The Scientific Temper (2024) Vol. 15 (2): 2333-2341
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2024.15.2.48
https://scientifictemper.com/
RESEARCH ARTICLE

A comprehensive review of urban growth studies and predictions using the Sleuth model

Bratati Dey*, Poonam Sharma

Abstract

Urban growth is a complex phenomenon It has been the subject of in-depth research for the last few years. There are various models used to measure and simulate urban growth. Most of these methods are founded on GIS & RS techniques coupled with the CA algorithm, as only these tools and techniques have the capabilities to conduct spatiotemporal studies, manage spatiotemporal dynamics, and provide a detailed depiction and modeling from the bottom-up tactic. Recently, the slope, land use, exclusion, urbanization, transportation, and hill shade (SLEUTH) model has been the most commonly used model. It is easily accessible because it is open source; moreover, its source code is also easily accessible. The SLEUTH model's name alludes to the necessary inputs —slope, land use, excluded area, urban extension, transportation, network and hillshade. The model has been used in many cities and has proven to be efficient. The present review paper reviews the past literature pertaining to urban development and prediction to further support the research on urban planning, urban growth and prediction.

Keywords: Urban growth, Urban growth prediction, SLEUTH, CA algorithm, Spatial analysis.

Introduction

Urbanization is a universal phenomenon that is rapidly changing the face of the planet. As the world's population continues to grow, so does the need for housing, infrastructure, and other urban amenities. However, urbanization can also have negative influences on the environment, such as land use change, loss of biodiversity, and increased carbon emissions. Batty and colleagues documented the evolution of urban models through their analysis of urban systems as cellular automata. To help researchers better understand urban phenomena, urban modeling often focuses on the urban design, construction, and process of mathematical models, especially for cities and areas (Batty *et al.*, 1997). Hägerstrand (1965) made the 1st attempts to construct mathematical CA models of urban systems of spatial diffusion models. Tobler (1970) developed a demographic model that explains the regional distribution of population growth in the Detroit region, building on previous work. Understanding and predicting urban growth patterns are important for managing the effects of urbanization. This review will focus on the SLEUTH model, a widely used urban growth simulation model that has been used in numerous studies to predict and analyze urban growth patterns. The present era addresses the growth and development of urbanization. Researchers are more concerned with studying urban growth and its pattern as well as predicting trends in urbanization. Many urban growth and prediction models have been found to yield valuable results. Some of the widely used models are listed below:

SLEUTH Model

In the field of urban development simulation, the SLEUTH model is a popular model that simulates urban expansion based on changes in land use, population increase, and other factors that contribute to urbanization. For the purpose of predicting urban development patterns, the model makes use of a variety of geographical variables, such as slope, land use/land cover, and transportation chains (Clarke *et al.*, 1997).

Cellular Automata (CA) Model

The CA model is yet another model that is commonly used for the purpose of predicting urban expansion (Tobler, 1979). A grid-based model that simulates land use alteration

Department of Geography, Shaheed Bhagat Singh College, University of Delhi, New Delhi, Delhi, India.

***Corresponding Author:** Bratati Dey, Department of Geography, Shaheed Bhagat Singh College, University of Delhi, New Delhi, Delhi, India., E-Mail: poonam.sharma@sbs.du.ac.in

How to cite this article: Dey, B., Sharma, P. (2024). A comprehensive review of urban growth studies and predictions using the Sleuth model. The Scientific Temper, **15**(2):2333-2341.

Doi: 10.58414/SCIENTIFICTEMPER.2024.15.2.48

Source of support: Nil

Conflict of interest: None.

Received: 16/04/2024 **Accepted:** 25/05/2024 **Published** : 15/06/2024

based on transition rules that describe the likelihood of a cell shifting from one land use type to another. This model is based on the concept of transition rules. The model is widely utilized in research globally, and it is able to simulate intricate patterns of urban expansion (Changlin Yin *et al.*, 2021).

Agent-Based Model

The agent-based model (ABM) is a simulation model that simulates the behaviour of individual agents, such as households or firms, and their interactions with each other and their environment. The model is capable of capturing the complex interactions and feedback loops that drive urban growth and has been used in several studies to simulate urban growth patterns (Fiexue Li *et al.*, 2020).

Pattern-Oriented modeling

"Patterns at many sizes should be examined in order to represent the underlying processes of a complex system, according to the pattern-oriented modeling (POM) paradigm, which has recently gained traction in ecology as an approach for understanding complex systems" (Judith A. *et al.*,2022).

Regression Models

Regression models are statistical models that provide predictions about the expansion of metropolitan areas by using historical data and other important factors, such as population, employment, and transportation infrastructure. Other relevant variables include the following: Models are often used to develop scenarios of future urban expansion under a variety of policy and land use situations (Nong Yu,2012).

Artificial Neural Networks

An artificial neural network (ANN) is a kind of machine learning model that attempts to anticipate urban expansion by simulating the structure and job of the human brain. It is possible for the models to capture the nonlinear correlations that exist between the factors that drive urban expansion and the patterns of urban growth (Stephane Cedric Koumetio Tekouabou *et al.*,2022).

GEM, FASOM, CURBA, SimLand, UrbanSim, LUCUS, DINAMICA, CLUE, and CVCA are some of the available urban growth models. These models are based on a mix of various techniques and consider a diverse range of causes of urbanization.

The Slope, Land Use, Exclusion, Urbanization, Transportation, and Hill Shade (SLEUTH)

Land use change model is a CA-based model that simulates urban growth patterns by modeling land use change as a function of population growth, economic development and other drivers of urbanization. The model was first established in the 1990s, and since then, it has been used extensively in studies pertaining to urban planning and land use management. For the purpose of simulating urban development patterns, the model makes use of geographical data, which include land use and land cover, slope, transportation networks, and restrictions on certain locations. The region under investigation is partitioned into a grid of cells by the model, with each cell representing a tiny portion of the land. In accordance with the land use and land cover that is now present in the cells, the cells are divided into several land use types. After that, the model simulates the transition of cells from one land use type to another based on transition rules that describe the likelihood of a cell shifting from one land use type to another. This is done to better understand the dynamics of the transition.

The SLEUTH model has several strengths, one of which is its capacity to replicate intricate urban development patterns, as well as its capacity to represent the impact of land use policy and transportation infrastructure on urban growth patterns, and its capacity to forecast future growth scenarios. In addition, the model is not too complicated to use and requires a small amount of data to be provided. There are, however, a few limitations associated with the SLEUTH model. The model operates on the supposition that urban development patterns will continue to follow the trends that have been seen in the past. It does not take into account the possibility of shifts in urbanization patterns that may occur as a result of changes in policy, demography, or other variables.

Moreover, the model is highly reliant on the data that are input, and any errors that occur in the data that are input might result in errors that occur in the output of the model. In addition, the model does not consider the spatial interactions that occur between cells, which might restrict its capacity to provide an accurate representation of intricate urban development patterns. When using SLEUTH for forecasting, the "seed" layer of the model is initialized using the most current data when the forecasting process begins. After that, SLEUTH will carry out a constrained collection of transition rules, which will include choosing cells at random and analyzing the spatial characteristics of the cells that are located in the surrounding area. The determination of whether a given cell is urbanized is based on an urbanization probability that is derived from the features of the local environment. A study revealed eight regulations that have an impact on the changes that occur inside the CA. Despite the fact that it has several shortcomings, the SLEUTH model continues to be a well-liked and regularly used instrument for the modeling and prediction of urban expansion. A number of studies have shown that this approach is useful for modeling and forecasting patterns of urban expansion. Furthermore, current research continues to enhance and improve model accuracy and application.

For the purpose of simulating urban expansion, the SLEUTH model has been used in many cities worldwide.

It has already been implemented in 66 distinct cities and regions" (Clarke *et al.*, 2007).

Background

The SLEUTH model, which includes a slope, land use, exclusion, urbanization, transportation, and hill shade, was created by Clarke and colleagues in 1997. It is a CA model that simulates urban expansion based on changes in land use, population increase, and other factors that contribute to urbanization. The simulation of urban development patterns is accomplished by the model by the use of a variety of spatial data, which includes land use/land cover, slope, and transportation networks. There are several places worldwide that have used the SLEUTH model, such as the United States of America, China, Asia, and Europe. To simulate the expansion of urban areas, the SLEUTH model divides the landscape into cells and then assigns a probability of urbanization to each cell. This probability is determined by a set of rules that takes into account a variety of factors that contribute to urbanization. For the purpose of calibrating and validating the simulation, the model leverages satellite images in addition to other geographical data. In addition, the SLEUTH model features feedback loops, which make it possible to simulate the intricate interactions that occur between demographic increases, changes in land use, and other factors that contribute to urbanization.

In recent years, urban prediction modeling and land cover change in Asian countries such as China, Thailand, and India have been studied using the CA-based SLEUTH urban growth model (Sangawongse, 2006). The model has gained popularity due to its efficiency in urban simulations and future growth scenario results. The model based on cellular automata is probably the most notable among all the documented dynamic models in terms of its technical progress in connection to urban claims. The SLEUTH model has been tested in more than 60 cities worldwide (Clarke, 2013). Using these models, city urban planners, decision-makers and policymakers can analyze the different scenarios of urban land use/land cover change and evaluate the effects on land use planning and policy (Veldkamp & Lambin, 2001). The current study involving model simulation provides spatial information on urban growth, which is a prerequisite for urban planners and decision-makers to understand both current and future growth scenarios in cities. This study will also serve as a basis for mitigating urban development and as a basis for planning and developing city policies.

It is possible to make accurate predictions and conduct in-depth analyses of urban development trends using the SLEUTH model. The model has been used in a great number of studies worldwide, and it has been shown to be suitable for modeling the expansion of metropolitan areas. However, the model does have certain restrictions. For instance, the model presupposes that urbanization is a linear process and does not consider the impacts of economic cycles or other social elements that might affect urban development patterns. Moreover, the model does not consider environmental issues (H. A Bharath, 2018).

Objectives

The SLEUTH model is used to fulfill three objectives

- The SLEUTH model was used to monitor and analyze urban growth.
- Prediction ability of the SLEUTH model for urban growth
- The SLEUTH model was used to predict future urban growth under different policy and land use scenarios.

Past Literature

SLEUTH has been used in a great number of studies for the purpose of forecasting and analysing patterns of urban expansion. For instance, Wu and Webster (2001) utilized the model to simulate urban expansion in the San Francisco Bay region and found that the model was successful in forecasting urban growth trends. Similarly, (Kumar and Agarwal, 2021) used the SLEUTH model to forecast urban expansion in the Pearl River Delta in China, and the results showed that the model was able to properly forecast the geographical patterns and breadth of urban growth in the area. In other research, the SLEUTH model has been used to construct scenarios of future urban expansion under a variety of policy and land use scenarios.

(Clarke & Gaydos,1998) "In their article, the metropolitan regions of San Francisco and Washington/Baltimore were subjected to a long-term urban development projection that was produced by combining a computer application (CA) and geographical information systems (GIS). The urban growth model (UGM), which Clarke designed, is used in this study. The purpose of this study was to determine whether the model is capable of accurately predicting growth in regions with unique shifts in growth patterns. Model calibration is performed using historical data for both areas, after which the prediction process begins when the model has been calibrated. Moreover, this study investigated the functions that GISs play and revealed three primary domains in which GISs play an essential role. The first function of the system is that of a data integrator. The second function is that of a visualization tool, which is used to make map displays based on the output of the model. The third function, which is the most essential, is the ability of a GIS to store and modify fresh data sets for applications such as decision-making tools.

(Candau, Rasmussen & Clarke,2000) Introduce the SLEUTH model as a novel approach that may be used for a large area that encompasses the states of Delaware, the district of Columbia, Maryland, North Carolina, novel York, Pennsylvania, Virginia, and West Virginia. The original unified geographic model (UGM) serves as the foundation for this model; however, it is combined with a deltatron land-use model (DLM). In this model, a turn-based method is used, and the UGM is responsible for applying the standard parameters to propagate land cover change across urban and non-urban land use over a period of one year. After that, the deltatron parameters are applied to each pixel that changes throughout the cycle. If the parameters are not satisfied, the pixel will return to its initial state without any further modification. This enables one to differentiate between regions with high transition confidence and regions with transition uncertainty. These cells are recorded, and an uncertainty map may be created if that is something desired.

(Silva & Clarke, 2002) Expand upon the previous work of Clarke and Gaydos (1998) by validating the universality of "the SLEUTH model in a European setting by using it to simulate two Portuguese cities, Lisbon and Porto, which offer extremely varied spatial and developmental features owing to topographical and historical cultural differences. Specifically, the model was used to mimic the cities of Lisbon and Porto. The calibration of the model for the two cities is the primary focus of the application since it is the step that is identified as being the most important in terms of guaranteeing a high degree of modeling accuracy". These authors listed the purposes of the study as follows: (1) to demonstrate that the same model could be applied not only to North America but also to European cities; (2) to demonstrate how important structural and geographical differences between applications could be revealed by calibrations that may be useful in comparative urban studies; (3) to reveal how spatial resolution improves model performance by making the model more sensitive to local conditions; and (4) to determine how sequential multistage optimization throughout different phases of calibration is the key to model application comparisons. The findings were satisfactory, and the model was able to precisely represent the distinct development trends for each city. The model provides valuable insights into the early stages of urban development and is well-suited for conducting comparative analyses of other cities. The study did make a comment about the high amounts of CPU time that are needed, but it was discovered that the SLEUTH model is simple to use and is well matched to the context of the planning application.

Jantz, Goetz & Shelley (2003) used the SLEUTH model, which is used to predict the effects of potential future policy scenarios on the utilization of urban land in the metropolitan region of Baltimore and Washington. The impact that urbanization has on the water quality and overall health of the Chesapeake Bay estuary and the streams that flow into it was the subject of the discussion that required attention. To make a projection of the amount of urban expansion up to the year 2030, the SLEUTH model was used. This projection considered three different policy scenarios: (1) current trends, (2) managed growth, and (3) ecologically sustainable growth. The implementation of SLEUTH was selected for the project because of its user-friendliness, its capacity to include varying degrees of security for various regions, and its simplicity in integrating with raster geographic information systems. Kocabas & Dragicevic (2004) also believe that this position is correct. Past data were obtained via remote sensing, with 1986 being selected as the "seed" year, followed by 1990, 1996, and 2000. The data had to be rescaled to a coarser scale since the computer resources that were available would not have been enough to analyze a resolution that was finer than 45 meters. The calibration of the model was accomplished via the use of a Monte Carlo simulation technique, which requires more than a week of processing time on a Beowulf PC cluster consisting of 16 nodes (each node is composed of an AMD processor, a 750 CPU MHz, and 1.5 GB of RAM). Despite the fact that this is a very time-consuming and hardware-intensive process, the data set covers a wide region that is 23-7 hundred kilometers squared. The study indicated that the SLEUTH model yielded excellent results at the regional level, but it was not accurate at identifying progress at the local level. This was discovered after examining the findings of the research. As a result, the study concluded that the SLEUTH is an excellent tool for decision-making and policy analysis at the regional level. However, the model must undergo considerable refinement before it can be used exclusively for this purpose at the local level.

In their simulation, SLEUTH aimed to forecast the expansion of urban areas and investigate the effects of various policy scenarios on the metropolitan region of Atlanta. This project's primary objective was to investigate the ways in which future urban expansion may have an impact on vegetative land cover and to find ways to safeguard the natural environment. Satellite remotely sensed images covering the years 1973 through 1999 were used to compile the data for the model. The data format, resolution, and dimension must be standardized before the model can be evaluated and executed. The process of calibration, which calls for Monte Carlo iterations, required approximately two weeks of CPU time due to the limits imposed by the hardware. However, researchers believe that more realistic simulations may be produced by altering the model's transition rules and considering additional growth limitations. The findings were positive; however, they believe that modifications could be made. According to one of the closing remarks, the model was an efficient instrument that allowed for the "imagination, testing, and selection of possible future urban growth scenarios in relation to various environmental and development conditions."

(Goldstein, Candau & Clarke,2004) Proposed an innovative method for CA modeling. For the purpose of simulating the historical development of Santa Barbara's urban area, they utilized the SLEUTH. They contend that the modeling of historical urban expansion has received very little attention during the course of recent research, which has mostly focused on predicting cities in the future. The researchers are of the opinion that "understanding the growth dynamics of a region's past allows for more intelligent forecasts of its future." By using this particular method of modeling, the researcher is able to investigate the impact that the repercussions of war, economic booms and collapses, technological advancements, and natural calamities have on the expansion of cities. One of the most significant factors preventing such an application from being implemented is the absence of historical spatiotemporal data or the high degree of distortion that is present in geographic data. The lengthy duration of time required for data collection, in addition to the interpolation needs for missing data sets, causes this form of modeling to take a much longer amount of time. To reconstruct data sets by making use of the "past" future, a modified version of the SLEUTH model is used.

The majority of the research that was examined expressed praise for the ability of a CA to predict the future of metropolitan areas and advocated for the use of CAs as a tool for decision-making. Despite the fact that local knowledge is an essential supplementary data source for CA modeling, it is necessary to make efforts to implement cellular modeling technology for the purpose of problem-solving in applied urban studies. During the process of modeling, "project planning, site selection, and temporal control require more input from local experts." These experts' local expertise is a crucial source of qualitative information" (Cheng & Masser, 2004).

Within the framework of a research project carried out by (Xuecao *et al*., 2020), the SLEUTH model was used to forecast the expansion of urban parts in the Beijing-Tianjin-Hebei region of China. Based on the findings of the research, it was determined that the model was capable of properly predicting urban development trends in the area over a period of 15 years. In addition, the authors recognized a number of influential elements that contributed to the expansion of urban areas. These factors included economic development, population increase, and transportation infrastructure.

Finally, (Wu *et al.*,2000) used the SLEUTH model to forecast the expansion of urban areas in the Yangtze River Delta in China. According to the findings of the research, the model was able to effectively anticipate urban growth designs in the area. Additionally, the study highlighted many major elements that are considered to drive urban expansion. These factors include economic development, transportation infrastructure, and land use rules.

In conclusion, the SLEUTH model has been used extensively in the field of urban development research for the purpose of forecasting and analyzing patterns of urban expansion in a variety of places worldwide. The model has been shown to be an efficient instrument for simulating urban expansion, and it has been used to produce scenarios of future urban growth under a variety of policy and land use scenarios.

Within the realm of urban development simulation models, the SLEUTH model is well-known and commonly used. Many studies have focused on forecasting and investigating the patterns of urban expansion in a variety of places worldwide. Within the scope of this literature review, we investigated a selection of the most important research that has made use of the SLEUTH model.

Mallouk *et al.* (2019) used a southern urban growth model coupled with GIS to simulate and predict the urban expansion of the Casablanca region, Morocco. They defined the indices for the precise evaluation of the calibration results in the SLEUTH model. The work was carried out to predict urban expansion for 2040, and the spatial layers for the work were created in ArcGIS software.

(Vaibhav Kumar Gangnani, 2017) Predicted that the author made an attempt to provide a very detailed explanation of the approach used to describe the urban expansion of Udaipur using the SLEUTH model. Both the data that were used and the procedures that were followed to perform the SLEUTH were detailed in great detail. The workflow of a suggested approach that focuses on tracking the temporal expansion of metropolitan areas using remotely sensed images is discussed. This approach comprises a number of stages, including the gathering of data from a variety of foundations, the processing of data using techniques such as image fusion and digitization, the mapping of time, and the assessment of the data based on geographical indications and comparisons. The primary quantitative analysis consists of morphological analysis, spatial pattern analysis, and the study of changes in land use structure together with the forecasting of forthcoming sprawl. To analyse these remote sensing data visually, visual image interpretation was performed. The interpretation of visual images has been digitized, and other layers, such as land use, urban, exclusion, and transportation, have been included. The outcomes have been aligned with the development plans that were completed previously. For the purpose of analyzing the likelihood of sprawl, supplementary data sources are consulted to gather information on factors that influence sprawl, such as outgrowth, roadways, slope, and land use.

(V. Kumar and S. Agrawal, 2022) Worked on urban modeling and land use forecasting are being done. The SLEUTH model was used to calibrate the urban land use-altering elements to predict the LULC for Prayagraj, India, which is a smart city that is now undergoing further development. Additionally, as part of their study, they considered numerous prediction models in relation to their respective applications. According to the development pattern that has occurred in the past and via the application of four growth rules that are encouraged by regulating elements, SLEUTH is a modified version of CA that forecasts urban growth. There are four different laws that govern growth: spontaneous growth, spreading center growth, edge growth, and road-influenced development. Five different coefficients—namely, dispersion, breed, spread, slope, and road gravity coefficient—are responsible for putting these laws into effect.

(Chandan, M.C. and Bharath, A.H.,2018) Discussed the constraints that the CA algorithm has in regard to predicting urban expansion. During the process of simulating urban transition using cellular automata-based SLEUTH modeling for Bhopal city, they described the conditions that were necessary to run the SLEUTH model at the same time.

Chaudhury *et al.* (2019) conducted a tripartite investigation of urban expansion, highlighting the significance of the SLEUTH model among all of the models of urban growth. They wanted to accomplish the following goals with their research: 1) To assess the connection between urbanization and the factors that contribute to it in Kolkata; (2). To determine whether or if it is necessary to include information about urban drivers in the SLEUTH urban simulation model and to evaluate the various methods that may be used to incorporate the information into the SLEUTH model to improve the accuracy of urban scenario forecasting. After running the SLEUTH model under a variety of different circumstances, the results of the normal SLEUTH simulation were compared with the results obtained from model runs that were changed by integrating the regression results. The results of the model runs were then compared to arrive at judgments on the effectiveness and achievement of each run.

Tobgye and Piyathamrongchai (2019) used the SLEUTH urban growth model to predict the urbanization of the Sarpang district of Bhutan for the next 30 years under three different management scenarios, namely, the business-as-usual scenario (BAU), the managed growth scenario (MGS), and the compact growth scenario (CGS), to understand the spatial growth change in the region. According to them, no certain model for urban growth prediction is accurate in reality, but the results of the SLEUTH model are found to be effective for urban planners and decision-makers.

Over time, researchers have proposed alterations to the SLEUTH model. These modifications include the incorporation of the influence of other significant urbanization explanatory variables and drivers, such as the cost of land, proximity to important roads, and public facilities, such as hospitals, recreational places, bus stands, and railway stations, into the simulation process (Ankit Saxena & Mahesh Jat,2020).

Debates on the variables of urban growth variables of urbanization and LULC change (Wentz *et al.*,2018) have listed the explanatory variables of land use and urban growth (Table 1).

Table 1: Explanatory variables for urban growth and land cover

S.No.	*Class of explanatory variable*	*Variables*
1	Neighbourhood	Proximity to residential area, city centre
2	Proximity	Distance to important locations
3	Demographic	Population parameters
4	Socioeconomic variables	Basic cost of livelihood
5	Institutional variables	Industries and institutions
6	Suitability	Land suitability factors
7	Economic variables	Income level and sources
8	Climatic drivers	Climatic variabilities and zones
9	Bio-physical drivers	Elevation, topographical characteristics
10	Restrictions	Reserved forest, green belt, airports

Source-Saxena et.al.,2020

Because the SLEUTH does not consider the appropriateness of the land in terms of a few significant explanatory factors for urbanization, being involved only in model calibration and simulation may ultimately lead to an improvement in the performance of the model. Consequently, a new version of the SLEUTH model, known as SLEUTH-suitability, has been created to include the SLEUTH requirements and previous versions.

Chaudhari and Clarke (2013) measured the accuracy of the prediction results of the SLEUTH model for the city of Gorizia (Italy). Different techniques of accuracy assessment were used, such as the kappa coefficient, kappa simulation, quantity disagreement and allocation disagreement. The study concluded that the accuracy of the predicted maps decreased due to urban history and the uncertainty of the input data and reference maps.

Gigalopolis, a project linked with the United States Geological Survey, makes the SLEUTH Urban Growth Model, which is an open-source software accessible to the general public. The various versions of the SLEUTH can also be checked on that webpage (http://www.ncgia.ucsb.edu/projects/gig/Dnload/download.htm). The most recent one available is SLEUTH GA, which was launched in April 2017, followed by the optimum SLEUTH metric (OSM) and SLEUTH 0beta, which come in different versions, such as SLEUTH 3.0beta, which was released on 12/2000, and SLEUTH 3.0beta-p01 0n 6/2005. These packages can easily be downloaded and installed on the Cygwin Linux interface in Windows.

Environment for SLEUTH

SLEUTH runs in the Cywin environment, but it sometimes results in errors in some versions of Windows; for that purpose, various other software can be installed, such as -1. MySys2, 2. Babun, 3. Cmder, 4. Ubuntu for Windows. It is

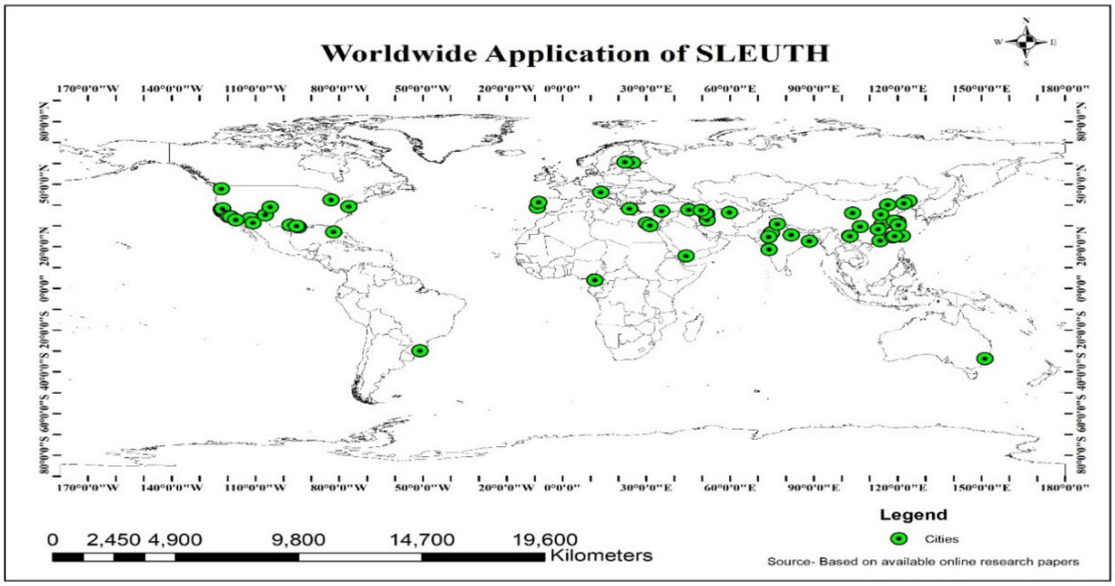

Figure 1: Worldwide application of the SLEUTH model

highly recommended to run SLEUTH 0beta-p01 in Mysys2 and Babun. The older version of the SLEUTH works well in the Cywin environment.

Workflow

The initial requirement is a binary classification of urban and non-urban data. The urban area is assigned a value of 100, and the non-urban area is assigned a value of 0. The temporal road layer is classified as 100 for roads and 0 for non-roads. Slope and land use/land cover were classified and weighted between 0 and 100 based on their importance in increasing urbanization. The excluded layer is given a weight of 100, and the moderately excluded layer is 50. All these layers are resampled with the same pixel value and finally converted into GIF format.

Model Operation

The whole process of the SLEUTH model is quite automated. We need to save the files properly in the scenario folder. Broadly, the following steps are followed for running the model:

- Setting up the Linux environment
- Linking the path of the software
- Installing the software
- Linking the input folder (where the main layers are saved)
- The scenario files from the scenario folder were tested.
- Testing the predicted scenario files.
- Check the result in the output folder.

Before proceeding, it must be ensured that the layers are properly saved in the input folder. The required predicted year must be edited in the scenario test file prediction start date and prediction stop date.

Worldwide Application of SLEUTH

The SLEUTH model is highly applicable and has been tested in various cities around the world. The researchers found it very useful, easy and effective.

Figure 1 shows that most of the work has been done in American cities, followed by China. Researchers seem to be less aware of this wonderful model; thus, its application is very limited. The SLEUTH model must be used for monitoring urban growth and predicting urban growth in almost all major cities of the world. The cities were identified through an online paper search, and the city names were manually searched in Google Earth Pro and saved in KML. Furthermore, the KML point file was converted into shapefile format and overlapped on the world shapefile boundary.

Conclusion

There are several models available for urban growth prediction, each with its own strengths and limitations. The choice of model depends on the research question, data availability, and modeling objectives. The SLEUTH model, cellular automata model, agent-based model, regression models, and artificial neural networks are some of the commonly used models for urban growth prediction. Future research should continue to refine and improve these models to enhance their accuracy and applicability for urban planning and land use management.

Acknowledgment

The present review paper is an initiative to unfold the advantages of the SLEUTH model for urban growth prediction. Urban growth and prediction studies have become an important field of research. Many tools and

techniques are coming up with various functionalities for prediction. The SLEUTH model is one such technique used for urban growth prediction. The paper will help the researchers to get more options for similar studies.

The paper is drafted during the Post Doctoral Research tenure. Thus, special thanks to the Indian Council of Social Science Research for giving me the privilege to pursue my post-doctoral research work. Finally, thanks to all the authors who worked on the SLEUTH model and explored its pros and cons for further enlightening us to explore even more.

References

Andersson., Claes.,Rasmussen., Steen., White., Roger. (2002). Urban Settlement Transitions. Environment and Planning. *Planning and Design*,29,841-865.

Anthony, G. O., Yeh., Xia, Li., and Chang, Xia.(2021). *Cellular Automata Modelling for Urban and Regional Planning*. Urban Informatics,865-883.

Batty, M., Couclelis, H., & Eichen, M. (1997). *Urban systems as cellular automata. Environment and Planning*.Planning and Design, 24, 159-164.

Bharath,H.A., Chandan,M.C., Vinay,S., Ramachandra,T.V., (2018). Modelling urban dynamics in rapidly urbanising Indian cities. The Egyptian Journal of Remote Sensing and Space Science,21, 201-210.

Chandan,M.C.,& Aithal., Bharath. (2018). Modelling Urban transition using Cellular Automata based Sleuth modelling. 10.1109/SSCI.2018.8628940

Chaudhuri, Gargi,.& Clarke, Keith. (2014). Temporal Accuracy in Urban Growth Forecasting: A Study Using the SLEUTH Model. Transactions in GIS. 10.1111/tgis.12047.

Chaudhuri, Gargi., & Clarke, Keith. (2013). *The SLEUTH land use change model: A review*. International Journal of Environmental Resource Research, 1, 88 - 105.

Chaudhuri, Gargi., & Clarke, Keith. (2014). Temporal Accuracy in Urban Growth Forecasting: A Study Using the SLEUTH Model. Transactions in GIS. 10.1111/tgis.12047.

Cheng, Jianquan., & Masser, Ian. (2004). Understanding Spatial and Temporal Processes of Urban Growth: Cellular Automata Modelling. Environment and Planning .Planning and Design,31. 167-194. 10.1068/b2975

Clarke, K.C., Hoppen, S., and Gaydos, L.(1997). A self-modifying cellular automaton model of historical urbanisation in the San Francisco Bay Area.Environ. Plann B. Planning and Design. 24(2), 247-261.

Clarke, KC., Gaydos, LJ.(1998).Loose-coupling a cellular automaton model and GIS- long-term urban growth prediction for San Francisco and Washington/Baltimore. Int J Geogr Inf Sci. Oct-Nov;12(7),699-714.

Clarke, Keith. (2006). Exploring the DNA of our regions: Classification of outputs from the SLEUTH model. Lecture notes in computer science,462-471.

Clarke, Keith. (2018). Land Use Change Modelling with SLEUTH: Improving Calibration with a Genetic Algorithm. Geomatic Approaches for Modelling Land Change Scenario,139-161.

Feixue, Li., Zhifeng Li., Honghua,Chen., Zhenjie,Chen., Manchun, Li. (2020). An agent-based learning-embedded model (ABM-learning) for urban land use planning: A case study of residential land growth simulation in Shenzhen, China. Land Use Policy. Volume 95.

Gangnani, Vaibhav., & Gandhi, Shaily. (2017). Predicting urban growth using SLEUTH urban growth model, Cygwin and GIS techniques.17th User Conference 2017.

Goldstein, Noah., & Candau, J.T., & Clarke, Keith. (2004). Approaches to simulating the "March of Bricks and Mortar". Computers, Environment and Urban Systems. 28. 125-147.

Hägerstrand, T. (1965). A Monte Carlo Approach to Diffusion. European Journal of Sociology, 6(01), 43-67

Jantz, Claire., & Goetz., Scott., & Shelley, MK. (2004). Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore-Washington metropolitan area. Environment and Planning B Planning and Design. 31. 251-271.

Judith, A., Verstegen., Katarzyna, Goch. (2022). Pattern-oriented calibration and validation of urban growth models: Case studies of Dublin, Milan and Warsaw. Land Use Policy. Volume 112

Kocabas, Verda., & Dragicevic, Suzana. (2006). Coupling Bayesian Networks with GIS-Based Cellular Automata for Modelling Land Use Change. Geographic Information Science. 4197. 217-233.

Kumar, V., Agrawal, S. (2023). Urban modelling and forecasting of landuse using SLEUTH model. *Int. J. Environ. Sci. Technol.* **20**, 6499–6518.

Kumar, Vivek., & Agrawal, Sonam. (2022). Urban modelling and forecasting of landuse using SLEUTH model. International Journal of Environmental Science and Technology. 10.1007/s13762-022-04331-4.

Mallouk, A., Elhadrachi, H., Malaainine, M.E.I., Rhinane, H.(2019) Using the SLEUTH urban growth model coupled with a GIS to simulate and predict the future urban expansion of Casablanca region, Morocco. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci*, *XLII-4/W12*, 139–145.

Sangawongse, S.(2006).Land Use/Land- Cover Dynamics in Chiang Mai: Appraisal from Remote Sensing, GIS and Modelling Approaches. CMU. Journal, 5(2),243-254.

Saxena, A., Jat, MK. (2020) Land Suitability and urban growth modelling: development of SLEUTH- Suitability. Compute Environ Urban System. 81:101475

Silva, E A., Clarke, K C. (2002). Calibration of the SLEUTH urban growth model for Lisbon and Porto, Spain. Computers, Environment and Urban Systems,525 – 552

Stephane, Cedric., Koumetio, Tekouabou., El, Bachir Diop., Azmi,Rida., Jaligot,Remo., Jerome, Chenal.(2022). Reviewing the application of machine learning methods to model urban form indicators in planning decision support systems: Potential, issues and challenges. Journal of King Saud University - Computer and Information Sciences, 34(8),5943-5967.

Tobgye, Lobzang., & Piyathamrongchai, Kampanart. (2019). Urban growth simulation using Remote sensing, GIS, and SLEUTH urban growth model: a case study under Sarpang District, Bhutan.

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. Economic Geography, 46, 234-240.

Veldkamp, A., Lambin, E.F., (2001). Predicting land-use change. *Agriculture, Ecosystems & Environment*. 85, 1-6.

Webster, C,,Wu, F.(2001), Coase, spatial pricing and self-organising cities. Urban Studies, 2037- 2054

Wentz, Elizabeth., & Nelson, David., & Rahman, Atiqur., & Stefanov, William., & Roy, Shouraseni. (2008). Expert system classification of urban land use/cover for Delhi, India. International Journal of Remote Sensing - INT J REMOTE SENS. 29. 4405-4427..

Wu, F., Webster, C.J.(2000) Simulating artificial cities in a GIS environment: Urban growth under alternative regulation regimes. Int. J. Geogr. Inf. Sci. 2000,(14) 625–648

Xuecao, Li., & Zhou, Yuyu., & Chen, Wei. (2020). An improved urban cellular automata model by using the trend-adjusted neighborhood. 9. 10.1186/s13717-020-00234-9.

Yang, X., Lo, CP. (2003) Modelling urban growth and landscape change in the Atlanta metropolitan area. Int J Geogr Inf Sci 17,463–488

Yin, Changlin., & Yu, Dingquan., Zhang, Honghui., You, Shengjing., & Chen, Guanghui. (2008). Simulation of urban growth using a cellular automata-based model in a developing nation's region. Proceedings of SPIE - The International Society for Optical Engineering. 7143.

Yu, Nong., Quinyan., Du.2012. Urban growth pattern modelling using logistic regression-spatial Information Science, Volume 12.62-67