A Review of Land Suitability Analysis for Urban Growth by using the GIS-Based Analytic Hierarchy Process

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ABSTRACT— *Urban growth inevitably decreases the sustainability of land use and the ecosystem. Thus, the application of innovative techniques is urgently necessary to advance the concept of sustainable growth. In recent years, the analytic hierarchy process (AHP) has become one of the most significant modern techniques for land suitability analysis by using a geographic information system (GIS) and multi-criteria approach. The integration between GIS environment and AHP is a potent tool for formulating future policies that are pertinent to urban growth. This paper aims to review the GIS-based AHP as a multi-criteria analysis/evaluation technique for land suitability analysis. The general characteristics of land suitability analysis for urban growth were described, and the different criteria used in the design of this model were classified. The results of this paper confirmed that the integration between AHP and GIS tools is important to address the limitations of GIS in terms of determining the relative weights for the criteria used objectively.*

Keywords— Analytic hierarchy process, land suitability analysis, urban growth, GIS.

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1. INTRODUCTION

In recent decades, cities around the world have been facing the issue of urban growth as a result of population and economic growth [1]. Urban growth gradually leads to the decline of natural and rural lands, and it affects the ecosystem in general [2]. Given this situation, strategies and policies are needed to address and preempt this phenomenon before negative effects on the biosphere begin to increase [3]. These strategies and policies may be long-term plans at the local, regional, national, and international levels, such as population and economic strategies and plans [4]. However, these strategies and policies may also come in the form of a technology that monitors and controls urban growth phenomenon. Examples of these techniques are remote sensing (RS) and geographic information systems (GIS) [5-7].

Urban development has become a global issue, resulting in the heightened concern planners and decision makers over the future impacts on the ecosystem [8]. Simulating urban growth patterns has become essential to ecosystem protection and sustainable development [9]. In addition, the complex structure of the urban environment must be understood to simulate urban dynamics correctly [9]. Urban growth simulation needs to consider the chronology of the issue of sprawl and wide historical information to understand spatial and temporal relationships accurately [10]. Hence, obtaining the true knowledge of growth factors that affect future land uses can be improved using simulation techniques, such as land suitability analysis [11]. Understanding the spatial and temporal changes, as well as all effective elements, is facilitated using remote sensing (RS) and geographic information system (GIS) techniques [12].

Suitability analysis for urban growth is considered one of the most important and effective techniques for identifying the best locations for urban growth by employing different types of criteria and weights [13, 14]. Land suitability evaluation involves the selection of suitable locations of development by mapping the suitability index of a specific area [15]. Moreover, GIS techniques have become significant tools for controlling and monitoring changes in urban development and their impact on ecosystems [16]. Land suitability analysis based on GIS environments is a process that

aims to identify the best locations of development while considering environmental sustainability [17].

Land suitability analysis is used for different types of applications: identification of suitable locations of urban development [16], prediction of future land-use changes [18], organization of green spaces [19], development of natural wastewater treatment systems [20], enhancement of crop production [21] and biomass production [22], and research on ecosystems [23], sanitary landfills [24], and coastal areas [25].

In setting the importance of the criteria used and computing the weights of factors, GIS tools must be integrated with other methods to improve the results of land suitability analysis. The integration of GIS tools and multi-criteria decision analysis is a powerful approach for evaluating land suitability [25]. The concept of sustainability generally leads to improved suitability analysis, which is a complex operation because of various types of factors and criteria that must be considered in the process [26]. The current study focuses on land suitability analysis by using the analytic hierarchy process (AHP) for selecting the best locations for urban growth and provides an overview of the major criteria used to identify such locations. A critical review of the urban AHP model as a significant model in land-use studies is implemented to study land suitability analysis in detail. The results can be used to determine future pillars of development and significantly address the limitations and defects of current land suitability analysis techniques.

2. ANALYTIC HIERARCHY ANALYSIS

AHP, which was developed by Saaty [27], is currently one of the important techniques for analyzing land suitability. AHP is categorized under the multi-criteria decision analysis approach and is an effective technique that helps planners and decision makers to analyze all data before arriving at a final decision for future land-use changes [25, 28]. AHP has been integrated with GIS tools to identify the importance of the criteria used and to calculate weights by using a scale of importance and the opinion of experts [29].

AHP is commonly applied to identify the weights of influencing factors on urban growth on the basis of the analysis functions of GIS. AHP is also a structured approach that can be used for complex cases of making decisions that include competing criteria [13]. The weights of factors in AHP can commonly be identified by using driven knowledge and driven data. The weights of factors can also be calculated by using a questionnaire given to specialists who have considerable experience in the field of urban growth and can then be determined by using pairwise comparison method to measure their relative importance vis-à-vis one another [13, 25, 29, 30].

The main challenge in applying this model is that AHP needs the right experts with the widest knowledge and experience in the fields of suitability analysis and application to judge the factors in terms of their importance and weights [25]. Identifying the relative weights of the factors used in land suitability analysis is generally difficult. Thus, the use of a technique that has a powerful capability to identify the weights is important. AHP is one of the significant techniques used in analyzing issues related to spatial nature [13]. Research on AHP continues to grow at present, as supported by the annual increase in journal publications on AHP in the field of land suitability analysis (Figure 1).
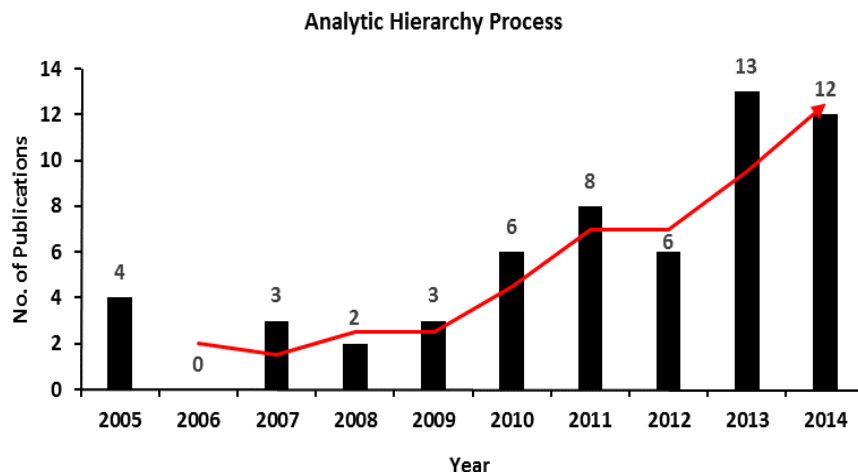

Figure 1: Increase in the number of journal publications on AHP (keywords used for the search: "Land Suitability Analysis using AHP"; ISI Web of Knowledge, Thomson Reuters http://apps.isiknowledge.com.www.ezplib.ukm.my, Jan 28, 2015).

3. DESIGNING THE FRAMEWORK OF AHP

Designing a GIS-based AHP model for the land suitability analysis of urban growth involves different phases (Figure 2). Each phase involves a particular preparation to produce a final output map of land suitability on the basis of various types of criteria.
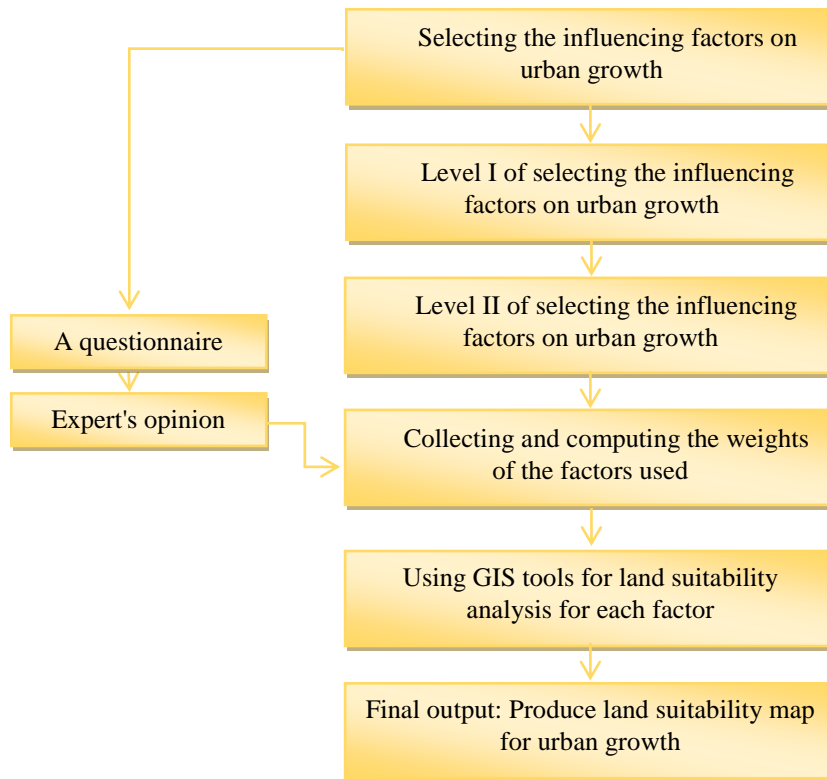

Figure 2: Framework of the AHP within a GIS environment

3.1 Selection and Preparation of Criteria Maps

Significant criteria are commonly used in designing the framework of AHP to identify the best locations for urban growth [29, 31, 32]. However, selecting the criteria used may depend on other causes that are related to data availability. Table 1 shows different factors that have been used in designing the model based on the type of application and data availability. Most significant data has been used in AHP studies to identify the appropriate sites for urban growth, such as accessibility factors (i.e., distance from main roads, highways, railways, urban areas, etc.) and physical factors (i.e. elevation, slope, hill shade, and aspect). However, environmental criteria (i.e. distance from rivers and water surface, soil categories, and land cover) are some of the main data used to identify the best locations for urban growth.

In general, socio-economic factors such as population density, distance from economic centers, and land price are still not mainly used in land suitability studies. However, in recent years, some studies have used certain types of social and economic factors to determine suitable sites for urban development [32-35]. The importance of using these factors comes from the fact that cities are complex combinations of social and economic factors [36]. Thus, a GIS-based AHP model is used to employ different types of data, either quantitative (such as population) or quantitative (such as land cover categories) [37]. Hence, applying traditional models is difficult because such models are rigid approaches [38]. Table 1 shows two types of criteria levels: level I, which includes a general overview on the criteria that will be used; and level II, which provides details on the main criteria (i.e., sub criteria).

3.2 Calculating the Weights of Influencing Factors

In real land suitability analysis, each parameter must be assigned some relative score such that the pairwise comparison matrix is created by applying the following nine-point weighing scale (Table 2). Pairwise comparisons are then applied on the basis of the criteria used and experts' opinions in the field of application [47].

These pairwise comparisons are then used as the input to establish a ratio matrix, and the relative weights are created as the output (Kumar & Shaikh, 2013). Nevertheless, some difficulties arise in this AHP design step, such as the lack of sufficient experts to identify the importance of each element. Moreover, the experts' impressions of the questionnaire and

survey stage may create mistakes in preference (Bagheri et al., 2013; Marinoni, 2004). Thus, Saaty [48] provided a single numerical index to ensure that the pairwise comparison matrix is consistent on the basis of the following equation:

$$CR = \frac{CI}{RI} \tag{1}$$

where **CR** is defined as the consistency ratio, **CI** is the ratio of the consistency index, and **RI** is the average consistency index.

$$CI = (\lambda - n)/(n - 1) \tag{2}$$

CI refers to the consistency index and provides a measure of departure from consistency. (**n**) refers to the number of criteria used. λ is simply the average value of the consistency vector.

Table 1: Applications of the criteria used in AHP and urban growth studies.

	Physical factors	Accessibility factors	Social factors	Economic factors	Environmental factors
Level I					
Level II	Slope, elevation, etc.	Distance from main roads, Distance from railway, etc.	Population density	Distance from economic centres, land value, etc.	Vegetation lands, soil types, land cover, etc.
Reference					
25	●	●			●
31	●	●			●
32	●	●	●		
39	●	●			●
35	●	●	●	●	
34			●	●	●
40	●	●			●
41	●				●
29		●			
33	●	●	●	●	
42		●			●
17	●	●	●		●
43	●	●			●
44		●	●		●
45			●	●	●
46	●	●			●

The importance of using the pairwise comparison matrix between the factors used in AHP is to identify the relative weight of the criteria according to the importance of each factor to decision makers [49]. The relative weights of the criteria used are determined through the effect of each factor on urban growth patterns [29]. Thereafter, the relative weights are computed quantitatively to produce a land suitability map [50]. A thematic map is then created by integrating the GIS methods with quantitative techniques that include the pairwise comparison matrix [51]. For the number of experts who will identify the relative weights of factors used, more experts will lead to the higher accuracy of the weights [52]. However, 10 experts in the field of urban growth will suffice to determine the relative weights of the factors [29].

Table 2: importance scale for factors used "Saaty, 1980"

Intensity of importance	Description	Suitability class
1	Equal importance	Lowest suitability
2	Equal to moderate importance	Very low suitability
3	Moderate importance	Low suitability
4	Moderate to strong importance	Moderately low suitability
5	Strong importance	Moderate suitability
6	Strong to very strong importance	Moderate high suitability
7	Very strong importance	High suitability
8	Very to extremely strong importance	Very high suitability
9	Extreme importance	Highest suitability

4. INTEGRATION OF GIS AND AHP

In this aspect, several types of GIS functions can be applied to develop and produce land suitability maps based on AHP [53]. GIS has a powerful capability to generate, organize, and layout map layers (raster logic) and conduct quantitative and logic analysis for land suitability processes [51]. However, GIS environments have no ability to determine the relative weights for the criteria used. AHP and multi-criteria models are provided an objective evaluation for the relative weights of each factor [51]. The structure of the integrated GIS and AHP model for urban growth is shown in Figure 3. Preparing the analytical layers of influencing factors on land suitability is the first part of the generation process of land suitability maps by using GIS environment [54-57]. Furthermore, the conversion tool is used to change the format of input data from vector to integer raster format. Moreover, buffer analysis is implemented for each influencing factor to identify the appropriate location for urban growth on the basis of the importance of the distance, density, limitations, etc. [58, 59]. Reclassification tool is employed to convert the layers used to either integer or floating raster's based on common scales for land suitability [60, 61]. The calculation tool is then used to compute the weights for each layer on the basis of the AHP procedures [62].
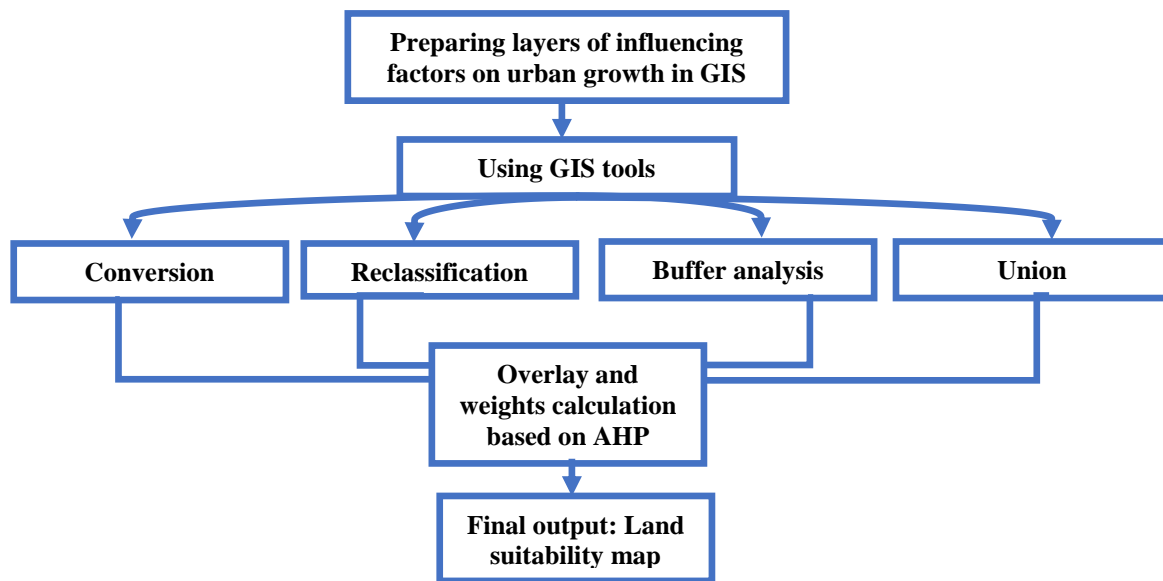

Figure 3: Integration approach between AHP and GIS tools

5. CONCLUSION

The use of AHP-based GIS for determining the best locations for urban development is a significant technique because of the simplicity of the model (i.e., easy to understand). Furthermore, this method can use different types of criteria, whether qualitative factors (such as land- use layers) or quantitative factors (such as population data). Moreover, the criteria used in this model can be evaluated objectively on the basis of the importance of each factor that influence urban growth. Knowledge of expert opinions is considered the strong point for this type of evaluation, that is, this model works by combining both human and technical factors. Therefore, the integration of GIS with AHP is powerful tool for land suitability analysis for urban development. This method requires only little computer skills within a GIS environment. The GIS-based AHP for land suitability has proven to facilitate efficiency from the economic point of view as compared to the traditional methods. This paper can contribute and will be useful as a prepared reference for those who wish to integrate GIS with AHP as a multi-criteria decision analysis for urban development.

6. ACKNOWLEDGEMENT

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