GIS-based Multi-criteria Decision Analysis of Land Suitability for Hillside Development

Imtiaz Ahmed Chandio, *Member IACSIT*, and Abd Nasir Bin Matori

Abstract—**Urban development is the continuous process towards hillsides which has been a challenging issue for developing Asian countries such as Malaysia due to limited flat land. Therefore, it is very crucial that their location should be carefully chosen. The objective of this study is to develop Geographic Information System (GIS)-based land suitability analysis model considering accessibility for locating optimal sites to the hillside development against environmental threats and economic pull factor. In order to determine suitable site towards hillside, the important factors are incorporated, namely accessibility and topography, land cover, and economic by using multi-criteria decision analysis (MCDA) method in decision making process. In this paper, pair-wise comparison matrixes, consistency ratio by using analytic hierarchy process (AHP) as a multi-criteria analysis method. Priority weights were obtained in Expert Choice software. As the result, consistency ratio (CR) was obtained, where Scenario 1 Accessibility is 0.04 and Scenario 2 Environment is 0.07. The outcomes of this study will be land suitability model for hillside developments in Malaysia as well as other developing countries.**
***Index Terms*: Analytic Hierarchy Process, GIS, Land suitability analysis, MCDA**

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I. Introduction

Over the years, the concept of rapid urbanization in Malaysia has shown a tendency for fast growth among developing Asian countries in terms of economy. There are various benefits of planned and controlled development to utilize human resources. It is the unplanned land use that may create urban environmental problems in growing cities [1]. However, the unplanned physical development is a big issue in developing countries [2]. At present, Penang is a creative developing state, which is extensively recognized as an attractive potential to invigorate the regional economy. It has a rapidly developing economy [3], and is a growing industrialized state as compared to other states in Malaysia.

The economic growth has increased to meet the high demand of housing, land for recreation, tourism, agriculture, highways and other human activities which have expanded to the hills and their peripheries.

However, Penang Island is facing future economic development and built environmental challenges due to its hilly topography and limited flat land [4]-[6]. The Geographic Information System has proven practical throughout the world and effective when used for determining suitable lands for a built environment [7].

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This is, above all, a fact; GIS can take advantage of spatially related factors to influence the built development of the hillsides. In developing a hillside land suitability model, the following criterion has to be considered, i.e. accessibility in terms of road, topography, land cover and economic. Furthermore, hillsides built developments have a big constraint of accessibility because hillsides contain elevation and slope contours [7]. Accessibility provides a key role in the economic development of any region. Consequently, when implementing an unplanned road network, it can be harmful to the natural environment. In this context, an effective route planning considers environmental concerns which take into account a sustainable built development [8]. This can be achieved in the beginning stage with a sustainable development [9]-[10] with integrated GIS-based MCDA approach. The term sustainable development was defined by the World Commission on Environment and Development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [10].

The objectives of this study are carried out in order to design a conceptual framework for understanding land evaluation using a land suitability multi-criteria decision analysis approach considering accessibility; to develop a GIS-based land suitability analysis model and formulate effective strategies for locating optimal sites for hillside development against environmental threats while considering the economic pull factor; and to determine the limitations in using the GIS-based land suitability and multi-criteria approach in the study area. The study site is possibly one of those defined by SP Setia, Penang. Keeping in mind, hillsides can increase the economy of the country in the context of attraction and natural environmental beauty. Application of GIS can manage a large quantity of spatially concerning information and facilitate integration of multiple data layers with land suitability models. Therefore, integrated the GIS-based MCDA process is used to evaluate land suitability for the hillside development and future land-use planning [11]. Furthermore, the purpose of integrating the GIS-based land suitability analysis using the multi-criteria evaluation (AHP) approach is that it is the most suitable method for solving complex problems related to land-use planning and any other kind of development. It has also been recognized as an effective multi-criteria decision support system [12]. No research work has investigated a land suitability analysis incorporating accessibility (Route network analysis modelling) in hillside development using GIS-based multi-criteria approach.

A. Accessibility

For economic development of any region accessibility plays an important key role. The most useful definitions are referred by Cuttis, [8] as follows:

Bhat et al. [13] used the following definition:

'Accessibility is a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time.' (p. 1)

Geurs and van Wee [14] defined accessibility in context of person's perspective and location perspective and a more tangible way:

'Access is used when talking about a person's perspective, accessibility when using a location's perspective.' (p128).

Bertolini, LeClercq and Kapoen [15] defined accessibility as 'the amount and diversity of places that can be reached within a given travel time and/or cost' (p. 209), and sustainable accessibility as accessibility 'with as little as possible use of non-*renewable*, or difficult to renew, resources, including land and infrastructure.' (p. 212)

These definitions clearly show that any kind of activity cannot be generated without sustainable accessibility. For the sustainable accessibility, prior steps should be taken like land suitability analysis using multi-criteria decision analysis approach. It can enhance economic activities from source to destination.

II. Background

It is observed, that there have been extensive studies carried out on the land suitability analysis using the GIS-based multi-criteria evaluation (MCE) procedures [16]-[18] land development. The AHP was introduced by Saaty in 1980 [19]. It has been widely used as a multi-criteria evaluation approach. MCE is also one of the most viable methods addressed in many studies on the land suitability analysis through GIS [20]-[22]. In addition, GIS-based land suitability analysis techniques are useful for decision makers, engineers and planners to provide a framework for land development as stated in literature [23]-[25]. It can alleviate notorious threats for hillside settlements by applying land-use suitability models for development purposes. Previous studies illustrate that the GIS-based AHP as a multi-criteria evaluation approach can be significantly crafted for future optimal site selections in developing countries. There are three principles of AHP, i.e.

1. Hierarchical Structuring;
2. Weighting; and
3. Logical consistency

Saaty developed the following ladder in 1980 for applying the AHP:

1. To state the problem
2. To design hierarchy structure of the problem of various levels including goal, criteria, sub-criteria, and alternatives keeping in view determining objectives and its outcome
3. To compare each element in the corresponding level and calibrated them on the numerical pair-wise comparison scale. Elements of a problem are compared in pairs with respect to their relative impact ("weight" or "intensity") on a property they share in common. Element matrix has reciprocal properties; which is:

$$aij = \frac{1}{aij}$$

4. To perform computations to find the maximum Eign value, consistency index CI, consistency ratio CR, and normalized values for each criteria/alternative
5. If there is any matrix with an unacceptable CR value or composite weight i.e. >0.10, the expert is required to make judgment on that matrix repeatedly till these values lie in a desired level

III. Methods

The analytic hierarchy process was developed by Saaty in 1980 for solving complex problems. It involves synthesis of prioritization as well as ideal prioritization [26] of a potential alternate solution. It helps in determining a suitable location for development on the hillside. It is a rational decision-making approach which simplifies complicated problems and breaks down into small parts into hierarchical structuring [25]. The process of AHP for solving problem is structured the decision problem in a hierarchical model establishing suitability criteria for built hillside development for example in Fig. 1.

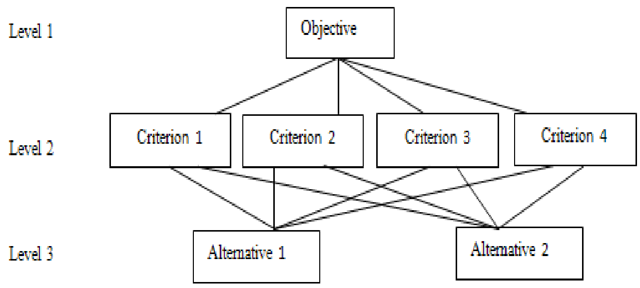

Fig.1. Structured problem with three different hierarchy levels

The hierarchical model is designed to function at three levels; the goal level, criterion level, i.e. accessibility, topography, land cover, economic and alternative level. Preliminary criteria are identified by discussions with experts and are found in previous studies presented in this paper. The AHP allows for the assessment of the individual contribution with respect to the criterion [27].

A. Research Design Process

In order to conduct this study, a research process presents an overall picture for carrying out the research methodology. It mainly consists of various components of research methodology. Each component plays an important role in finding suitable land on the hillside. Keeping in mind the goal and objectives, the first component focuses establishing set of criteria and sub-criteria. The second is to assign ranks to the criteria and alternatives by expert's opinion. A pair-wise comparison method/matrix is carried out to get relative weights from expert's opinion. Then, gathered weights were computed in the multi-criteria evaluation process tool using Expert Choice software (ECS) [25] keeping view consistency ratio (CR). If CR is satisfactory, the computed weights will be recorded for further processing. Finally, sensitivity analysis can be conducted in ECS that validates the decision making weights because of uncertainties in decision weightages [25]. In this paper, the important criterions are incorporated i.e. accessibility and topography, land cover, and economic. Each MCDA approach contributes a general approach called here a general model of MCDM as inFig.2.

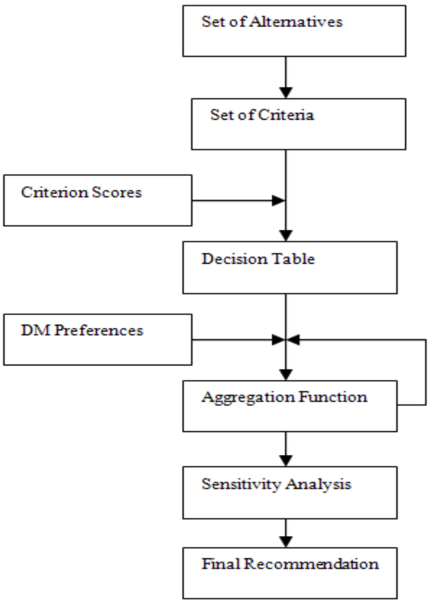

Fig.2.A general model of MCDM (after JanKowski, [29])

IV. Results and Discussion

A. Computation of the Pair-Wise Comparison Matrix And Consistency

Pair-wise comparison matrix is created to assign weights by experts. Weights are evaluated to find alternatives and estimating associated absolute numbers from 1 to 9 in fundamental scales of the AHP presented in Table I.

TABLE 1: Pair-Wise Comparison Scale for AHP Preferences (after Chandio et. al. [25])

Intensity of Relative Importance	Definition
1	Equal Importance
2	Equal to moderate importance
3	Moderate importance of one over other
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or Demonstrated importance
8	Very, very strong
9	Extreme Importance

Currently, the obtained weights can be computed automatically in IDRISI [28] as well as in Expert Choice [25] softwares called MCDA tool. The results of relative weightage of land suitability criterion Scenario 1 Accessibility and Scenario 2 Environment are shown in Table II and III based on criterions to compute the relative weights of decision elements. Thus, pair-wise comparison matrixes are calculated into Expert Choice determining priority weightages in this paper. Then, these will be entered in ArcGIS for spatial analysis to determine the suitability for hillside development.

TABLE II: Relative Weightage of Land Suitability Criterion Based on Scenario 1 Accessibility

Suitability Criterion	Accessibility	Topography	Land Cover	Economic	Priority Vector/Weight
Accessibility	1				0.478
Topography	1/2	1			0.182
Land Cover	1/4	1/2	1		0.105
Economic	1/3	2	2	1	0.235
Weightage ∑=1.0					1.0

Consistency Ratio (CR)= 0.04

TABLE III: Relative Weightage of Land Suitability Criterion Based on Scenario 2 Environment

Suitability Criterion	Accessibility	Topography	Land Cover	Economic	Priority Vector/Weight
Accessibility	1				0.13
Topography	3	1			0.068
Land Cover	1/4	1/5	1		0.529
Economic	1/3	1/4	3	1	0.268
Weightage ∑=1.0					1.0

Consistency Ratio (CR)= 0.07

TABLE IV: Average Random Consistency Index (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

B. Estimation of the Consistency Ratio

As, to calculate the entire pair-wise comparison matrix to find the maximum Eigen value (λmax), and the consistency index (CI), the value for λmax is simply the average value of the consistency vector. To calculate the consistency index, CI as follows: CI= $(\lambda_{max}-n)/(n-1)$, where n is the matrix size. RI is the average random consistency index is shown in Table IV. Therefore, judgments consistency can be checked taking the consistency ratio CR=CI/RI.

CR is determined through Expert Choice software described in this paper. If CR is satisfactory, if does not exceed from desired range i.e.>0.10. If CR value is undesirable range, the obtained judgment matrix is needed to review till these values should be improved and satisfactory [26]. In this study, the CR of the matrix of paired comparisons in the suitability analysis of Scenario 1 is 0.04 and 0.07 of Scenario 2.

V. Conclusion

The GIS-based MCDA approach in land suitability analysis is advocated technically to identify suitable land and sustainable accessibility for hillside development. Pair-wise comparison matrix was constructed using AHP method and priority weights were calculated in Expert Choice decision analysis software. This technique can also apply to various decisions analysis fields, and Expert choice software should be applied widely in the future land use planning. This research can assist the researchers, experts and development organizations in incorporating their policy as a development model. The advantages of an integrated GIS are the development of a coherent framework for the land suitability analysis methods than hitherto such as MCA for developing countries. This study can also be strength to a new approach for decision-makers, reducing future environmental hazards on the hillside development. However, it is a sustainable approach; we understand and take measures at early stages to control the cost of inhabitants and the country in terms of landslides. In addition, accessibility provides a key role in the economic development of any region. Unplanned road network can be harmful to the economy and environment.

The outcome of the present research will have a significant contribution in land suitability analysis considering accessibility to the hillside development using the integrated GIS-based multi-criteria decision analysis method. If hillside development can be safe from environmental threats, than it will be more attractive for the people and can contribute to the economy of the country. GIS-based MCDA methods provide more realistic, achievable objectives on a non-biased basis for making decisions on site selection. The study concludes by contributing a body of scientific results and knowledge related to the land suitability analysis. In addition, the results have been obtained through the proposed systematic research design process and will be published accordingly.

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