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Development of an Urban Growth Model Using Geographical Information System in Malaysia: A Review

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Abstract: Urbanization is one of the major problems faced by various countries over time. The process by which rural regions transform into cities and people move from rural to urban areas is known as urbanization. Urban land use development is influenced by a variety of factors, including physical, socioeconomic, and environmental issues. While urbanization benefits many stakeholders by enhancing social, economic, and infrastructure aspects, it also poses risks to people's safety and harms the physical, social, and cultural landscape as more buildings are constructed. Consequently, spatial models for urban growth are often used in planning to develop strategies for controlling land use actions, such as GIS, GIS-based remote sensing, CA-Markov, AHP, and MCE. GIS and CA-Markov are among the models widely employed by researchers to simulate land use change. Malaysia also tends to utilize urban growth models as part of its efforts to plan for sustainable cities in the future. Therefore, this study was conducted to assess and review the use of GIS in developing an urban growth model in the Malaysian context. The results indicate that GIS and other models or techniques can serve as a strategic framework for urban development policy.

Keywords: Urban Model; GIS; Urbanization; Land Use; Urban Planning

1.0 Introduction

Rapid urbanization, coupled with rapid population growth in cities in developing countries, creates a demand for land resources and poses serious environmental problems (Hassan and Elhassan, 2020). The development of urbanization, especially in large urban areas, has resulted in the reduction of agricultural and green spaces, threatening the social and economic well-being of some residents (Yusof et al., 2008). Urbanization can be defined as the process by which rural areas become urban, driven by economic and industrial development factors (Peng et al., 2011). According to a United Nations report cited by Samat et al. (2011), the urban population is estimated to double by 2050, increasing from 3.3 billion in 2007 to 6.4 billion in 2050.

Furthermore, Samat et al. (2012), referencing a study by Samad, Shahrudin, Hadi, and Fariz in 2010, identified three phases of urbanization in Malaysia: the phase of early urbanization (nascent phase), the phase of pseudo-urbanization, and the phase of urbanization in mega-urban areas (the rise of mega-urban regions). In the 18th century, Malaysian townships emerged in connection with British administration, focusing on the development of tin mining and rubber plantations, which became the main commodities in Malaysia (Idrus et al., 2010). This historical context has influenced the internal structure of cities, including the establishment of administrative centers, residential areas for officials, and British courts. The pseudo-urbanization phase has highlighted the involvement of some Malaysians in various sectors and services, such as farming and law enforcement (Hussain and Byrd, 2016). They have also become aware of the economic gap and are actively engaging in politics (Hussain and Byrd, 2016).

The urbanization of mega-city areas illustrates the contagion of urbanization and modernity among residents, significantly affecting their lifestyles (Hadi et al., 2018). Kuala Lumpur is an example of a mega-city region that leads the entire mega-city region in Malaysia and serves as a center for wealth creation through its export industry, renowned financial services, education, infrastructure development, and more (Hadi et al., 2018). Urbanization has positively impacted the economy, society, and infrastructure of communities (Simon et al., 2004). However, the urbanization process can also influence land use changes, leading to negative effects on people, society, and the environment. This has contributed to urban sprawl, where the city center loses space and expands into suburban areas (Bakeri, 2018). Additionally, poor urban planning can deplete natural resources and undermine land sustainability.

The advancement of globalization allows for the free exchange of data and information, making it easier and quicker to obtain. Planners and policymakers are increasingly aware of the need to monitor the behaviors of individuals or local urban organizations in shaping urban landscapes (Samat, 2009). Geographic Information Systems (GIS) have been utilized by various stakeholders due to their critical role in enhancing sustainability. Therefore, GIS and spatial models are suitable tools to help understand, monitor, and simulate urban growth (Hassan and Elhassan, 2020). This study aims to review urban growth models utilizing GIS for environmental and urban planning in the future. Thus, it involves various models and techniques for spatial integration with GIS, including GIS-based CA-Markov, GIS-based Analytical Hierarchy Process (AHP), GIS-based Multi-Criteria Evaluation (MCE), and GIS-based remote sensing.

2.0 Methodology

Secondary data refers to information obtained from other researchers who have conducted studies in the same field (Masri, 2005). This data is considered an officially published source. Relevant information for this study can be drawn from previous research. The objective of this study is to review the urban growth model using Geographic Information Systems (GIS). In alignment with this purpose, the study will examine relevant records of research conducted in Malaysia. Therefore, various GIS-related techniques employed by previous researchers will be discussed in this article.

3.0 Urban Growth in Malaysia

Urbanization is the process of industrialization and economic growth that transforms rural areas into cities. Demographically, urbanization is associated with the shift of the population from rural to urban areas (Peng et al., 2011). According to the Department of Statistics Malaysia (2024), the estimated population in Malaysia from 1980 to 2023 is 33.7 million. The progress of globalization and unchecked development has led to increasingly rapid urbanization.Factors affecting the development of urban land use can be categorized into three groups: physical, socioeconomic, and environmental (Samat, 2009). The industrial sector is a significant economic factor that contributes to the creation of industrial areas and cities, promoting population growth (Alia and Firdaus, 2017). For example, Pasir Gudang is one of the fastest-growing industrial areas, attracting foreign investors from Korea, China, and Japan, and increasing employment opportunities for the local community (Alia and Firdaus, 2017). Additionally, a study by Mahamud et al. (2016) indicates that low housing prices, public facilities, and

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proximity to workplaces are key factors influencing urban growth in the combined city known as the George Town Conurbation. Municipalities have shaped landscapes to serve human needs while also promoting local and regional environmental changes by altering land cover, hydrological systems, and biogeochemical processes (Grimm et al., 2008). Furthermore, municipalities can positively impact economic, social, and infrastructure improvements (Simon et al., 2004). However, the urbanization process can also lead to land use changes that may have negative consequences for people, society, and the environment.

4.0 Geographic Information System (GIS)

Geographic Information Systems (GIS) are utilized by various parties because they play an important role in enhancing sustainability. GIS consists of a combination of computerized software, hardware, and data that manipulates, analyzes, and presents information related to the Earth's surface (Escobar et al., 2008). It employs computer technology to process geographic data, producing digital information and maps (Hua, 2015). GIS organizes geographic data to facilitate easy selection by users viewing a map for specific activities or projects (Băneș, 2010). It is useful for problem-solving, decision-making, and data visualization in a spatial context (Yew et al., 2019). GIS technology is crucial in improving urban modeling systems, serving as a method for developing practical plans, particularly regarding land use change (Kim, 2012). Information on land use or land cover changes, as well as urban growth studies, is particularly valuable to urban planners, local governments, and decision-makers for guiding strategies for sustainable development in each region's future (Ghurah et al., 2018; Sundarakumar et al., 2012).

4.1 Urban Growth Model

The urban growth model has become a common approach in planning and management to implement strategies that control land use actions, especially in metropolitan areas (Fertner, 2016). Spatial models play a significant role in simulating spatial changes in land use and can be utilized for predictions in urban development (Hu and Lo, 2007). A model is a simplified representation of a system that describes how the system operates (Abdou et al., 2011). Several spatial models are integrated with GIS to simulate or predict urban growth in Malaysia, including GIS-based CA-Markov, GIS-based Analytical Hierarchy Process (AHP), GIS-based Multi-Criteria Evaluation (MCE), and GIS-based remote sensing.

4.2 GIS-based CA-Markov Model

Cellular Automata (CA) models have been increasingly developed in geographic modeling for land use planning and urban or regional planning (Gale and Olsson, 2012; Li and Yeh, 2000; Engelen et al., 1999). CA was created by John von Neumann and Stanislaw Ulam in the 1940s at the Los Alamos laboratory in New Mexico as a framework for investigating the logical basis of life (Ghost et al., 2017). While CA is a powerful model for representing the spatial variables of land use, it is less suitable for depicting micro-scale economic, social, and cultural drivers in urban areas (Liping et al., 2018). The integration of CA and GIS enhances the explanatory power of the model in both geography and reality (Engelen et al., 1999). Information stored in GIS databases can be easily accessed during the modeling process, as CA models can be developed within GIS (Li and Yeh, 2000). CA is also important for application in future-oriented planning and for observing or monitoring natural trends (Pratomoatmojo, 2018).

CA-Markov is a suitable tool for predicting land use and land use change. It has been widely employed in land use and land cover (LULC) modeling to identify spatial interactions and simulate different types of LULC (Hadi et al., 2014). CA-Markov plays a key role in modeling and explaining land use changes across time periods, providing a basis for forecasting future changes (Mondal et al., 2019). According to the study by Camara et al. (2020), the CA-Markov model was evaluated by comparing actual and simulated 2015 maps using the kappa index value. The kappa coefficient is an accuracy measure that assesses the consistency between a graded image or map and reference data (Zeshan et al., 2021). Rwanga and Ndambuki (2017) refer to the study by Landis and Koch (1977), which presents Kappa statistical categorization criteria in Table 1.

Table 1: Category criteria of Kappa statistics (Rwanga and Ndambuki, 2017)

No. Category	Kappa statistics	Strength for accuracy
1	< 0.00	Weak
2	0.00 – 0.20	Slight
3	0.21 – 0.40	Fair
4	0.41 – 0.60	Moderate
5	0.61 – 0.80	Substantial
6	0.81 – 1.00	Almost perfect

In the study by Camara et al. (2020), mapping and analysis were conducted using ArcGIS 10.2 and IDRISI 17.0 software. The CA-Markov model performed admirably in this analysis, demonstrating a strong ability to simulate the 2015 land use map, with a Kappa value of 0.92 and a Klocation value of 0.97. Additionally, four land use change factors were identified to simulate land use in the Selangor River basin for 2024 and 2033 (Figure 1). The results indicated an expected increase of 33 percent in urban areas over the next two decades, while forest areas are projected to decrease by 8 percent. Agricultural land is expected to increase by 4 percent, and water bodies may see a slight increase of 1 percent, whereas approximately 30 percent of green areas are anticipated to decline. Furthermore, spatial models such as Cellular Automata (CA) and Markov are frequently used to analyze urban growth and land use change, predicting general land use patterns likely to emerge due to economic, social conditions, or specific policies (Stevens and Dragićević, 2007).

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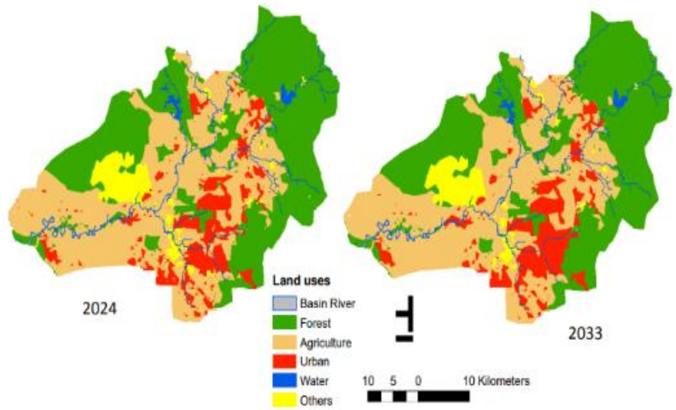

Figure 1: Simulation of future land use changes in the Selangor River Basin in 2024 and 2033 (Camara et al., 2020).

4.3 GIS-based Analytical Hierarchy Process (AHP)

AHP is often used to determine the weights of factors influencing urban growth based on the analytical capabilities of GIS (Hassan and Elhassan, 2020). AHP seeks to resolve complex and unorganized problems by dividing them into a set of component factors (Youssef, Pradhan, and Tarabees, 2011). In the study by Aburas et al. (2017), a pairwise comparison matrix was employed to assign weights to each factor based on its suitability for urban growth. The GIS-based AHP analysis utilized four main factors: physical, socio-economic, environmental, and utility. Factor weights were calculated after forming the pairwise comparison matrix. Next, the Consistency Ratio (CR) was calculated to measure the consistency of expert opinions (Aburas et al., 2015). A CR of less than 0.10 indicates reasonable consistency in pairwise comparisons, which in this case was 0.04. A map of land suitability for urban growth was produced, showing that suitable and less suitable lands cover approximately 35.19 percent of the total area, while extremely suitable areas for urban growth account for 48.26 percent. Furthermore, the results indicated that a significant portion of land in Seremban is not suitable or does not meet the requirements for urban development. There is a need for sustainable urban development to ensure the long-term preservation of Seremban's ecosystem (Aburas et al., 2017). The initial step in the AHP approach is to identify the development factors using a simulation model and the insights of decision-makers (Wu, 1998). Therefore, urban planning and environmental management can greatly benefit from the use of the GIS-based AHP model, as demonstrated in previous studies.

4.4 GIS-based Multi-Criteria Evaluation (MCE)

The use of MCE as a method for assessing land suitability in GIS is frequently explored in research. The purpose of employing MCE models is to identify solutions to decision-making challenges by considering various options evaluated using decision criteria (Pourebrahim et al., 2011; Jankowski et al., 2001). MCE modules are utilized for land use planning, risk and hazard assessment, sustainable forest management, hazardous materials transportation planning, and emergency planning (Malczewski and Rinner, 2015). Furthermore, MCE offers a flexible approach to land use decisions (Pourebrahim et al., 2011; Malczewski, 1996). GIS-based MCE involves combining spatial data (map criteria) and decision-maker preferences to evaluate decision options (Eldrandaly, 2013). In a previous study by Mohammed et al. (2016), GIS-MCE techniques were used to identify potential areas for future development in Balik Pulau, Penang, in 2010. This analysis employed five factors based on weights determined by pairwise comparison: proximity to population centers (0.28), proximity to the road network (0.40), proximity to developed areas (0.04), proximity to water bodies (0.23), and land value (0.14). All criteria or factors were combined using a weighted linear combination (WLC) approach to produce a suitability map (Figure 2). The integration of GIS and MCE is a valuable technique that supports urban planners and decision-makers in implementing sustainable urban land use (Mohammed et al., 2016).

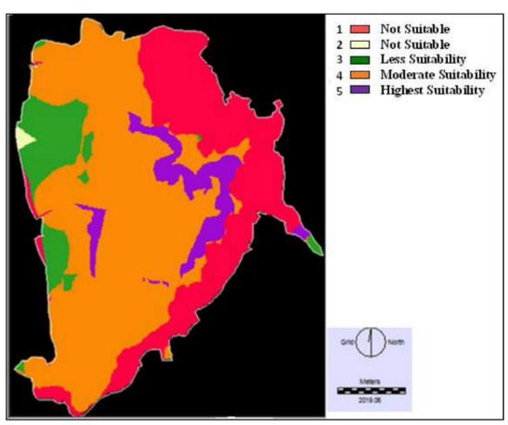

Figure 2: Balik Pulau's future development site suitability map (Mohammed et al., 2016).

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4.5 Integration GIS and Remote Sensing

Remote sensing is not limited to digital, satellite-based sensor systems; it also encompasses photogrammetry and traditional analog sensor techniques, such as aerial photography (Xiao and Zhan, 2009). Remote sensing can provide large-area datasets with high spatial detail and temporal frequency (Noor and Rosni, 2013). The utilization of very high-resolution (VHR) imagery has made remote sensing a valuable tool for urban planning and management (Noor and Abdullah, 2015). For example, Landsat-1, the first remote sensing satellite launched in 1972 for monitoring Earth's resources and the environment, has provided data that has been utilized for urban planning purposes (Kamarulzaman et al., 2023; Wulder et al., 2019). Additionally, the integration of remote sensing with GIS technology has effectively monitored and detected land use at various scales, yielding beneficial results (Wilson et al., 2003). This integration serves as a data source for mapping urban areas and for analyzing and modeling urban growth and land use or cover change (Wilson et al., 2003). For instance, in a previous study by Boori et al. (2015), satellite images and census data were used to track the dynamic phenomena of urbanization in Kuala Lumpur using remote sensing and GIS methods. Three different satellite images were employed: Landsat TM for 1989, Landsat ETM+ for 2001, and Landsat 8 for 2014, acquired by various types of sensors. The study produced three land use or land cover maps that illustrate different land use classes (settlement, agriculture, forest, and water body), with buffering zones created for every kilometer (km) distance (Figure 3).

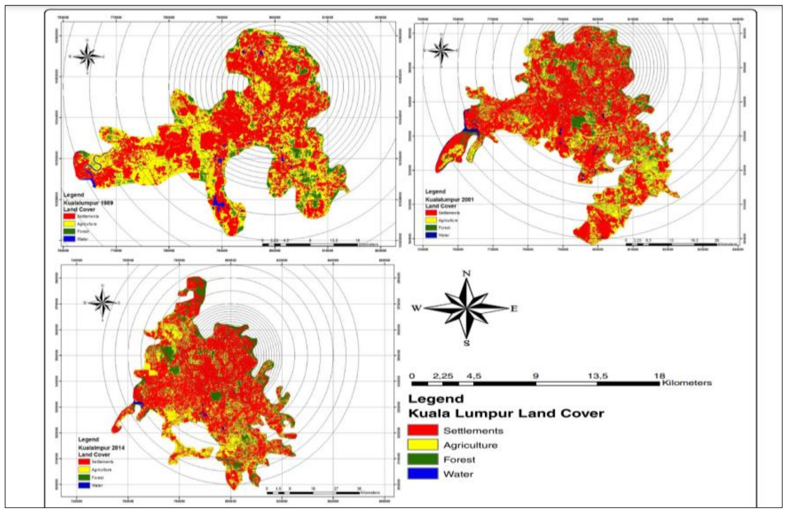

Figure 3: Multi-buffering zones of land use/land cover map for 1989, 2001 and 2014 (Boori et al., 2015)

The results indicated that the built-up area increased by 1,206.24 km² from 1989 to 2014. The urban area in Kuala Lumpur demonstrated significant development over three decades, rising from 51.81 percent in 1989 to 60.22 percent in 2001 and further increasing to 64.36 percent in 2014. Furthermore, the study analyzed density patterns involving 50 buffering zones ranging from 1 to 50 km, revealing that city density expanded significantly at distances of 5, 8, 15, 20, and 30 km between 1989 and 2014. Therefore, GIS and remote sensing provide a new perspective on the geographical effects of policy changes, helping urban planners and policymakers evaluate compact urban strategies (Boori et al., 2015).

5.0 Conclusions

The results of this study confirmed that the urban growth model using GIS is a technique that can mitigate the negative effects of urban issues by creating maps that predict future land use changes. Furthermore, the integration of GIS-based CA-Markov, GIS-based AHP, GIS-based MCE, and GIS-based remote sensing verifies that these simulation or prediction models provide accurate and realistic approaches. This study assists urban planners and policymakers in making better decisions by helping them develop more appropriate strategies for encouraging long-term development. Researchers should conduct ongoing studies on the application of GIS and urban development models to raise awareness and provide information to all stakeholders regarding GIS's potential to systematically address land use change issue.

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