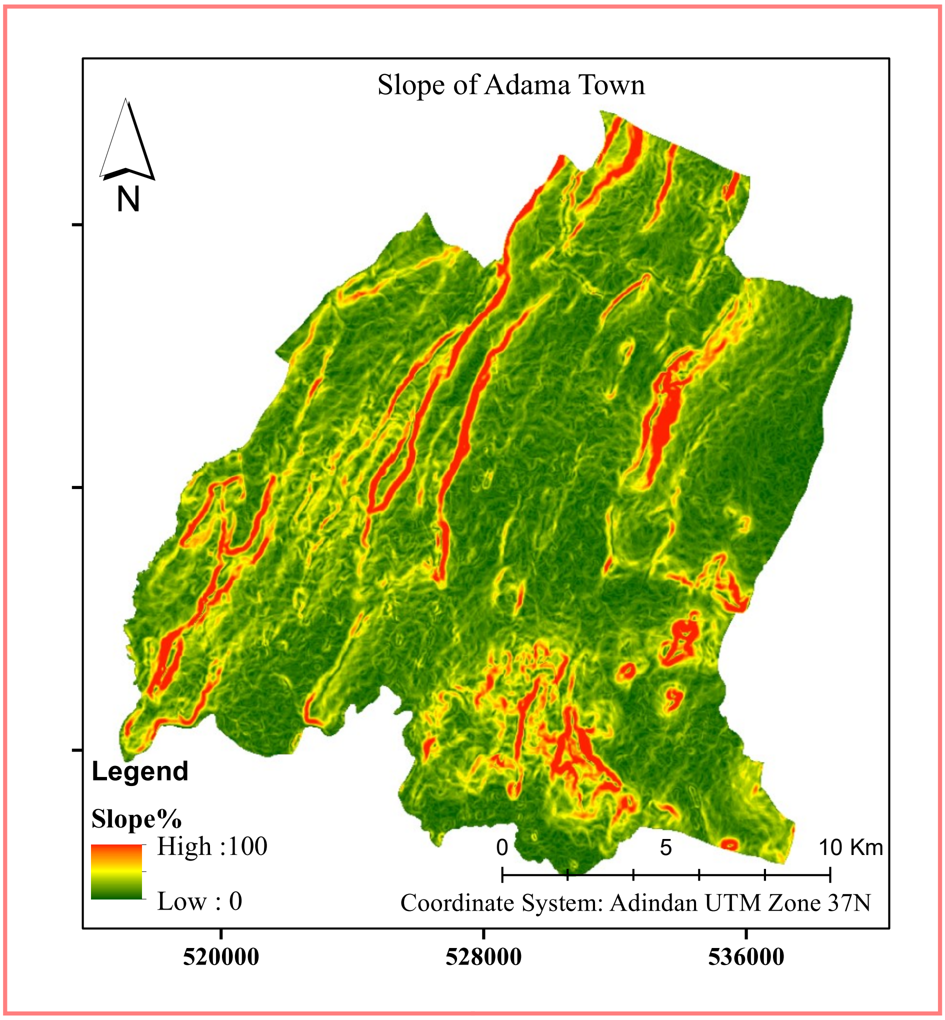


Figure 4.1The Layer of Terrain Slope

4.1.3. Land use/land cover layers

Land use, land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil and/or artificial structures Land use, on the other hand, has a more complicated aspect as it involves social sciences and management principles and is defined as the social and economic purposes and contexts for and within which lands are managed Although land use and land cover are frequently used together, there is a very clear divergence between the two. (Coomes et al., 2001).

Land use, land cover type of the Adama Town was prepared from 30 meter resolutions of Landsat 5 TM satellite images from the following years were obtained: 12/06/1990 and 11/06/2019 by using maximum likelihood of supervised classification through the use of ground verification or field inspections. It was classified into six general classes (Urban, Agricultural, and Shrub, Barren land, Water body and unclassified). Figure 4.2. Pixel value range: 0 – 255. Accuracy assessment of Land use classes for each year was calculated as shown (Table 4.2).

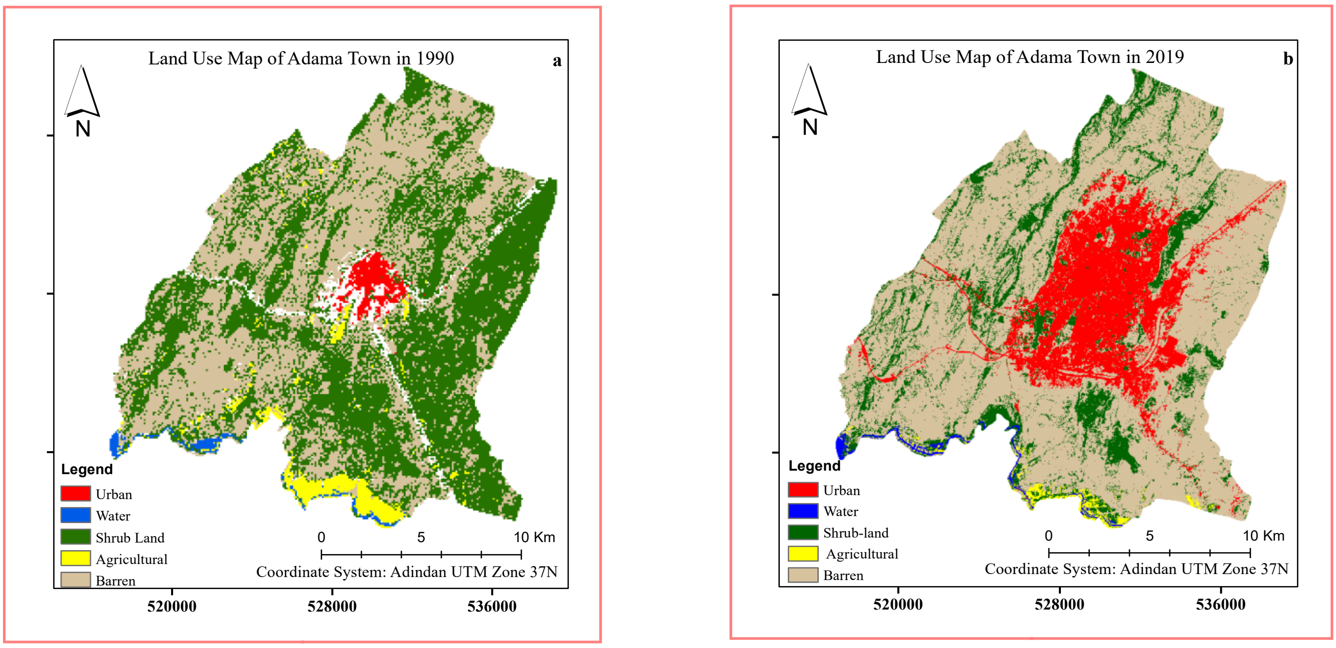


Figure 4.2 Land use land cover layer for the study area

4.1.4. Urban Extent

The urban extent for the start year, or *seed*, is used to initialize the model and is the basis for the CA driven urban growth. For calibration, the earliest urban year is used as the seed, and subsequent urban layers, or *control years*, are used to measure several statistical best fit values. For this reason, at least four urban layers are needed for calibration: one for initialization and three additional for a least-squares calculation. The definition of "urban extent" is up to the creators of the data set. The model simply requires a binary classification of urban/nonurban. (Hua, et al ,,2014).

Methods used urban extent layers of 1990 and 2000 were derived from the corresponding satellite images. The images for these two years were classified into two classes; urban and nonurban. Urban extent layers for the years 2010 and 2019 were extracted from the classified LU/LC layers. Urban extent at the beginning year (known as the "seed") is used to initialize the model, and other years (called a control layer) is applied during calibration phases for the least squares calculation to generate the optimal statistic result. Mentioned in (Figure. 4.3). Pixel value range (0-256) 0 = Non-urban 0 < n < 256 = urban.

The urban extent layer only requires a binary classification of urban and non-urban pixels. The pixel values for the layer ranges from 0 to 255 with 0 being non-urban areas and the rest of the non-zero values being defined as urban areas This input provides information on the urbanized area for a given location and serves as a reference for the calibration of the model and a basis on which the goodness of fit of the model is determined. (Chaudhuri & Clarke, 2013). As shown in Figure 4.3 the classified urban growth results are more objective and classes are easily separated than pixel based. The generated urban growth based land use, land cover classification data urban extent layers indicated as follows as a) Urban Extent 1990, b) Urban Extent 2000, c) Urban Extent 2010 and d) Urban Extent 2019.

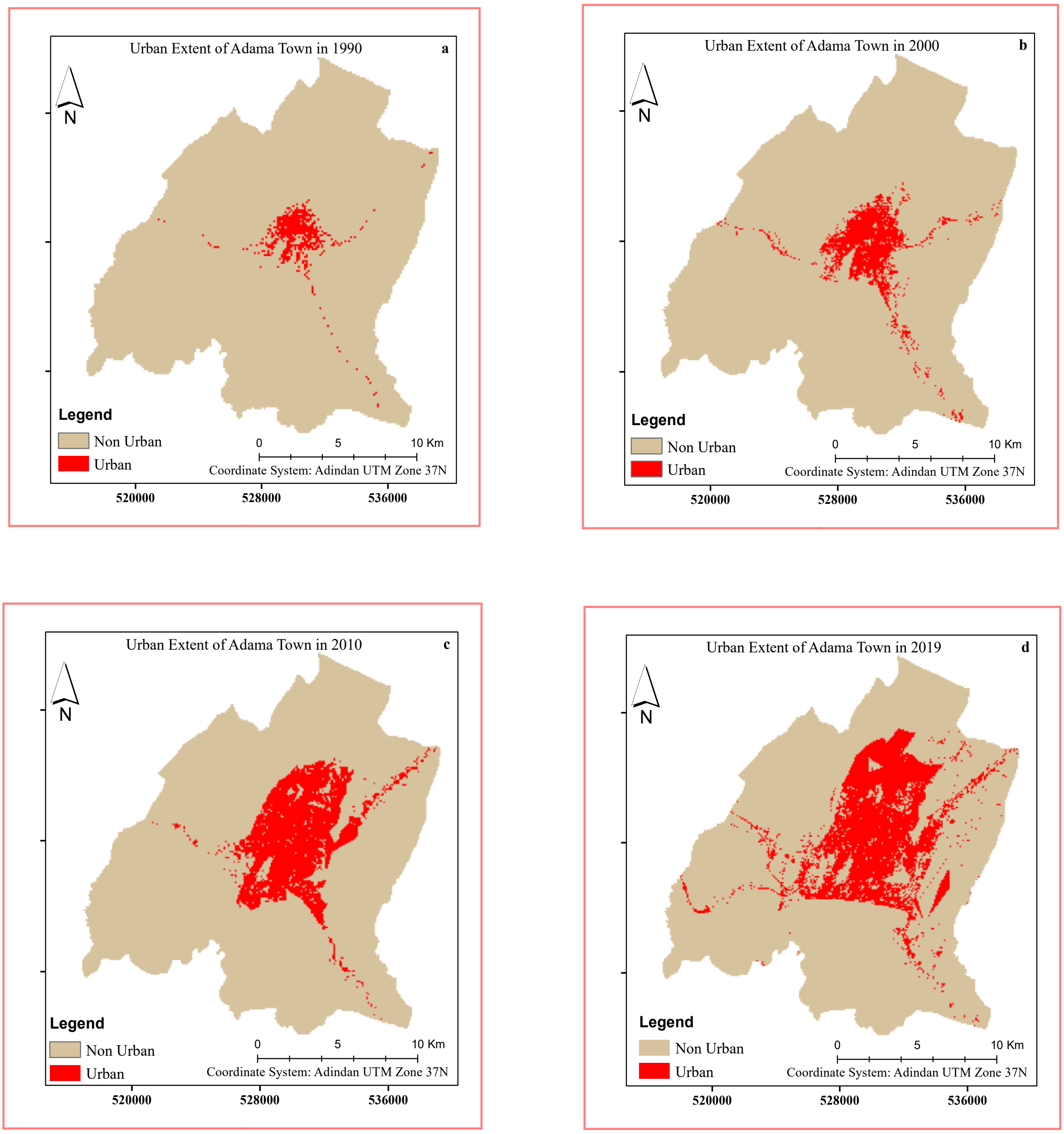


Figure 4.3 Urban Extent layers a) Urban Extent 1990, b) Urban Extent 2000, c) Urban Extent 2010. d) Urban Extent 2019.

4.1.5. **Excluded layer**

The excluded image defines all locations that are resistant to urbanization. Areas where urban development is considered impossible, like National Parks, Military parks, monuments and water bodies like rivers, Green Areas, /Reserved Areas, Recreation and Environmental Sensitive Area, water canals and dams In Adama Town uninhabitable areas like Environmental Sensitive Area industrial parks are shown in below maps. Figure. 4.4.

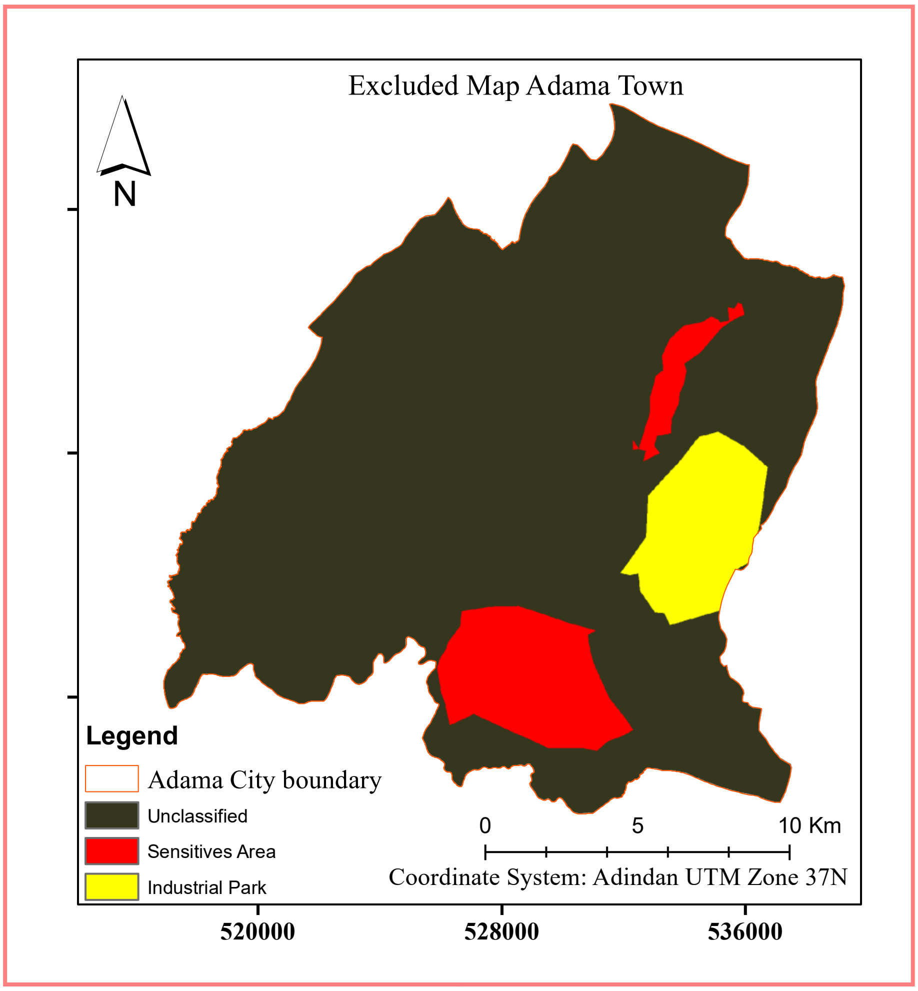


Figure 4.4Excluded layer

4.1.6. Transportation layer

As indicated by the data presented in Fig. 4.5,Major road networks have a great influence on the urban growth as cities tend to develop from the downtown to the directions along the transportation system. Road networks for the years 1990, 2000, 2010 and 2019 were digitized using ArcGIS 10.4.1 as shown in figure 4.5. Google Earth pro is also used for control purposes. After digitization process, all the vector layers were converted into raster format.

Road accessibility is one of the important parameters for urban development as it provides linkage between the settlements. See figure 4.5. d Road 2019.The distance to existing urban areas is important because they significantly impact moving costs, so the roads are an important factor in housing development because their presence indicates human activity.

The road influenced growth dynamic included in SLEUTH simulates the tendency of urban development to be attracted to locations of increased accessibility pixels were assigned to a value of 100 and non-road pixels were assigned a value of 0 Figure 4.5 shows the reclassified road map of Adama Town.

Roads with higher values, such as highways, allow for a larger distance to be travelled along the road for urbanization, and hence allows for urbanization to occur further along the road network, whereas roads with a lower value have a more localized effect on urbanization this layer can be classified as either binary (road/no-road) or with relative values. The pixel value for the layer ranges from 0 to 255 with 0 values indicating no roads.

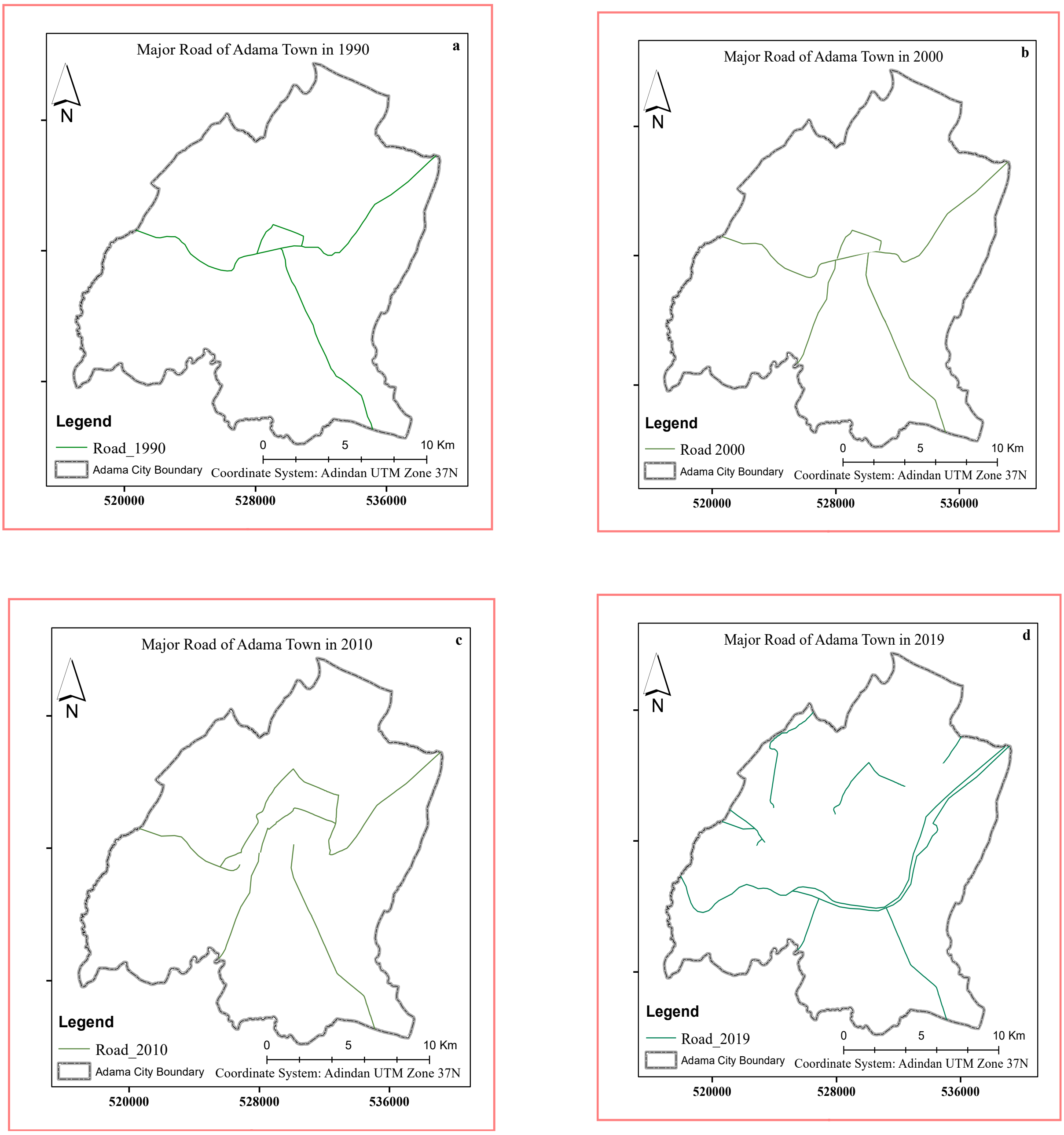


Figure 4.5 Major Transportation layer of the Study Area a) Road 1990 ,b) Road 2000, c) Road 2010,,d) Road 2019.

4.1.7. **Hill shade layer**

The Hill shade tool obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position of a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells. It can greatly enhance the visualization of a surface for analysis or graphical display, especially when using transparency. By default, shadow and light are shades of gray associated with integers from 0 to 255 (increasing from black to white).The Hill shade layers used for a better spatial visualization rather than participating in the simulation, a shadow in the output image as the background. The hill shade layer is used for visualization purposes and derived from the DEM layer See Figure.4.6.

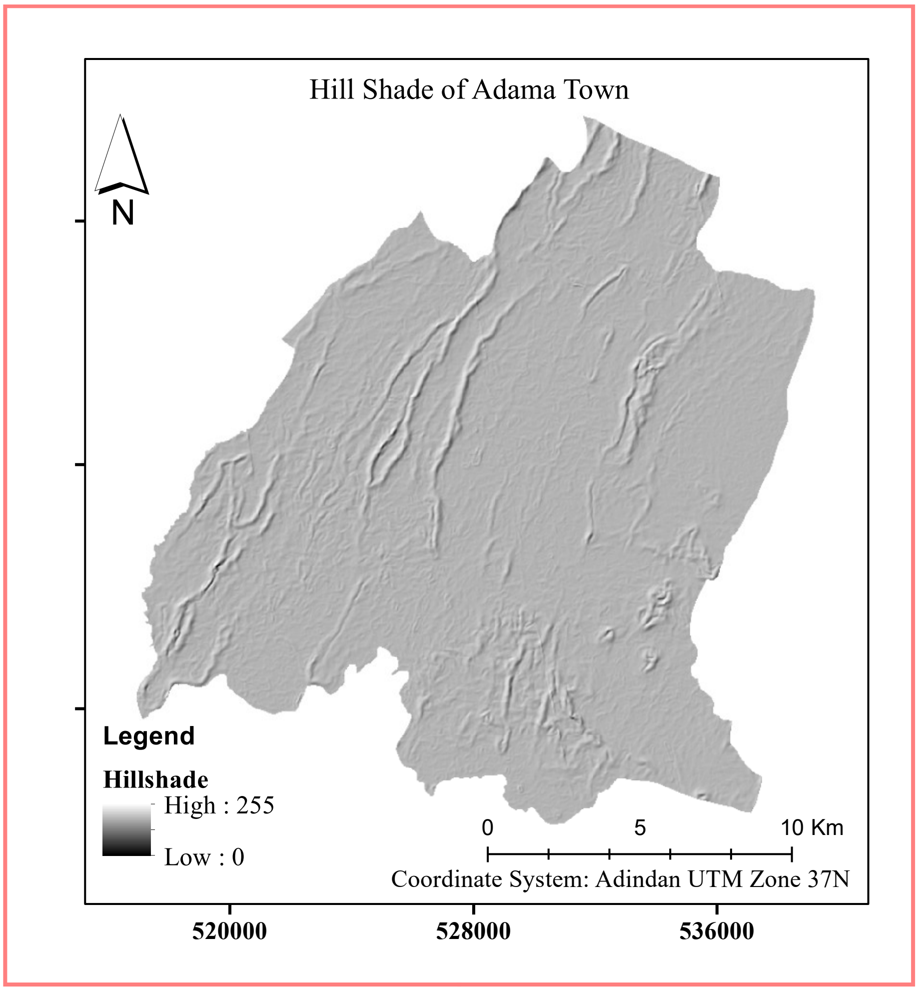


Figure 4.6Hill shade layer.

4.2. Accuracy assessment

In the study area, Landsat 5 TM satellite images from the following years were obtained: 12/06/1990, 11/06/2000, 03/07/2010 and 11/06/2019. All image pre-processing was performed using maximum likelihood of supervised classification methods. LU/LC maps derived from satellite images may contain some degree of error. Thus, this is very important that this error should be determined, today, classification accuracy assessment is extremely important for the mapping project. Nowadays the error matrix has become the standard procedure in order report for the accuracy of remotely sensed data. Therefore, for each/LC Ground coordinates are created randomly for the study area using ERDAS IMAGINE 2014 software for each LU/LC layer. The results can be seen in table (4.2) below.

Another measure of accuracy, Kappa has also been used for accuracy assessment of remotely sensed data Kappa values greater than 0.75 refer to strong agreement beyond chance, values between 0.40 and 0.75 indicate fair to good, and values less than 0.40 indicate poor agreement.

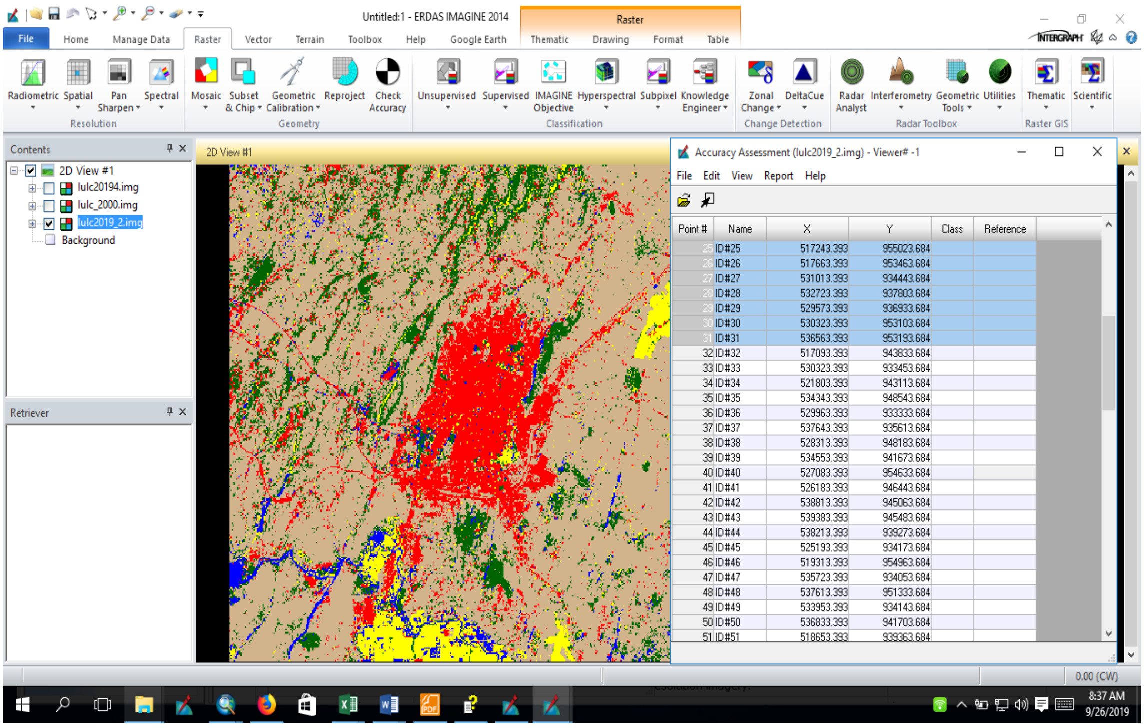


Figure 4.7 Selection of training fields and classification procedure

Table 4.2 Accuracy assessment of land sat image classification. a) LULC classification Accuracy of the 1990, b) LULC classification Accuracy of the 2000, c) LULC classification Accuracy of the 2010. d) LULC classification Accuracy of the 2019.

a

ACCURACY TOTALS	LULC Classification Accuracy for years 1990				
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	4	4	4	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Water	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Shrub	2	2	2	100.00%	100.00%
	0	0	0	---	---
Agriculture	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Barren	5	6	5	100.00%	83.33%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Urban	0	0	0	---	---
Totals	11	12	11		
Overall Classification Accuracy =		91.67%			
Overall Kappa Statistics = 0.8723					

b

ACCURACY TOTALS	LULC Classification Accuracy for years 2000				
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	2	2	2	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Water	0	0	0	---	---
Barren	4	5	4	100.00%	80.00%
	0	0	0	---	---
	0	0	0	---	---
Shrub	1	0	0	---	---
Agriculture	0	0	0	---	---
urban	0	0	0	---	---
Totals	7	7	6		
Overall Classification Accuracy =		85.71%			
Overall Kappa Statistics = 0.7200					

c

ACCURACY TOTALS	LULC Classification Accuracy for years 2010				
Class Nam	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassi	4	4	4	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Wate	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Shrul	2	2	2	100.00%	100.00%
	0	0	0	---	---
Agricultu	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Barre	5	6	5	100.00%	83.33%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Urbai	0	0	0	---	---
Total:	11	12	11		
Overall Classification Accuracy =		91.67%			
Overall Kappa Statistics = 0.8723					

d

ACCURACY TOTALS	LULC Classification Accuracy for years 2019				
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassifie	10	9	9	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Water	0	0	0	---	---
Barren	5	8	5	100.00%	62.50%
	0	0	0	---	---
	0	0	0	---	---
Shrub	2	0	0	---	---
Agricultur	0	0	0	---	---
urban	1	1	1	100.00%	100.00%
Totals	18	18	15		
Overall Classification Accuracy =		83.33%			
Overall Kappa Statistics = 0.7202					

4.3. Criteria for prefer SLEUTH Model

A major distinction among methods can be drawn on the basis of their purpose and the objective of their study. For the purpose of this study The major criteria for evaluating the operation of two modeling approaches are data requirement, linkage with GIS, and interpretability.

- Data requirement
- Linkage with GIS
- Interpretability

Table 4.3 Comparison of CA-SLUETH Model and Agent Based Models (ABMS) for urban spatial growth modeling.

S/L	Criteria to select a Modeling	CA-SLUETH Model	Agent Based Model (ABMS)
I	Data requirement	It uses Spatial data	Uses computational method
		Remote sensing GPS	Statistical data
II	Linkage with GIS	Integrated into GIS	ANN and Arc view
		Spatial modular	Logistic regression
III	Interpretability	CA-SLUETH Model focus on landscapes and transitions	Models are lack of explanatory power
		CA-SLUETH Model is most suitable in urban simulation contexts for representing infrastructure.	Interpretation of statistical models
		CA-SLUETH Model is only capable of exchanging data spatially with their neighborhoods	Agent-based models focus on human actions
			Better used to model population dynamics
			Agents can be given functionality that allows them to evolve over time

4.4. Model Calibration

According to Qi, (2012) The most noteworthy advantage of SLEUTH is that the model has an ability to calculate the optimal combination of coefficients based on the characteristics of the study area. There are five factors to manage the behavior of SLEUTH Diffusion, Breed, Spread, Slope Resistance, and Road Gravity, they all varies from 0 to 100. Determining the probability of a random pixel to be urbanized, DIFFUSION controls the entire depressiveness of detached urban cells generated by Spontaneous Growth. In Road Influenced Growth, DIFFUSION specifies the pixel number and interval moving along the road network. A BREED constraint influences the New Spreading Center Growth and Road Gravity Growth by controlling the probability to become another growth center of a new born urbanized pixel, and the times of a cell moving along a road in the Road influenced growth. SPREAD is invoked by the Edge Growth, if there is a sprawl center with more than two urban neighbors in its 3x3 surroundings, SPREAD decides the urbanized probability of other cells in the cluster. The likelihood of settlement extending up steeper slopes is controlled by SLOPE_RESISTENCE.
Before urban growth prediction, a particularly demanding step Calibration is accomplished by the comparison of simulated urbanization with historical growth to refine the controlling coefficients to the specific study area.

There are two methods available to carry out the calibration phase i.e. Brute force and Genetic Algorithm. In this study brute force calibration method has been adopted to sequentially narrow down the ranges of coefficient values with respect to the increasing spatial resolution of datasets in the three phase i.e., Coarse, fine, final. Accordingly, all the input layers were resampled to 120, 60, and 30-m resolutions corresponding to the coarse, fine, and final resolutions, respectively, and exported as unsigned 8-bit, gray scale GIF format images using ArcGIS 10.4.1. In this study, it was decided to use Lee Sallee metric, which is a measure of spatial fit between the modeled urban growths of the known urban extent of control years, as a primary measure to narrow down the coefficients(K. C. Clarke, 2008).

The Lee-Sallee metric is defined as the “ratio of the intersection and the union of the simulated and actual urban areas, it measures the degree of match between the growth predicted by the model with the actual extent of urban growth that has been seen in the control years (Chaudhuri & Clarke, 2014). This index is comparable in interpretation to the r-square value used in statistics, with a range from 0 to 1 and 1 being a perfect fit using either a single metric or a combination of multiple metrics as the best option to determine a robust goodness of fit has been a controversial subject. When using a combination of the thirteen metrics, there have been a number of metrics that appear to be correlated with each other, leading to a bias in the best fit result. Subsequently, omissions of certain metrics for the analysis have led to a low goodness of fit results(Chaudhuri & Clarke, 2013c).

Calibration is the process of training the general purpose SLEUTH model to represent a specific urban area that is being analyzed, such as Albuquerque Calibration is performed using statistical and spatial information of the past to predict a known future, then comparing this prediction produced by the model with the actual observed information for the location being studied and using this information to adjust the next phase of calibration to further fine-tune the replication of the actual observation within model.

The standard method of calibration of SLEUTH is known as “Brute Force” calibration. The alternative to brute force calibration is a user developed variant of SLEUTH that uses a separate Generic Algorithm in the calibration process. As compared to genetic algorithm calibration, brute force calibration is a well-defined, documented and researched process. So, for the purpose of this research brute force calibration process will be used.

The brute force method of calibration utilizes a Monte Carlo simulation to produce coefficient values for the five urban growth coefficients(K. Clarke & Barbara, 2017).It is a sequential method of calibration that is completed in three phases –Coarse, Fine, and Final. Starting from a coarse phase, the number of Monte Carlo iterations is increased at every phase while the range of the coefficients is narrowed based on the calibration results from the previous phase.

In the “Coarse” phase the entire range of possible coefficient values from 0 to 100 with an interval step of 25 units is used for all the five growth coefficients.

The range of best fit values derived from the “Coarse” calibration phase is used to narrow down the range of coefficients used in the “Fine” phase of the calibration process. In the “Fine” phase, coefficient values that had been narrowed down using results derived from “Coarse” phase are used as input with step increments of 5 – 10 units between the lowest and the highest predicted coefficients. Lastly, the range of best fit values derived from the

“Fine” phase is used to further narrow down the range of the coefficients and step interval of 1 – 3 units between the lowest and the highest predicted coefficients is used to determine the “Final” value for the calibration Each phase of the calibration produces thirteen goodness of fit metrics of the current run (See Table 4.3). Lee-Sallee metric it measures the degree of match between the growth predicted by the model with the actual extent of urban growth that has been seen in the control years (Herold, & Clarke, 2003).

The final prediction mode is used in forecasting the future of urban growth and land use change in the study area. During the execution of SLEUTH in this mode, the best fit value of the coefficients derived during calibration is used for the forecast. The final stage of this mode, based on the preference of the user, creates data files producing statistics on the goodness of fit metrics, value of growth coefficients during each Monte Carlo iteration, memory storage and system performance along with image files representing the forecasted urban growth and land use(Al-shalabi & Pradhan, 2014).

The growth cycle ends after all three brute force calibration phases are completed and the final best fit value of the coefficients has been derived. The last stage of this mode produces several output statistics and provides an option of producing image files based on the preferences defined by the user Table 4.3:, Table 4.4: show the selecting coefficients with Lee-Sallee metric.

Table 4.4Selecting coefficients with Lee-Salee Metric

Run	Compare	Pop	Edges	Cluster	Cluster S Size	Leesale	e Slope	%Urban	Xmean	Ymean	Rad	Fmatch	Diff	Brd	Sprd	Slp	RG
				Result after coarse calibration phase													
77.00	0.47	0.99	0.78	0.93	0.33	0.31	0.88	1.00	0.35	0.54	1.00	0.68	1.00	1	75	1	50
454.00	0.51	1.00	0.81	0.05	0.02	0.31	0.91	1.00	0.33	0.60	1.00	0.67	1.00	75	75	1	100
579.00	0.52	1.00	0.84	0.94	0.23	0.31	0.91	1.00	0.51	0.91	1.00	0.67	1.00	100	75	1	100
229.00	0.51	0.99	0.77	0.40	0.08	0.31	0.86	1.00	0.37	0.88	1.00	0.67	1.00	25	100	1	100
			Result after fine calibration phase														
25.00	0.60	1.00	0.78	0.40	0.00	0.42	0.96	0.99	0.40	0.23	0.99	0.67	1	1	75	20	60
745.00	0.61	1.00	0.76	0.63	0.09	0.42	0.97	0.99	0.43	0.35	0.99	0.66	5	1	75	20	60
24.00	0.60	1.00	0.78	0.64	0.02	0.42	0.96	0.99	0.45	0.43	1.00	0.66	1	1	75	20	50
			Result after Final calibration phase														
795.00	0.32	1.00	0.78	0.56	0.04	0.52	0.99	0.73	0.19	0.00	1.00	0.64	1	4	7	93	30

Table 4.5 Values of the five coefficients for prediction after self-modification

No	Growth Coefficients	Coefficient for prediction
1	Diffusion	2
2	Breed	1
3	spread	75
4	Slope Resistances	20
5	Road Gravity	60

4.4.1. Advantages and Disadvantages of Adopting SLEUTH Model

The Advantage SLEUTH has been at the forefront of cellular automata urban simulation models. not only as a research tool but also as a planning support instrument, the model has yielded useful policy implications for a variety of urban regions .This implies that a possibility of choosing the best fit parameter set greatly depends on the nature of raster data used as well as the data handling Process. SLEUTH transportations networks are considered as input factors and model integrates the cellular automata modelling framework with GIS technology. The use of GIS data not only makes it possible to initiate the model from within the actual geography but also suggests a way of taking into account the effect of various driving forces contributing to land use change dynamics. A loose coupling with a GIS application is not critical as the model has a certain Capacity for spatial data processing and visualization.

The disadvantage is the time and cost necessary for the development and use of such one off models. This is not a new issue in urban modelling and again there is no one right approach for this. However, the development of small and extendible models based on a common modelling framework can provide a partial solution to this. The calibration of Results are selected by manual.

4.4.2. Research Limitations and Future Work

SLEUTH do not require Non-spatial data for future simulations and can be run from a single time point, this study faced a major challenge with attaining Non-spatial data, and especially for the calibrations steps the model it consume more than 7 hrs.to the current study. For calculating the growth parameters to reduce this custom iterations was a possible option, this will be attempted in future research.

4.5. Historical Urban Growth Simulation

The growth of urban areas was analyzed with respect to its coverage inside the boundary of Adama Town during. The year 1990, 2000, 2010 and 2019. Temporal variation in the Landsat series of satellites based on urban classification exhibits substantial changes in urban areas. The study indicates that area of changes urban lands 7.4 to 53.6 sq.km respectively, but the percentage of the built-up growth area in south direction is comparatively higher than in other directions. Built-up area during 1990–2000 as 7.4 sq.km to 134.1 % and 2000–2010 as 41.4.sq.km, with a 139 % rate 2010-2019 of growth of built-up area increased by 30 %.see figure 4.8.

Table 4.6 Change in Urban Area 1990-2019

Urban Name	Year	Area km 2	Growth Rate
Adama	1990	7.4	
Adama	2000	17.34	134.1%
Adama	2010	41.4	139%
Adama	2019	53.6	30%

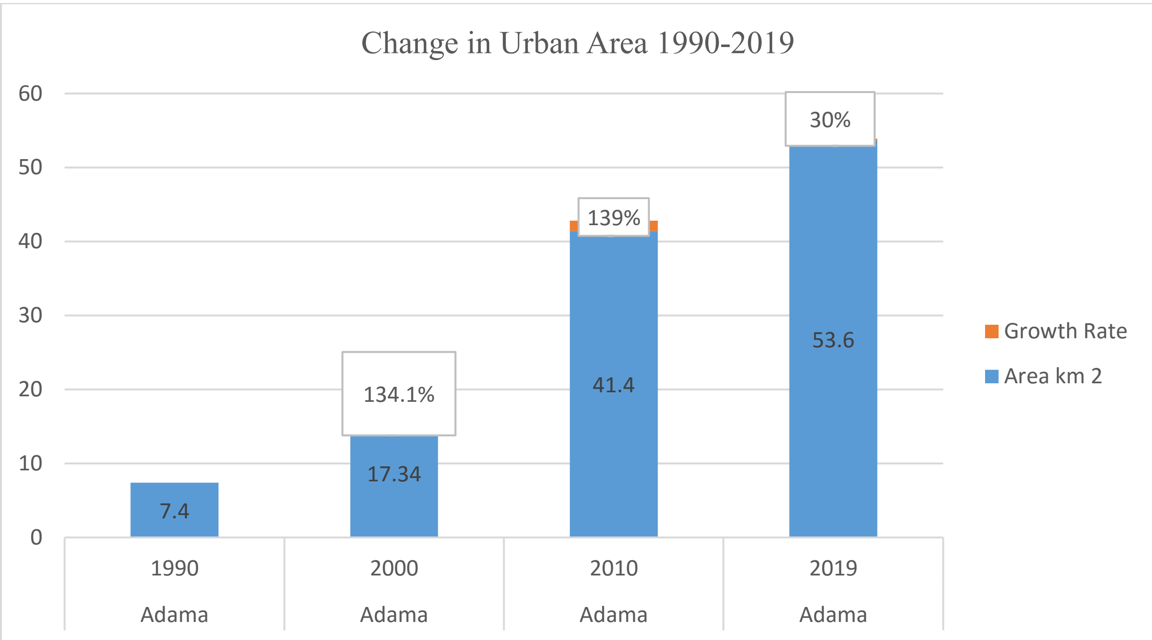
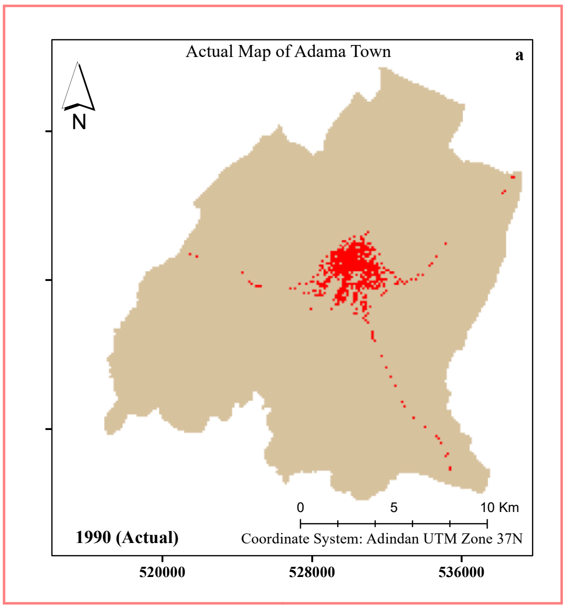
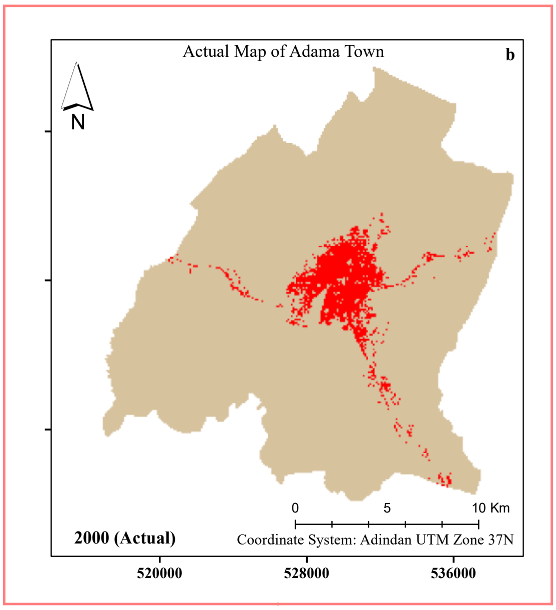


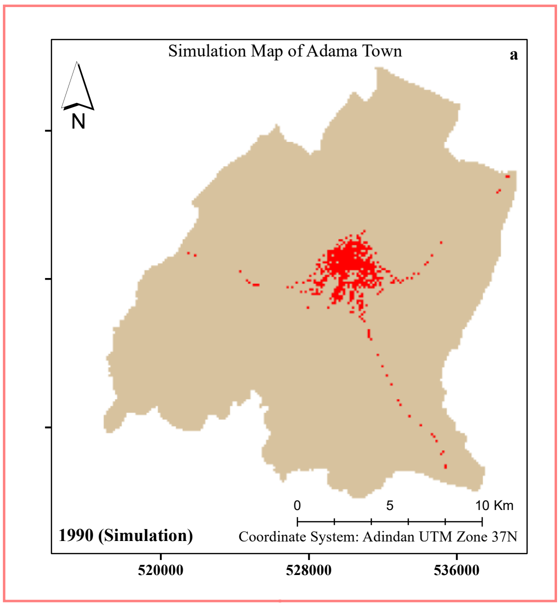
Figure 4.8 Urban Changes during 1990–2019

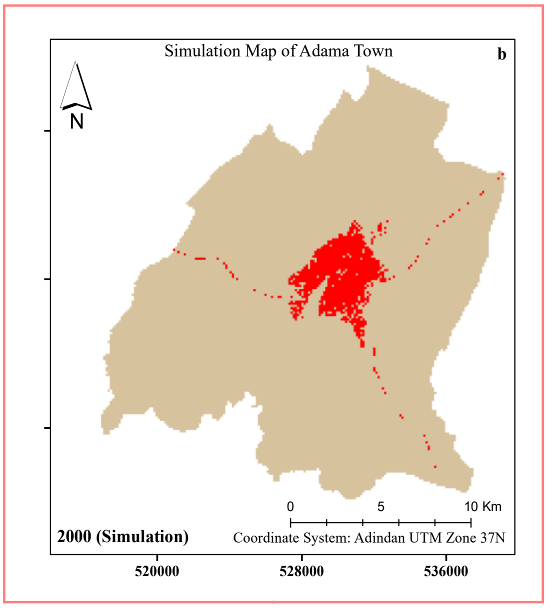
The historical urban spatial growth of Adama Town was simulated with the execution of the model was controlled by what is known as a "scenario file". A generic scenario file that was provided with the model was edited in order to personalize the model to fit and run the data for Albuquerque. Major portions of the scenario file that were edited will include: I. PATH NAME VARIABLES that defined the path pointing towards the input and output directories; IV. Log File Preferences that indicated which information to create logs of; VII. MONTE CARLO ITERATIONS that stated the number of Monte Carlo iteration to run, VIII. COEFFICIENTS that delineated the five growth coefficients after each brute force calibration process and during the production phase of the model; IX. PREDICTION DATE RANGE that showed the range of dates for which the model would be predicted, X. INPUT IMAGES that defined the input images; XII. COLORABLE SETTINGS used for defining the colors for the input and output maps, and XIII SELF-MODIFICATION PARAMETERS as shown in Appendix 5.sources code of simulation mode.

However, a further simulated urban land map illustrates that Edge growth and Road-influence growth play a key role in urban spatial growth from 1990 to 2019 the urbanization level of Adama Town is high that the urban sprawl mainly accrues around existing urban growth centers and expands along the transport network at the beginning 2000 rapidly urbanized and isolated growth centers has been springing up in rural parts. During the past twenty years Adama Town experienced rapid urbanization process from the Villages to Town the actual and simulated urban area growth of four periods, 1990, 2000, 2010 and 2019 are presented in Figure 4.9. Total urban land areas estimated by the model are 54,8514 km2 in 2019 increased by 641.2 % compared to 7.4 km2 urban land in 1990 additionally, for gaining more details in simulation results of each year urban land expansion patterns and total urban land areas of the four years are most important urban agglomerations in Adama Town are listed in Table 4.6 for the further scrutiny.


Actual Map of Adama Town
a
N
0
5
10 Km
1990 (Actual)
Coordinate System: Adindan UTM Zone 37N
520000
528000
536000


Actual Map of Adama Town
b
N
0
5
10 Km
2000 (Actual)
Coordinate System: Adindan UTM Zone 37N
520000
528000
536000


Simulation Map of Adama Town
a
N
0
5
10 Km
1990 (Simulation)
Coordinate System: Adindan UTM Zone 37N
520000
528000
536000


Simulation Map of Adama Town
b
N
0
5
10 Km
2000 (Simulation)
Coordinate System: Adindan UTM Zone 37N
520000
528000
536000

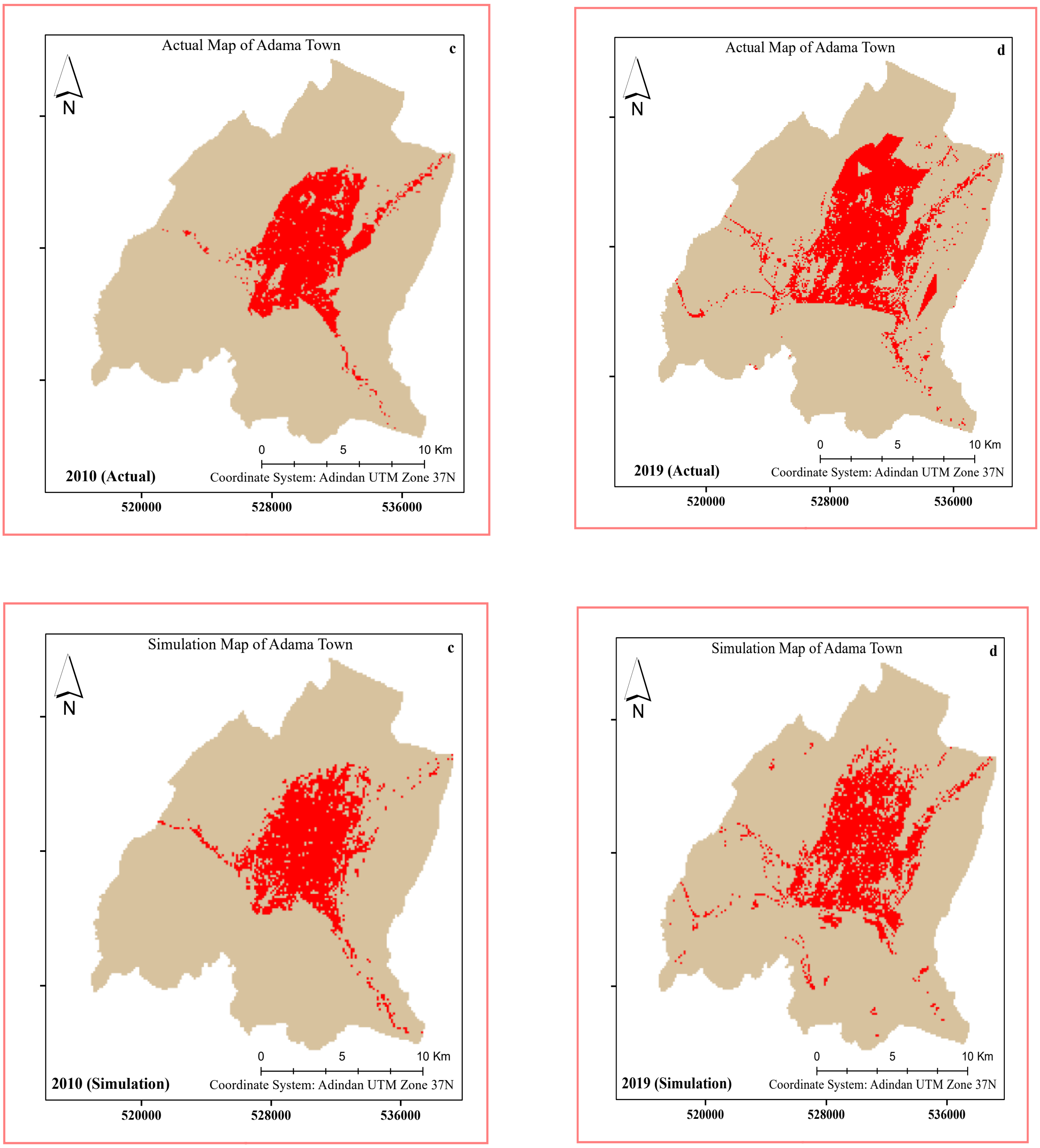


Figure 4.9 The Simulated and Actual urban growth of Adama Town a) Simulated and Actual 1990 ,b) Simulated and Actual 2000, c) Simulated and Actual 2010, d) Simulated and Actual 2019.

The series of simulation results Within SLEUTH Model, urban spaces are represented as a grid of cells that can change states (e.g., urban and non-urban) as the model iterates. The state of each cell is depending on its current state and neighboring cells' states.

Using historical land use land cover maps, transportation layers, a digital elevation model (DEM), and a map of areas excluded from urbanization as model inputs, SLEUTH approximates spatial-temporal patterns of urban development by calibrating five parameters.so that simulation results are used to better understand urban dynamics and to support urban planning for Updating and making a frequent urban spatial data as per the need for checking and follow up urbanization rates this shows in the following Table 4.6 and Table 4.7.

Table 4.7 Simulation result by SLUETH Model Urban Input Grid

No	Year	Urban Input Grid	Index	Pixel count	Percent Of Image
1	1990	Non-Urban	0	618678	96.67%
		Urban	255	21322	3.33%
2	2000	Non -Urban	0	618678	96.67%
		Urban	255	21322	3.33%
3	2010	Non -Urban	0	593766	92.78%
		Urban	255	46234	7.22%
4	2019	Non- Urban	0	573063	89.54%
		Urban	255	66937	10.46%

Table 4.8 Simulation result by SLUETH Model land use Input Grid

No	Year	land use Input Grid	Index	Pixel count	Percent Of Image
1	1990	Water	0	5941	0.93%
		Urban	1	21649	3.38%
		Agricultural land	2	130390	20.37%
		shrub-land	3	18469	2.89%
		Barren land	4	463551	72.43%
2	2019	Water	0	67616	10.56%
		Urban	1	7352	1.15%
		Agricultural land	2	94983	14.84%
		shrub-land	3	25633	4.01%
		Barren land	4	444416	69.44%

This study before the predicted future urban model of Adama Town SLEUTH simulation results was validated using an independent 2019 urban map derived from a Landsat 8 image. For determining the cell by cell matching index in this study, the urban extent data of Adama Town the Year 2019 predicted by SLUETH Model from Observed urban extent of year 2019Using the values of Calibrated best fit growth coefficient and the observed urban extent of Adama Town the year 2019 developed by ERDAS IMAGE 2014 software from the satellite Image of Adama in the year of 2019 were used in relation to this first the urban Pixels of two urban extents were recorded as one and all the other non-urban pixel were recorded in ARCGIS 10.4.1 was used to undertake overlay analysis and identify the number of matching pixel (intersection). (Figure. 4.10).

Finally, the cell by cell matching index was determined as the ration of the number of Machining (Intersecting) urban pixel to the number of urban pixel of the observed urban extent of Adama Town of the year 2019 After validating the prediction performances of SLUETH Model, it was run under the Prediction mode by using the best fit Coefficient values with the objective of predicting the urban extent of Adama Town by 2040. The accuracy of Land uses land cover data was analyzed as shown in Figure: 4.10. The overall classification accuracy was estimated to be 85.71 %. The overall statistical Kappa values were also reported 0.7200 respectively. As indicated in Appendix 4 Kappa statistics measure the level of agreement between the predicted and observed data Kappa statistics was calculated from the predicted and actual land use maps of 2019 since all Kappa statistics value were above 85.71%% the CA- SLUETH Model, is suitable to predict future land use changes in the study area Wang, et al ,, (2012).

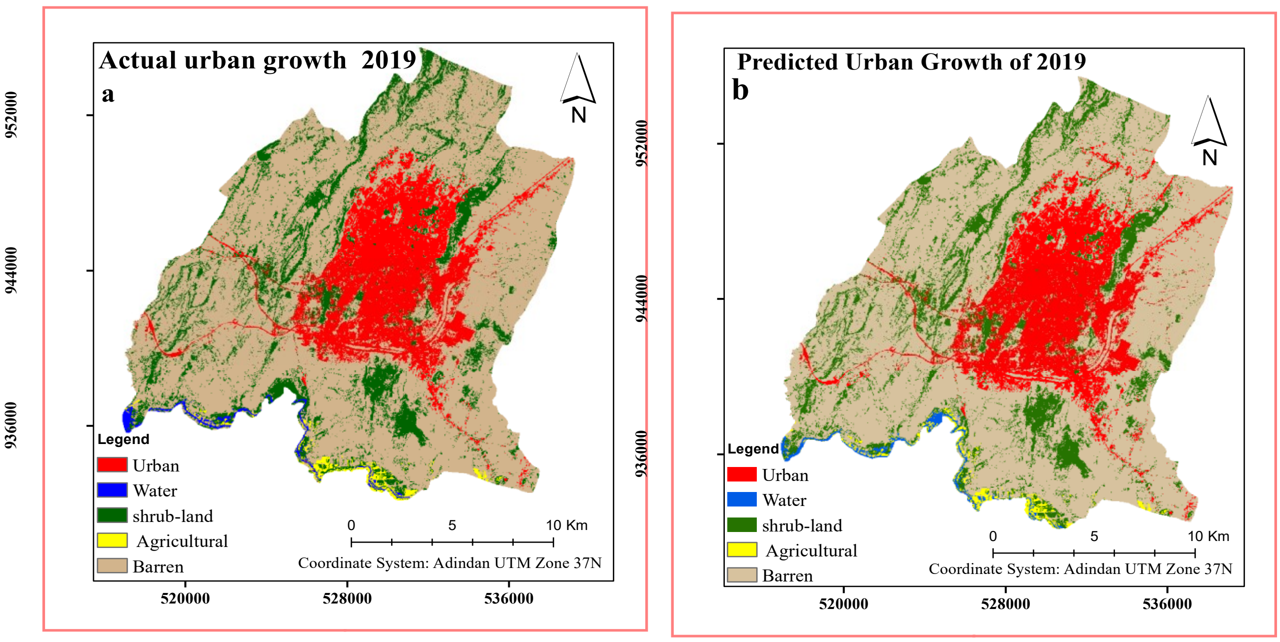


Figure 4.10 Predicted and Actual urban growth of Adama Town in the year 2019 used for Model validation a) Actual Growth2019, b) Predicted Growth2019.

Table 4.9 Comparison of Predicted and Actual urban LULC type in 2019

No	LULC type	Area			
		Actual map		Predicted map	
		(Class per ha)	(%)	(Class per ha)	(%)
0	Water	227.88	1%	249.3	1%
1	Urban	5384.07	17%	5485.14	19%
2	Agricultural	299.61	1%	285.57	1%
3	Shrub-land	4850.28	15%	4165.92	14%
4	Barren land	20544.12	66%	19028.52	65%

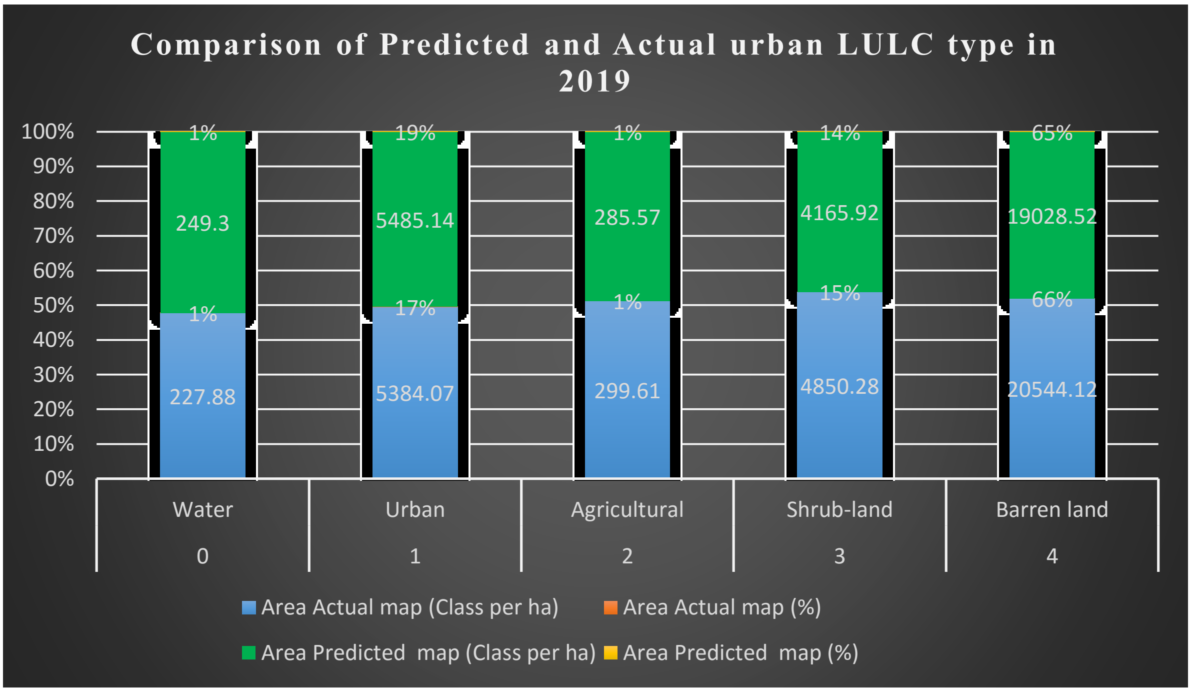


Figure 4.11 Comparison of predicted and actual spatial pattern of LULC in 2019

4.6. Future Urban Growth Predication under different Scenario

Results for validation using Lee-Sallee were derived as an outcome of the calibration process For the purpose of statistical validation, the SLEUTH model was executed in the Predict mode with the starting prediction year of 2019 and end prediction year of 2040 for business as usual, Aggravated scenario and restricted scenario.

To examine the predictive power of the CA -SLUETH Models and to explore the possibility of the urban development in Adama Town Agglomeration, the paper run three alternative 2040 prediction scenarios shown in Table 4.7 and Figure 4.12.

Based on the simulation results The area of the Town expanded about 627.56 % from 1990 to 2019, reaching 53.84 km^2.The highest urban expansion, leading to the degradation of an overwhelming amount of land and natural resources. Based on the calibration data, future urban growth trends were predicted for 2040 assuming three development scenarios.

According to (Dijk & Fransen, 2016) Self-modification, is prompted by an unusually high or low growth rate. The growth rate is the sum of the four different types of growth defined by the model for each model iteration or "year." The limits of "critical high" and "critical low" kick off an increase or decrease in three of the growth control parameters: diffusion, breed, and spread. The increase to the parameters is by a multiplier greater than one, "boom," imitating the tendency of an expanding system to grow ever more rapidly, while the decrease is by a multiplier less than one, "bust", causing growth to taper off as it does in a depressed or saturated system. However, to prevent uncontrolled exponential growth as the system increases in overall size, the multiplier applied to the factors is slightly decreased in every subsequent growth year (Clarke & Gaydos, 1996).

The result of the final values of the five growth coefficients yielded from the calibration process is illustrated in Table 4.3. The final calibration results indicate a very high breed and spread coefficients that directly influence diffusive and edge (organic) growth respectively, a relatively low diffusion coefficient and an extremely low road growth and slope coefficients. The SLEUTH model applies these five growth coefficients derived in the calibration process to the four growth rules to predict the growth pattern of Adama Town.

4.6.1. Urban growth Predication by Business as usual scenarios

Business as usual in view of the future demand for land uses in Adama Town and to comprehensively consider the current situation of land use in Adama Town are used to predict urban spatial growth of the Town under business as usual scenarios. It is based on its own developmental process. The quantitative demand for land use is mainly based on the urban change from 1990 to 2019, and the SLEUTH Model is used to predict the land use change in 2040. Figure 4.15.

Here, the same results for some future Prediction and assume that Urban growth rate are continuing as last twenty years for futures under this scenario no external constraints or conditions, the growth would be just the same as the CA- SLUETH model depicted i.e. Same number of pixels transitioned and same spatial allocation of change pixels, urban growth was reported 90.2Sq.Km in 2040.

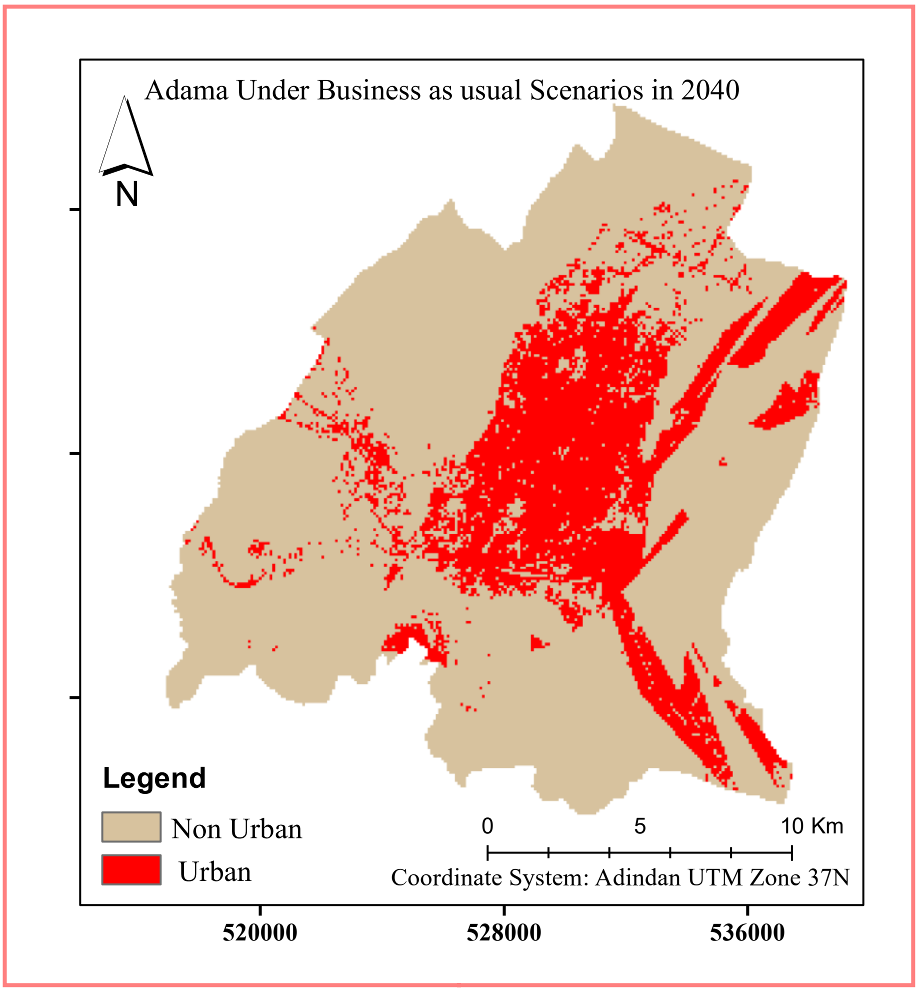


Figure 4.12 Predicted Map of Adama Town in 2040 Under Business as usual scenarios

4.6.2. **Urban growth Predication by Aggravated scenarios**

In this scenario, the current study assume that the urban development would be more compact, has increased the tendency of loss of the surrounding arable land to urbanization this may can lead greater poverty and governments unable to provide services for the people concentrated energy lead to air pollution with significant impact on human health and animals. If this scenarios are implemented multiple health hazards are happen this can be magnify the risk of environmental hazards such as fragmentation of natural resources, environmental pollution, and residential crowding and traffic congestion and it can be create unplanned Town and urban sprawl with unsustainable Urban Growth problems with negative economic and social environmental consequences Under this scenario, urban growth are well predicted is higher than that of 2040, with 101 Sq.km respectively; increase by 10.8 Sq.km more than business-as-usual scenarios, which is a relatively high urban growth rate of 11.9 %. The resulting in this transformation of agricultural land in urban land (Figure 4.13).

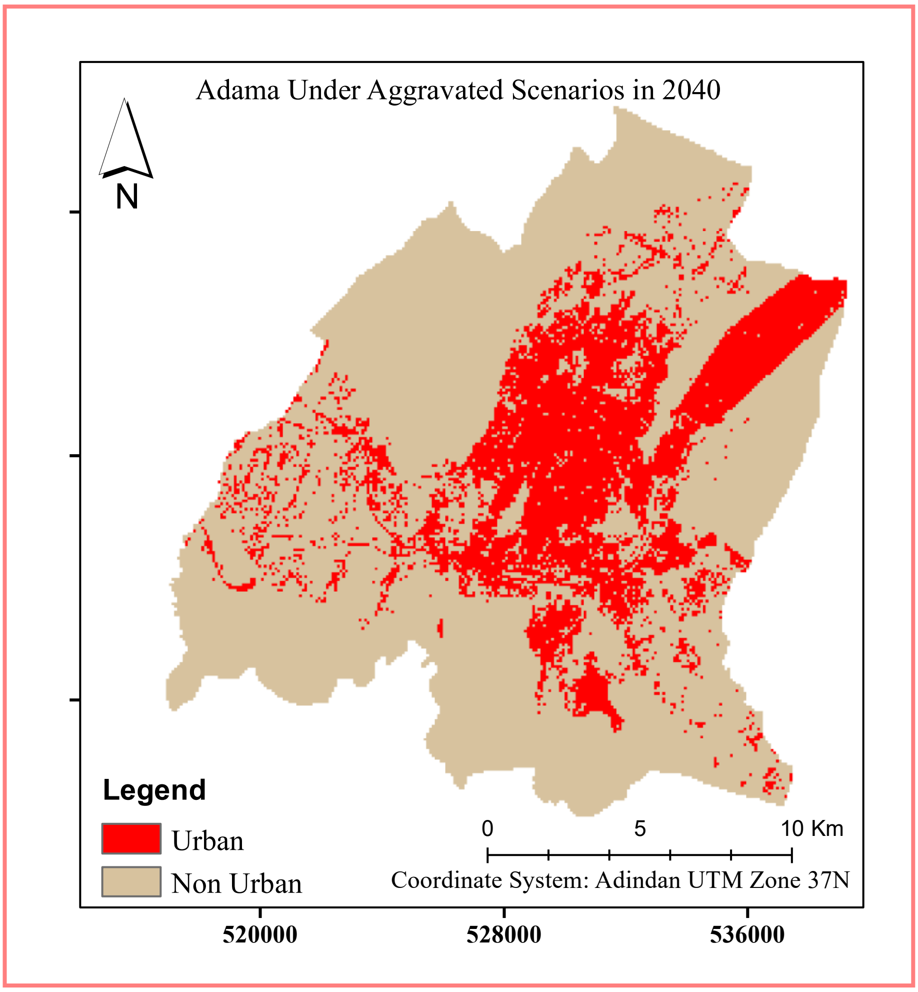


Figure 4.13 Predicted Map of Adama Town in 2040 Under Aggravated scenarios

4.6.3. **Urban growth Predication by Restricted growth scenarios**

Under this scenario, urban growth is well protected (Figure 4.14). Urban growth is limited and the forecast is equal to an urban extent of 2019, with 53.84 **Sq.km** respectively; Restricted growth scenarios, maintaining the ecological imbalance and sustainable development in the study area. This may create conflicts of interest of different stakeholders and groups.

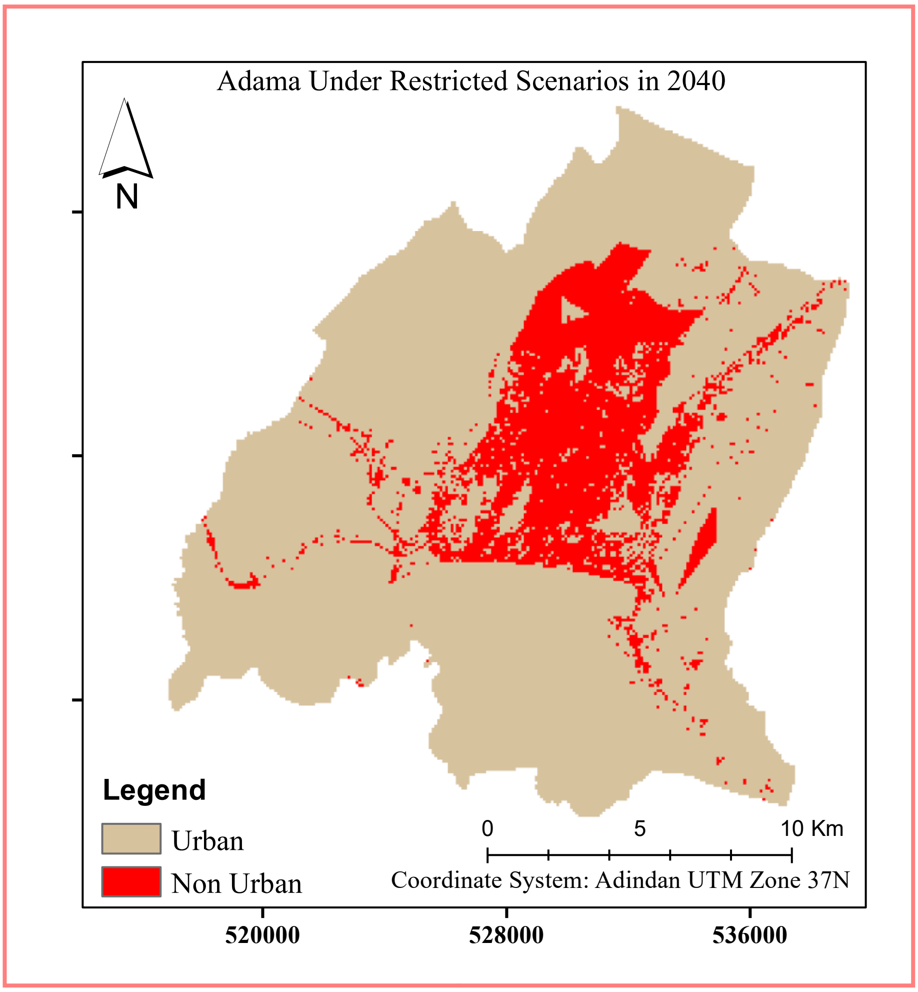


Figure 4.14 Predicted Map of Adama Town in 2040 Under Restricted growth scenarios

Table 4.10 Predicted Area (Sq.km) of LULC conversions by three scenarios

No	LULC 2019	Area in [Sq.km]2019	Conversion to Urban [Sq.km] Alternatives in 2040		
			Restricted growth scenarios (1)	Business as usual scenarios (2)	Aggravated scenarios (3)
1	Urban	53.84	53.84	90.2	101
2	Non -Urban	259.2022	259.2022	222.842	212.04
3	Total Area	313.0422			

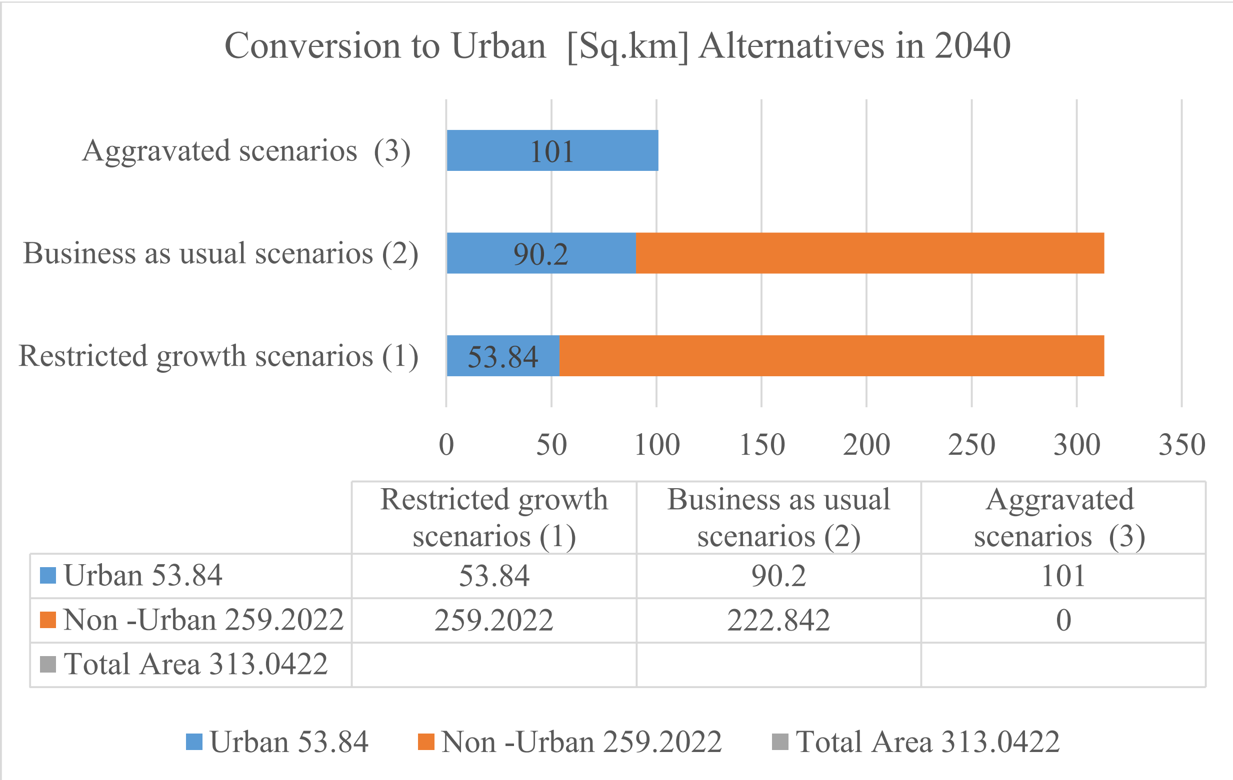


Figure 4.15 Conversion to Urban [Sq.km] Alternatives in 2040

4.7. Discussion

The results of SLEUTH model simulations are discussed with respect to the current studies and from the objective aspect, the paper introduces a realizing format of cellular automata SLEUTH model to simulate urban growth and their coefficient, transform rules and calibration process, and applies the model to simulate and forecast urban growth of Adama Town. From the objective aspect, this study is aimed at analyzing the sustainability of urban growth in Adama Town using by analyzing the simulation results, it could be stated that it is feasible to using SLEUTH model in urban growth simulation and forecasting urban dynamics. This section discusses the simulations and prediction results with comparison of simulated and actual spatial pattern of urban dynamics in the study area.

4.7.1. Urban Growth Simulation Result

Results of SLEUTH model simulations indicate that there would be an extensive growth along with the various drivers across the Adama Town. Whereas there would be an extremely high growth, density towards the major roads. Results also indicated by SLEUTH Model simulations it was possible to identify the direction of urban expansion in Adama Town. The study identified that Adama Town has been experiencing rapid urbanization over the past three decades, urban expansion in Adama has seen almost in every direction from the initial urban center. According to SLEUTH model simulation results. Figure 4.14 shows the proportion of urban land area express by **Sq.km** and the percentage in the Adama Town over the past three decades. Accordingly the urban lands of the Town have been experiencing urban change during last 30 years. Adama Town increment in urban land in the Periods under the study is from 7.41 to 53.84 km^2 respectively. Terfa, et al,, (2019) which agrees with this study. More over Nigussie,et al .,(2016) Found the simulation of urban growth compared to his study simulation coefficients and results are which is similar with the result of this study indicated in Table 4.4 (the simulation of urban growth parameter) and the results are compared to with this work which agreed with the results of this study concentrated on the same calibration coefficient values selection techniques is this shows that urban growth with the simulation are more important in the current study. Simulation results which are increase to know the current urban extents of study area this helped to make a good and reasonable decision making in urban spatial growth changes in urban areas are shown with pixels wises this is running using the Appendix 4 source code.

4.7.2. Overall Scenario-Based Prediction Model

SLEUTH is applied for establishing optimal urban planning scenario to predict and evaluate urban expansion under different conditions (Adams & Barbara, 2015).Predication has been attempted to model the urban growth from the present to project future changes for different scenario Prediction of future urban growth scenarios results of selected parameter values, which dictates the form of urban growth and affect urban growth rules in this study remote sensed urban extents parameter values are used to select spatial forecasting parameter this show that scenarios based urban spatial growth are preferred method compared to single planning approach. From the scenario considerations, points of view, the studies conducted by, Kugler, et al,, (2007) and Yang, & Song, (2015). Considered business as usual, restricted, and aggravated growth scenarios similar to the current study. On the contrary, to Jokar, et al,,(2013) these studies shows the spectrum of different urban growth scenario for evaluation of the future land use dynamics of the Town in SLEUTH Model, see Table 4.6. This is important for providing alternative policy, strategic options for Town Administrative Body by indicating policy intervention, urban planning guidance, foreign investment and other issues.

The model simulations shows that the eastern part of Adama Town has good potential for urbanization. It agrees with the masterplan of the town.The current study confirms that Business As Usual is the more optimal urban growth scenario based on the assumptions that balance the growth the business activities and the environmental impacts in the Town. As per (UPSBB, 2012) the national Urban planning and Implementation policy supports the confirmed urban growth scenario at a national level that is in line with the current study.

4.7.3. **Prediction Result Validation**

The prediction result was completed using the full resolution data (30x30) and 100 or higher Monte Carlo iterations. Predication has been attempted to model the urban growth from the 2019 to 2040 using growth coefficient, average values, which resulted from calibration stage and three different scenarios. The paper defines the three different according to the locale Characteristic to show the usefulness of the SLEUTH modeling method and also to provide a context comprehensible for the Town managers and urban planners. Urban growth was predicted based on three business as usual, Aggravated scenario and restricted scenario which described in part 4.5. The final result of the SLEUTH model is a probability Map of the years for the (2040). This map showed each cell probability value to become an urbanized, the current study was used two factors to check the prediction results, namely: violation of excluded areas, regression analysis both are used as control parameters.

As the general rule violation of excluded areas are protected among all Predicted Models to evaluate and create crisp map. For selecting the urbanization the should on the probability map. Accordingly the Business as usual scenario The result of prediction based on Business as usual Scenario showed that 36.36 Sq.Km to 53.84 Sq.Km will be added to existing Town extent till 2040.all there is no violation of excluded layers exclusions layers are well protected in on Business as usual Scenario as shown figure 4.12. The regression analysis results showed that more closer results to regression analysis output and as shown in figure 4.16,. This showed a positive correlation as per the standards indicated in section 4.2.

The result of Aggravated scenario illustrates that if urban grows without any controlling condition, only beside on historical growth trends, until the year 2040 about 47.16 Sq.Km will be added to current area in 2019. On the other hand, Town extent will be 87.59% This is While Adama Town has high-value agricultural resources in its surrounding area especially in northern. . And violation of excluded areas is shown in this scenario If the urban growth continues historical trends, most of these resources will be wasted. So in this paper considered environmental protection scenario to preventing lands in surrounding areas. On the other hand 45.24%. With Utilizing this scenario increasing urban extent in northern of the Town will be controlled and led to protection from agricultural and resources.in Aggravated scenario violation of excluded areas in the study area, are not fully violated the current urban growth scenario was reported as in figure 4.13 and predicted urban growth spatial domain violated and regression analysis are bit different from this scenario This implies that the current urban growth scenario is, Poor in terms the regression result , violation of exclusion criteria and. as indicated figure 4.10 Business as usual, aggravated scenario and final result are presented in figure 4.12 and figure 4.13.

Considering the result of two current scenario, local characteristics and urban manager policies, we founded that urban growth, according to the Business as usual Scenario is the preferred scenario for the Adama Town's future growth. This scenario will be resulted in the least damage to the environment.

Finally, restricted scenario expected no more urban growth in the year 2040.if this scenario implemented fulfill only a violation of excluded areas are protected. A restricted scenario may can create inadequate land for housing: in the Town access to affordable land and housing is a critical contemporary challenge. Due to this some residents have been subjected to the worst living condition, insecure land, and Illegal constructions of buildings unplanned urban may happen with respect to this the scenario may create conflicts of interest of different stakeholders and groups.

Logistic regression (LR) is one of the experimental and statistical methods to Describing and quantifying the spatiotemporal dynamics of urban expansion of three scenarios this technique/model questions the relationship between the data at certain times by encoding the dependent and independent variables. Görmü, et at,, (2017). Following this, taking into account the results of CA-SLUETH MODEL prediction analysis, a set of predictor variables selected a priori based on previous model result In order to analyses the relationship of urban growth pattern and the scenarios predictions for the yare 2040 logistic regression model is shown in figure 4.16. Prediction result Validation summary are indicated in table 4.10 and figure 4.16.

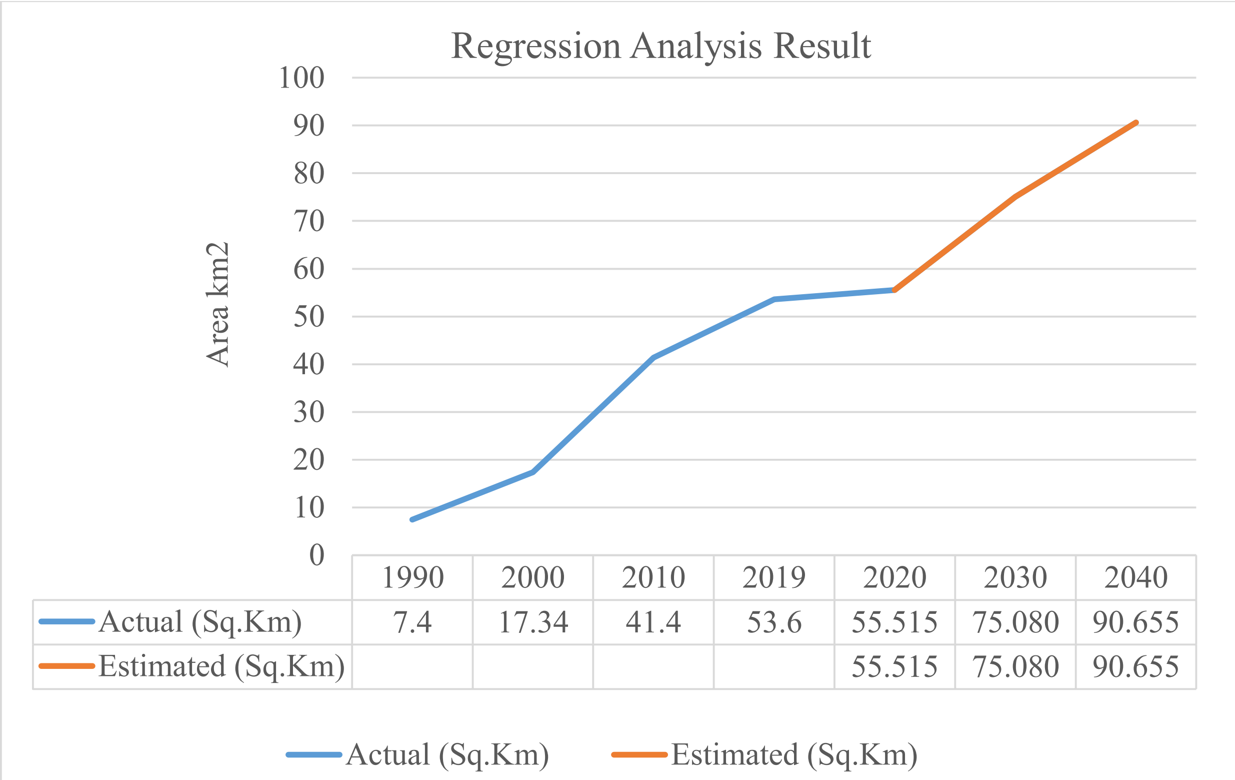


Figure 4.16 Regression Analysis Result

Table 4.11 Criteria for selecting scenarios

scenarios	**Criteria for selecting scenarios.**		
Criteria	Conversion to urban [Sq.km] Alternatives in 2040	Regression Analysis Result in 2040	Violation of excluded areas
Aggravated scenario	101	90.65	Violated excluded areas
Business as usual	90.2	90.65	No violation of excluded layers
Restricted scenario	53	90.65	No violation of excluded layers

CHAPTER FIVE

5. Conclusion and Recommendation

5.1. Conclusion

The current study focused on modeling the urban spatial growth of Adama Town is using the CA - SLEUTH Model for the last three decades from the year 1990. Accordingly, based on the generated results, findings, and methods applied the following conclusions were drawn:

For better understanding urban dynamic simulation is required.. (Parsa & Salehi, 2016) For this reason, dynamic CA –SLUETH being gives the possibility to predict future urban development rather than to explain urban expansion like the other analytical and static urban models. So that simulation of Land uses land cover 1990,2000,2010, and 2019 are validated with the result of the actual urban extent of the study area and matching statistics output are analyzed between simulated and actual urban extents. The CA –SLUETH Model simulation result showed that CA –SLUETH are more efficient tools for simulation of urban dynamics.

CA –SLUETH Models allow to predict options and comparable future states, and thus comprise an implement to investigate the probability of a preferred situation through testing CA SLETH models represent a possible approach for regional scale modelling. Furthermore, important Models for selecting appropriate urban spatial growth strategy by simulation and prediction of future urban growth in a more realistic way. This can be significant for updated Land use, land cover information and provides a prediction regarding the state, compositions and configuration of the urban changes which can be used as an early warning system for proper Planning on timely policy and reasonable decision making (SHAFEEQ, 2015). In another words the obtained information in this study will be useful to help the decision and policy makers to make proper decision and policies to control incremental trend of urbanization and decrease the possible negative consequences of urbanization in the near future as well as help develop complex adaptive measures.

Land uses land cover is changing in time and space is inevitable. This study has highlighted the magnitude, six driving forces and implications of LULC change in the Adama Town during the last three decades considered most affected LULC categories over the study time period, as it significantly. The area of built up of the Town in 1990 was calculated as 7.41

Sq.Km which is 97.6 % of the total area of current new Administrative boundary the Town. The built up area expansion of the Town between 2000 and 2019 was 24.06 Sq.Km which is 138.7 % expansion. The furthest built up area in 2000-2019 was towards south direction following the main road to east direction and in 2000 the main possible reason could be the flat topography. The study found that significant LULC change has occurred in the study area, with associated land resource degradation. The major changes observed include expansion of urban land, bare land expansion, and loss of shrub lands and agricultural lands.

In this paper, applied the SLEUTH model for prediction Adama urban growth. Prediction occurred based on three different scenarios and compare the results showed that considering more local characteristics of the model can reach to the appropriate growth scenario. The accuracy simulation and prediction outputs showed that SLEUTH can be as an appropriate tool for Adama Town Administration urban managers for future urban planning. They can identify the effective local characteristics that affect future growth of the Town, and consider their policies for future of Town, by creating multiple scenarios Comparing the result of scenarios show when a policy or factor are considered, how the Town growth and can help urban planners and decision makers to take proper policy and planning for future development needs.

5.2. Recommendation

Depending on the finding of this study, author recommend the following measures that have to be taken by Town managers to improve the urban dynamic in the study area. The remote sensing data are available free of charge for the whole of the world use it and SLEUTH model that has been developed as Unix-based, open source is run with a Unix emulator SLEUTH was written in C and C++ programming language. Less cost for implementing the following points recommended from point of view the Author.

- Despite these considerations, the results obtained from applying SLEUTH in a Adama Town demonstrate that the model has considerable potential as a decision-making tool and helps Town managers to realize the outcome of possible actions they might take.
- The Town administration should enact proper scenarios regarding allocating land for urban growth with CA-SLEUTH Model.
- It is recommended to integrate the SLEUTH model with local level planning as per the scale of this study.
- This study recommended the uses of SLEUTH model are a scientific urban dynamic mechanism such as simulation, validating of implementation of master plan and predicting future urban growth with respect to a scientific criteria for enables to maximize Sustainable Urban Growth developments
- The recommended strategic urban growth scenario for Adama Town is Business As Usual. This study confirms that the limited available land resources can be utilized in a sustainable manner in the coming years by the mentioned urban growth scenario.
- CA-SLEUTH Model can be potentially recommended to be used for Cities like Adama for updating, urban dynamics and supervising the actual growth with proposed plan or scenarios to avoid nonconforming problem. This is because the model has the capacity to integrate different growth scenarios and time series data for evaluation of the simulated conditions in the future period.
- Simulation result showed good result, however, further studies should be carried out in Use of high resolution remote sensing datasets can help model multiple land use categories change predictions with greater ease.

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APPENDICES

Appendix 1 Research Questionnaire

Adama Science and Technology University

School of Civil Engineering and Architecture

The Department of Geomatics Engineering

This questionnaire is prepared to collect information from selected respondents for the Accomplishment of Thesis program with the topic of Modelling Spatiotemporal Growth of Adama Town using CA-SLEUTH model. By Sintayehu Haile Damu .The study is carried out as aPartial fulfillment of the requirement for the master of degree "In Geomatics Engineering (Specialization in Geoinformatics Engineering).

The main objectives of this questionnaire are to assess the Urban Spatial Growth, of Adama Town the findings of the study will be used for public and Adama Town Administration to make Recommendation based on findings in order to improve the Sustainable Urban Growth and hence you are kindly requested to forward your Views and Experiences as carefully as possible. Each of Your answer have great contribution for the Completeness of the research paper.

Questionnaire

Personal Information

1. Your current position in the organization________________________________
2. Sex: - Male ☐ Female ☐
3. Marital status: Married ☐ Single ☐
4. Age ___________
5. Educational background

- Vocational and Technical ☐
- Diploma ☐
- Bachelor Degree ☐
- MA, MSC and above ☐

Please, tick on

No 1 if you strongly disagree. **No 2 if you disagree.**

No 3 if you do not have opinions. **No 4 if you agree.**

No 5 if you strongly agree.

No	**Questions**	**1**	**2**	**3**	**4**	**5**
1	Do you have an organized spatial data handling system?					
2	Spatial data under your department is adequate?					
3	Do you have enough training on spatial data manipulation?					
4	Is spatial information clearly illustrated on maps?					
5	Is a timetable for updating design/plan with actual urban growth?					
6	Is strategy for monitoring & inventorying design/plan Change?					
7	Is it describe the new urban spatial growth in updating Stage?					
8	Have you supporting documents included with the Master Plans (urban modeling software, GIS, etc.)?					
9	Is there clear standards of urban growth monitoring?					
10	Was there have an alternative urban growth scenarios for the Town?					

Opinion of the Expert. ---

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--

--

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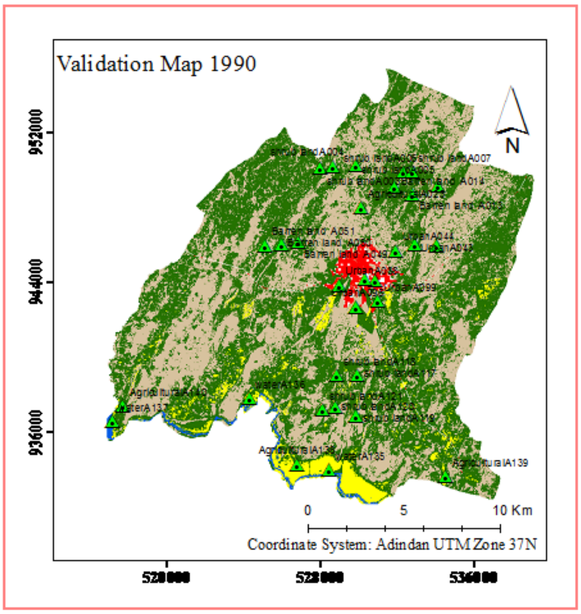
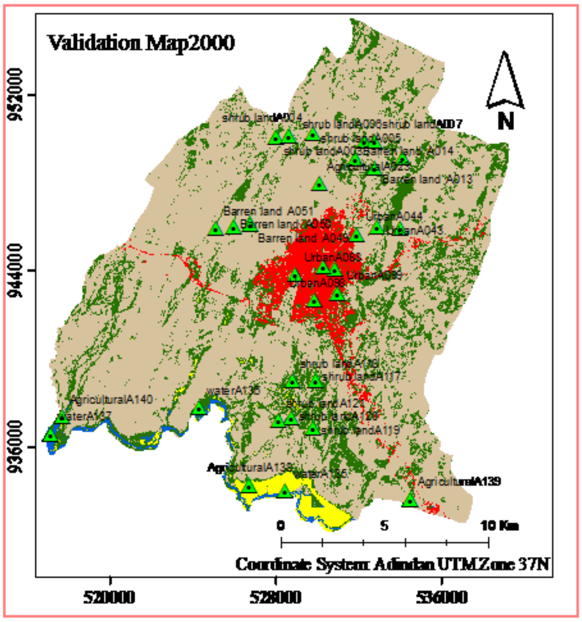
Thank you for your cooperation

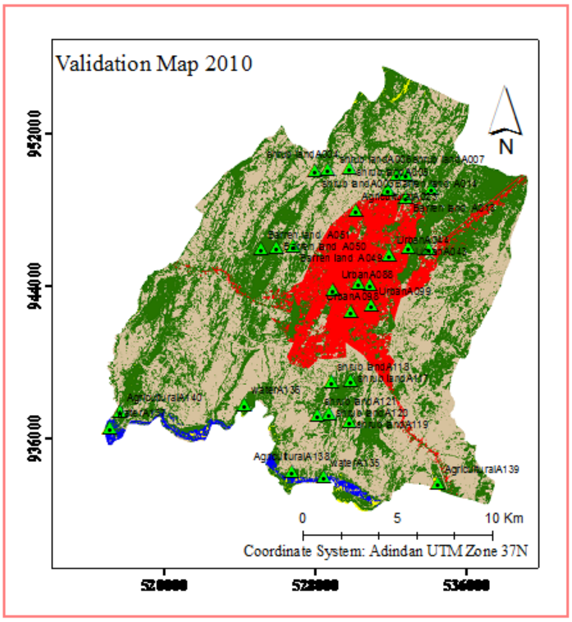
Appendix 2 GCP used for validation of the model

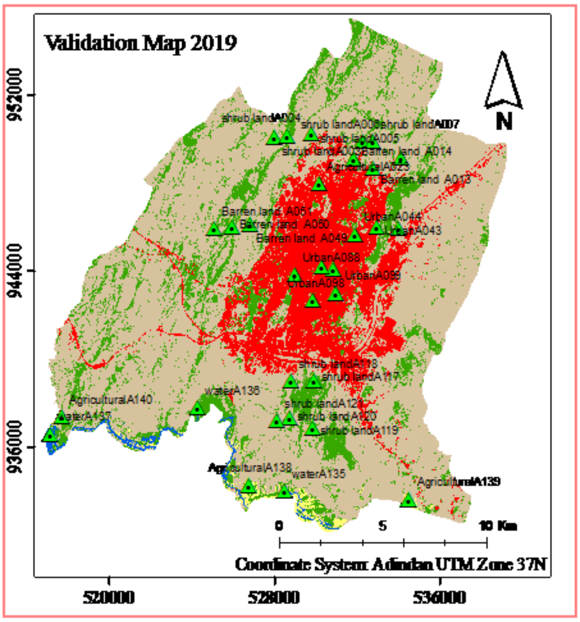
ST	E	N	Remark
1	527988.3	950054	shrub landA003
2	528615	950132.1	shrub landA004
3	529802.1	950187.6	shrub landA005
4	532265.8	949862.5	shrub landA006
5	532758	949852.5	shrub landA007
6	534099.2	949086.8	Barren land A012
7	532781.2	948643	Barren land A013
8	531843	949065.2	Barren land A014
9	530112.6	947944.9	AgriculturalA023
10	533998.9	945922.1	UrbanA042
11	532905.4	945988.3	UrbanA043
12	531907.3	945641.8	UrbanA044
13	526796.9	946108.7	Barren land A049
14	525947.4	945995.7	Barren land A050
15	525105	945921	Barren land A051
16	530840.8	944080.6	UrbanA086
17	530275.2	944145.9	UrbanA087
18	528949.9	943814.9	UrbanA088
19	529839.3	942652.7	UrbanA098
20	530979.3	942969.3	UrbanA099
21	529892.3	939017.7	shrub landA117
22	528817.4	938981.3	shrub landA118
23	529825.4	936870.2	shrub landA119
24	528732.5	937309.4	shrub landA120
25	528124.2	937191.5	shrub landA121
26	528453.4	933968.3	waterA135
27	524271	937761.6	waterA136
28	517132.4	936566.5	waterA137
29	526737.5	934258	AgriculturalA138
30	534488.8	933612.1	AgriculturalA139
31	517690.9	937381.7	AgriculturalA140

Appendix3 Validation Map









Appendix 4 Predicted Model validation in 2019

ACCURACY TOTALS Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	2	2	2	---	---
Water	0	0	0	---	---
Barren	4	5	4	100.00%	80.00%
Shrub	1	0	0	---	---
Agriculture	0	0	0	---	---
urban	0	0	0	---	---
Totals	7	7	6		

Overall Classification Accuracy = 85.71%

Overall Kappa Statistics = 0.7200

Appendix 5 Source code of Simulation

```
# FILE: 'scenario file' for SLEUTH land cover transition model
#       (UGM  v3.0)
#       Comments start with #
I.PATH NAME VARIABLES
INPUT_DIR=../Input/astu/
OUTPUT_DIR=../Output/astu_test/
WHIRLGIF_BINARY=../Whirlgif/whirlgif
# II. RUNNING STATUS (ECHO)
ECHO(YES/NO)=yes

# III. Output Files
WRITE_COEFF_FILE(YES/NO)=yes
WRITE_AVG_FILE(YES/NO)=yes
WRITE_STD_DEV_FILE(YES/NO)=yes
WRITE_MEMORY_MAP(YES/NO)=YES
LOGGING(YES/NO)=YES

# IV. Log File Preferences
LOG_LANDCLASS_SUMMARY(YES/NO)=yes
LOG_SLOPE_WEIGHTS(YES/NO)=no
LOG_READS(YES/NO)=no
LOG_WRITES(YES/NO)=no
LOG_COLORTABLES(YES/NO)=no
LOG_PROCESSING_STATUS(0:off/1:low verbosity/2:high verbosity)=1
```

```
LOG_TRANSITION_MATRIX(YES/NO)=yes
LOG_URBANIZATION_ATTEMPTS(YES/NO)=no
LOG_INITIAL_COEFFICIENTS(YES/NO)=no
LOG_BASE_STATISTICS(YES/NO)=yes
LOG_DEBUG(YES/NO)= yes
LOG_TIMINGS(0:off/1:low verbosity/2:high verbosity)=1

# V. WORKING GRIDS
NUM_WORKING_GRIDS=4

# VI. RANDOM NUMBER SEED
RANDOM_SEED=1

# VII. MONTE CARLO ITERATIONS

MONTE_CARLO_ITERATIONS=4
# VIII. COEFFICIENTS
CALIBRATION_DIFFUSION_START= 5
CALIBRATION_DIFFUSION_STEP=  1
CALIBRATION_DIFFUSION_STOP=  5

CALIBRATION_BREED_START=     5
CALIBRATION_BREED_STEP=      1
CALIBRATION_BREED_STOP=      5

CALIBRATION_SPREAD_START=    10
CALIBRATION_SPREAD_STEP=     1
CALIBRATION_SPREAD_STOP=     10
CALIBRATION_SLOPE_START=     95
CALIBRATION_SLOPE_STEP=      1
CALIBRATION_SLOPE_STOP=      95

CALIBRATION_ROAD_START=      5
CALIBRATION_ROAD_STEP=       1
CALIBRATION_ROAD_STOP=       5

PREDICTION_DIFFUSION_BEST_FIT=  20
PREDICTION_BREED_BEST_FIT=  20
PREDICTION_SPREAD_BEST_FIT=  20
PREDICTION_SLOPE_BEST_FIT=  20
PREDICTION_ROAD_BEST_FIT=  20

# IX. PREDICTION DATE RANGE
.
PREDICTION_START_DATE=2019
PREDICTION_STOP_DATE=2040

# X. INPUT IMAGES
#    <>  = user selected fields
#   [<>] = optional fields
```

```
# Urban data GIFs  #  format:  <location>.urban.<date>.[<user info>].gif
URBAN_DATA= ethoroadama.urban.1990.gif
URBAN_DATA= ethoroadama.urban.2000.gif
URBAN_DATA= ethoroadama.urban.2010.gif
URBAN_DATA= ethoroadama.urban.2019.gif
# Road data GIFs
#  format:  <location>.roads.<date>.[<user info>].gif
#
ROAD_DATA= ethoroadama.roads.1990.gif
ROAD_DATA= ethoroadama.roads.2000.gif
ROAD_DATA= ethoroadama.roads.2010.gif
ROAD_DATA= ethoroadama.roads.2019.gif
#
# Landuse data GIFs
#  format:  <location>.landuse.<date>.[<user info>].gif
#
#LANDUSE_DATA= ethoroadama.landuse.1990.gif
#LANDUSE_DATA= ethoroadama.landuse.2000.gif
#LANDUSE_DATA= ethoroadama.landuse.2010.gif
#LANDUSE_DATA= ethoroadama.landuse.2019.gif
#
# Excluded data GIF
#  format:  <location>.excluded.[<user info>].gif
#
EXCLUDED_DATA= ethoroadama.excluded.gif
#
# Slope data GIF
#  format:  <location>.slope.[<user info>].gif
#
SLOPE_DATA= ethoroadama.slope.gif
#
# Background data GIF
#  format:   <location>.hillshade.[<user info>].gif
#
#BACKGROUND_DATA= demo200.hillshade.gif
BACKGROUND_DATA= ethoroadama.hillshade.gif

# XI. OUTPUT IMAGES
WRITE_COLOR_KEY_IMAGES(YES/NO)=yes
ECHO_IMAGE_FILES(YES/NO)=yes
ANIMATION(YES/NO)= yes

# XII. COLORTABLE SETTINGS
#default DATE_COLOR= 0XFFFFFF white
DATE_COLOR=     0XFFFFFF #white

#    3. PROBABILITY COLORTABLE FOR URBAN GROWTH
#               low,  upper,   hex,  (Optional Name)
PROBABILITY_COLOR=   0,    50,         , #transparent
PROBABILITY_COLOR=   50,   60, 0X005A00, #0, 90,0 dark green
```

```
PROBABILITY_COLOR=   60,   70, 0X008200, #0,130,0
PROBABILITY_COLOR=   70,   80, 0X00AA00, #0,170,0
PROBABILITY_COLOR=   80,   90, 0X00D200, #0,210,0
PROBABILITY_COLOR=   90,   95, 0X00FF00, #0,255,0 light green
PROBABILITY_COLOR=   95,  100, 0X8B0000, #dark red

#  C. LAND COVER COLORTABLE
#    pix, name,     flag,   hex/rgb, #comment
LANDUSE_CLASS=  0,  Unclass , UNC   , 0X000000
LANDUSE_CLASS=  1,  Urban   , URB   , 0X8b2323 #dark red
LANDUSE_CLASS=  2,  Agric   ,       , 0Xffec8b #pale yellow
LANDUSE_CLASS=  3,  Range   ,       , 0Xee9a49 #tan
LANDUSE_CLASS=  4,  Forest  ,       , 0X006400
LANDUSE_CLASS=  5,  Water   , EXC   , 0X104e8b
LANDUSE_CLASS=  6,  Wetland ,       , 0X483d8b
LANDUSE_CLASS=  7,  Barren  ,       , 0Xeec591

#  D. GROWTH TYPE IMAGE OUTPUT CONTROL AND COLORTABLE
#  0 == first
VIEW_GROWTH_TYPES(YES/NO)=NO
GROWTH_TYPE_PRINT_WINDOW=0,0,0,0,1995,2020
PHASE0G_GROWTH_COLOR=  0xff0000 # seed urban area
PHASE1G_GROWTH_COLOR=  0X00ff00 # diffusion growth
PHASE2G_GROWTH_COLOR=  0X0000ff # NOT USED
PHASE3G_GROWTH_COLOR=  0Xffff00 # breed growth
PHASE4G_GROWTH_COLOR=  0Xffffff # spread growth
PHASE5G_GROWTH_COLOR=  0X00ffff # road influenced growth
#**********************************************************
#  E. DELTATRON AGING SECTION
#  0 == first
VIEW_DELTATRON_AGING(YES/NO)=NO
DELTATRON_PRINT_WINDOW=0,0,0,0,1930,2020
DELTATRON_COLOR=  0x000000 # index 0 No or dead deltatron
DELTATRON_COLOR=  0X00FF00 # index 1 age = 1 year
DELTATRON_COLOR=  0X00D200 # index 2 age = 2 year
DELTATRON_COLOR=  0X00AA00 # index 3 age = 3 year
DELTATRON_COLOR=  0X008200 # index 4 age = 4 year
DELTATRON_COLOR=  0X005A00 # index 5 age = 5 year

# XIII. SELF-MODIFICATION PARAMETERS
ROAD_GRAV_SENSITIVITY=0.01
SLOPE_SENSITIVITY=0.1
CRITICAL_LOW=0.97
CRITICAL_HIGH=1.3
#CRITICAL_LOW=0.0
#CRITICAL_HIGH=10000000000000.0
CRITICAL_SLOPE=21.0
BOOM=1.01
BUST=0.9
```

Appendix6 Source code of Prediction

```
# FILE: 'scenario file' for SLEUTH land cover transition model
#      (UGM  v3.0)
#      Comments start with #
# I.PATH NAME VARIABLES
INPUT_DIR=../Input/astu_pred/
OUTPUT_DIR=../Output/astu_pred/
WHIRLGIF_BINARY=../Whirlgif/whirlgif
# II. RUNNING STATUS (ECHO)
ECHO(YES/NO)=yes

# III. Output Files

WRITE_COEFF_FILE(YES/NO)=no
WRITE_AVG_FILE(YES/NO)=no
WRITE_STD_DEV_FILE(YES/NO)=no
WRITE_MEMORY_MAP(YES/NO)=YES
LOGGING(YES/NO)=YES
LOG_LANDCLASS_SUMMARY(YES/NO)=yes
LOG_SLOPE_WEIGHTS(YES/NO)=no
LOG_READS(YES/NO)=no
LOG_WRITES(YES/NO)=no
LOG_COLORTABLES(YES/NO)=no
LOG_PROCESSING_STATUS(0:off/1:low verbosity/2:high verbosity)=1
LOG_TRANSITION_MATRIX(YES/NO)=yes
LOG_URBANIZATION_ATTEMPTS(YES/NO)=yes
LOG_INITIAL_COEFFICIENTS(YES/NO)=no
LOG_BASE_STATISTICS(YES/NO)=yes
LOG_DEBUG(YES/NO)= no
LOG_TIMINGS(0:off/1:low verbosity/2:high verbosity)=1
# V. WORKING GRIDS
#
NUM_WORKING_GRIDS=10

# VI. RANDOM NUMBER SEED
RANDOM_SEED=4

# VII. MONTE CARLO ITERATIONS 100
.

MONTE_CARLO_ITERATIONS=4

# VIII. COEFFICIENTS
CALIBRATION_DIFFUSION_START= 1
CALIBRATION_DIFFUSION_STEP=  25
CALIBRATION_DIFFUSION_STOP=  1

CALIBRATION_BREED_START=     3
CALIBRATION_BREED_STEP=      25
CALIBRATION_BREED_STOP=      5
```

```
CALIBRATION_SPREAD_START=    11
CALIBRATION_SPREAD_STEP=     25
CALIBRATION_SPREAD_STOP=     11

CALIBRATION_SLOPE_START=     0
CALIBRATION_SLOPE_STEP=      25
CALIBRATION_SLOPE_STOP=      100

CALIBRATION_ROAD_START=      1
CALIBRATION_ROAD_STEP=       25
CALIBRATION_ROAD_STOP=       1

PREDICTION_DIFFUSION_BEST_FIT=  2
PREDICTION_BREED_BEST_FIT= 1
PREDICTION_SPREAD_BEST_FIT=  75
PREDICTION_SLOPE_BEST_FIT=  20
PREDICTION_ROAD_BEST_FIT= 60
# IX. PREDICTION DATE RANGE
# The urban and road images used to initialize growth during #
PREDICTION_START_DATE=1990
PREDICTION_STOP_DATE=3000

# X. INPUT IMAGES
# IF LAND COVER IS NOT BEING MODELED: Remove or comment out
# the LANDUSE_DATA data input flags below.
#    <>  = user selected fields
#   [<>] = optional fields
# Urban data GIFs
#  format:  <location>.urban.<date>.[<user info>].gif

URBAN_DATA= ethoroadama.urban.1990.gif
URBAN_DATA= ethoroadama.urban.2000.gif
URBAN_DATA= ethoroadama.urban.2010.gif
URBAN_DATA= ethoroadama.urban.2019.gif
#
# Road data GIFs
#  format:  <location>.roads.<date>.[<user info>].gif
#
ROAD_DATA= ethoroadama.roads.1990.gif
ROAD_DATA= ethoroadama.roads.2000.gif
ROAD_DATA= ethoroadama.roads.2010.gif
ROAD_DATA= ethoroadama.roads.2019.gif
#
# Landuse data GIFs
#  format:  <location>.landuse.<date>.[<user info>].gif
LANDUSE_DATA= ethoroadama.landuse.1990.gif
#LANDUSE_DATA= ethoroadama.landuse.2000.gif
#LANDUSE_DATA= ethoroadama.landuse.2010.gif
LANDUSE_DATA= ethoroadama.landuse.2019.gif
```

```
# Excluded data GIF
#  format:  <location>.excluded.[<user info>].gif
#
EXCLUDED_DATA= ethoroadama.excluded.gif
#
# Slope data GIF
#  format:  <location>.slope.[<user info>].gif

SLOPE_DATA= ethoroadama.slope.gif
# Background data GIF
#  format:   <location>.hillshade.[<user info>].gif
#BACKGROUND_DATA= demo200.hillshade.gif
BACKGROUND_DATA= ethoroadama.hillshade.gif
# XI. OUTPUT IMAGES
WRITE_COLOR_KEY_IMAGES(YES/NO)=Yes
ECHO_IMAGE_FILES(YES/NO)=YES
ANIMATION(YES/NO)= YES

# XII. COLORTABLE SETTINGS
#
#    2. COLORTABLE SETTINGS
#         SEED_COLOR: initializing and extrapolated historic urban extent

#         WATER_COLOR: BACKGROUND_DATA is used as a backdrop for
#SEED_COLOR= 0XFFFF00 #yellow
SEED_COLOR=  249, 209, 110 #pale yellow
#WATER_COLOR=  0X0000FF # blue
WATER_COLOR=  20, 52, 214 # royal blue

#     3. PROBABILITY COLORTABLE FOR URBAN GROWTH
PROBABILITY_COLOR=   0,    1,         , #transparent
PROBABILITY_COLOR=   1,    10, 0X00ff33, #green
PROBABILITY_COLOR=   10,   20, 0X00cc33, #
PROBABILITY_COLOR=   20,   30, 0X009933, #
PROBABILITY_COLOR=   30,   40, 0X006666, #blue
PROBABILITY_COLOR=   40,   50, 0X003366, #
PROBABILITY_COLOR=   50,   60, 0X000066, #
PROBABILITY_COLOR=   60,   70, 0XFF6A6A, #lt orange
PROBABILITY_COLOR=   70,   80, 0Xff7F00, #dark orange
PROBABILITY_COLOR=   80,   90, 0Xff3E96, #violetred
PROBABILITY_COLOR=   90,  100, 0Xff0033, #dark red

#  C. LAND COVER COLORTABLE

#  D. GROWTH TYPE IMAGE OUTPUT CONTROL AND COLORTABLE
#  0 == first
VIEW_GROWTH_TYPES (YES/NO)=NO

#*********************************************************
# #  E. DELTATRON AGING SECTION
```

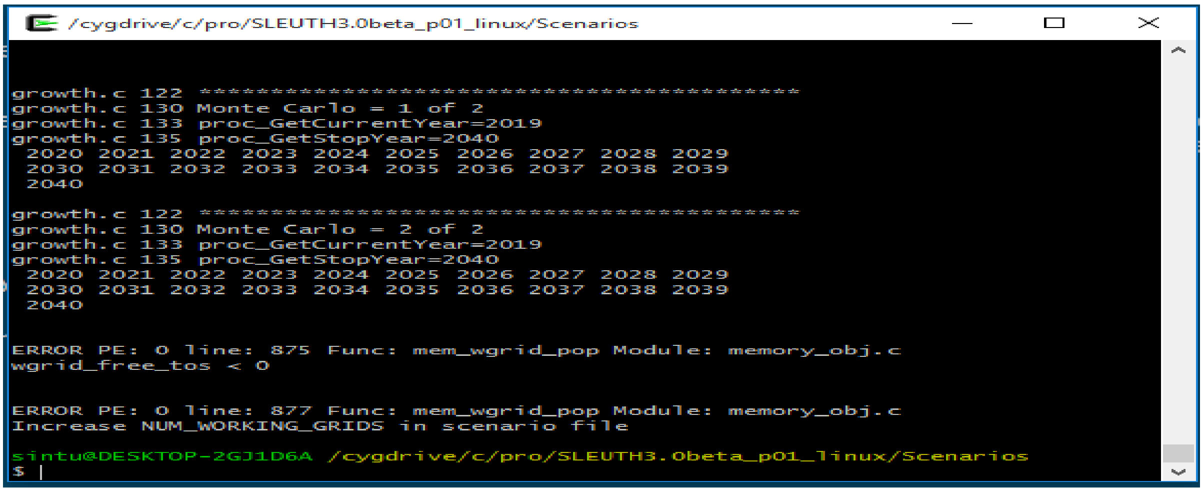
```
#  From here you can control the output of the deltatron grid
#  just before they are aged
#
#  VIEW_DELTATRON_AGING(YES/NO) provides an on/off
#  toggle to control whether the images are generated.

#  DELTATRON_PRINT_WINDOW provides a print window
VIEW_DELTATRON_AGING(YES/NO)=NO
DELTATRON_PRINT_WINDOW=0,0,0,0,1930,2020
DELTATRON_COLOR=  0x000000 # index 0 No or dead deltatron
DELTATRON_COLOR=  0X00FF00 # index 1 age = 1 year
DELTATRON_COLOR=  0X00D200 # index 2 age = 2 year
DELTATRON_COLOR=  0X00AA00 # index 3 age = 3 year
DELTATRON_COLOR=  0X008200 # index 4 age = 4 year
DELTATRON_COLOR=  0X005A00 # index 5 age = 5 year

# XIII. SELF-MODIFICATION PARAMETERS
ROAD_GRAV_SENSITIVITY=0.01
SLOPE_SENSITIVITY=0.1
CRITICAL_LOW=0.97
CRITICAL_HIGH=1.3
#CRITICAL_LOW=0.0
#CRITICAL_HIGH=10000000000000.0
CRITICAL_SLOPE=15.0
BOOM=1.01
BUST=0.09
```

Appendix 7Run Time Error and its solution

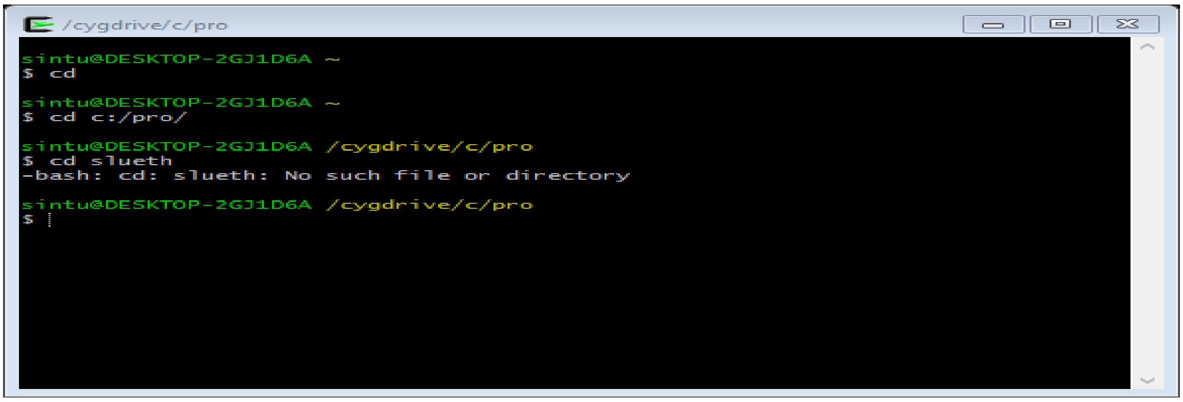
Some problems when running the SLEUTH model



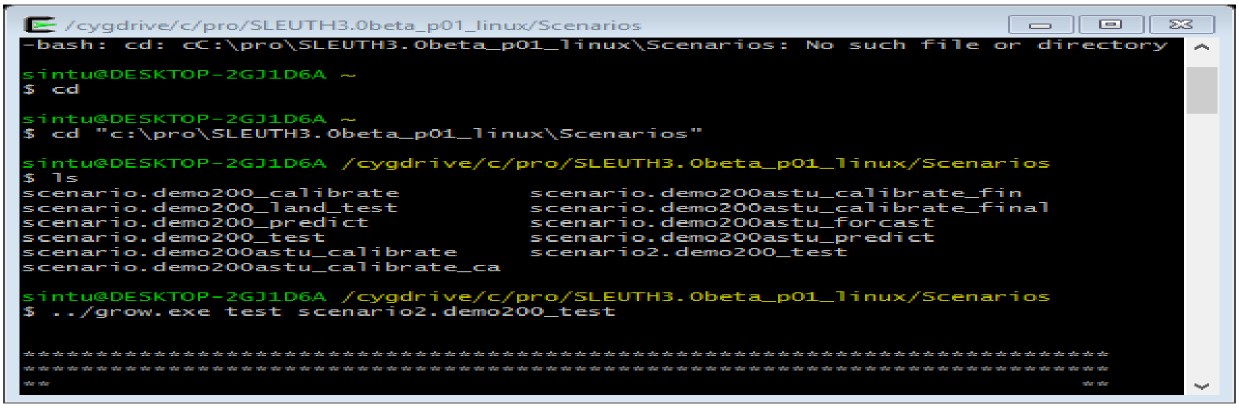
Solution Define the variables

$ ../grow.exe calibrate scenario.changhe200_calibrate

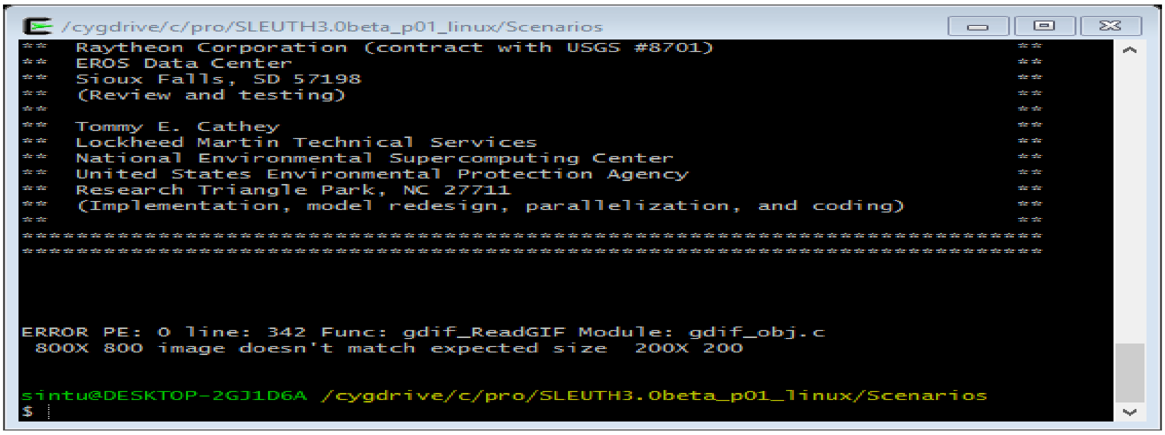
main.c 789 pe: 0 Please make sure the following env variables are defined
main.c 791 pe: 0 USER — set to your username
main.c 793 pe: 0 HOST — set to your machines's name = uname -n
main.c 795 pe: 0 HOSTTYPE — set to your machines's type such as Sparc, Cray
main.c 797 pe: 0 OSTYPE — set to your machines's OS type such as Solaris2.7
main.c 799 pe: 0 PWD — set to your current working directory
main.c 817 pe: 0 caught signo SIGSEGV : Invalid storage access
Currently executing function: scen_init
glb_call_stack[1]= scen_init
glb_call_stack[0]= main



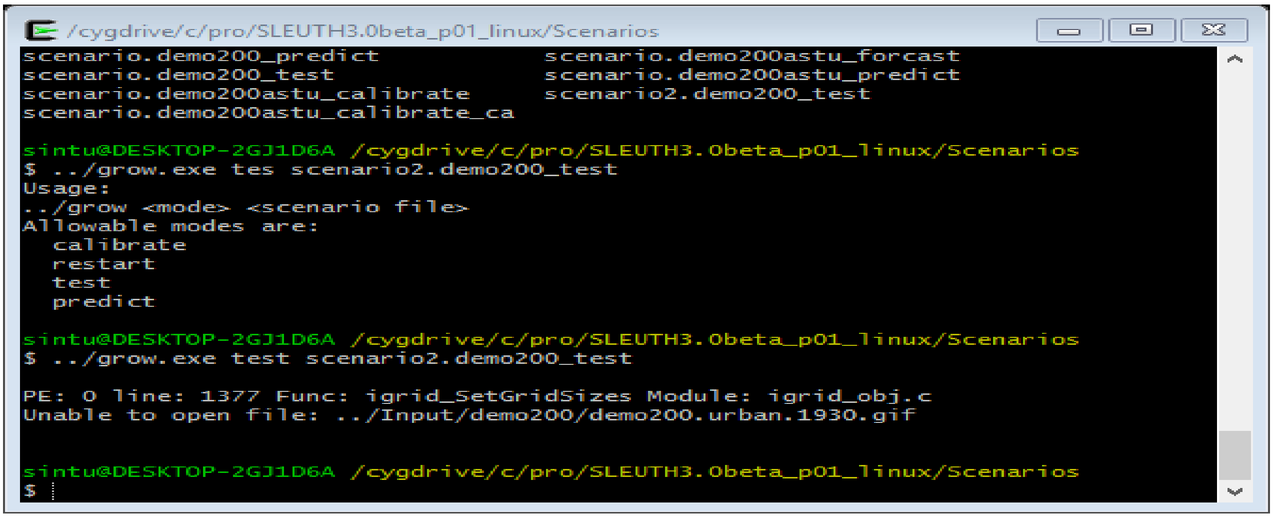
Solution set your current working directory



Solution You can increase RAM or run the model on a better-equipped computer. Another option is Increasing capacity of the computer memory.



Solution resample as the input image as per the model request



Solution Rewrite the input data (land use data) Change the land use map (time series or changing the spatial detail of the land use map) or: Update the land use in % (assuming some % increase or Decrease as per model calibration request.