Integrated GIS-Based Site Selection of Hillside Development for Future Growth of Urban Areas

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RECEIVED ON 19.08.2015 ACCEPTED ON 16.02.2016

ABSTRACT

Urbanization is a challenging issue for developing countries, like Malaysia. Penang Island is one of the states of Malaysia selected as a study area where limited flat land exists. As a result, this would create urban environmental problems, such as unstable slopes and landslides due to uneven topography. The purpose of this study was to develop land suitability model for hillside development. Hence, this research aims land suitability analysis modelling for hillside development by using integrated GIS (Geographic Information System) based MCDM (Multi-Criteria Decision Making approach. The hill land portion of Penang Island was selected for hillside site development using GIS and AHP (Analytic Hierarchy Process) as a MCDM method for sustainable hillside development. This study found that 15% of land was highly suitable, 27% moderately suitable, 41% less suitable, and 17% not suitable. Therefore, this research can be consistently used by the concerned authorities for sustainable hillside urban planning and development. This approach can be used as a policy tool in decision making of urban planning and development.

Key Words: **Analytic Hierarchy Process, Geographic Information System, Land Suitability Modelling, Multi-Criteria Decision Making.**

1. INTRODUCTION

Rural to urban migration is a big issue in Penang Island because of industrialization which encourages development activities to the hilly topography due to limited flat land [1].Such development growth brings environmental challenges and natural hazards such as landslides, global warming etc., which threaten flora and fauna as well as the local population. These potential environmental consequences can be decreased from the start by utilizing a sustainable approach to development management [2-3]. This research paper aims to develop a sustainable LSAM (Land Suitability Analysis Model) for hillside development at the proposed study area (Penang Island), Malaysia that can overcome aforementioned issues on certain level. Since 1970s, GIS has contributed a lot in engineering, urban environmental planning and computer fields etc. There is a wide scope of GIS in the spatial analysis specifically in location research [4]. This shows PIS

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(Planning Information System) in terms of GIS has a tendency that can play an important function in managing and controlling development directions. The development of GIT (Geographic Information Technology) has significantly affected the positive features of urban and regional planning decision making at present [5]. Therefore, an integrated GIS-based AHP approach was adopted to develop a LSA (Land Suitability Analysis) model, called SMCDA (Spatial Multi-Criteria Decision Analysis) approach of hillside development for future population growth [6]. Various applications of SMCDA have used in past for spatial problems by Chandio, et. al. [7], Alfy, et. al. [8], Miller, et. al. [9], and Ayalew, et. al. [10]. These studies clearly show the importance of GIS-based MCDM approaches in land suitability modelling for site selection and in various spatial issues [11]. The result of LSAM can be a viable in decision-making as a planning policy tool for sustainable land-use planning issues. Therefore, this study can provide a future direction of site selection guidelines to the urban planners and decision-makers to determine suitable sites for future urban growth. Integrated GIS-based site selection methods for hillside development by using LSA approach can be a useful tool managing the components of hillside urban areas in aspect of urban growth [12].

2. STUDY AREA

Study area is located at Penang Island, Malaysia as shown in Fig. 1. The study area's Latitude and Longitude are located about between upper right (100^o 16’ 32.457" E and 5^o 25’ 45.426" N) and lower left (100^o 10’ 29.151" E and 5^o 25’ 45.721" N). Total study area is taken 150 square km. for this research.

3. METHODS

Hillside land suitability criteria and sub-criteria are important steps of SMCDA approach. AHP and GIS applied to develop land suitability model for hillside development. AHP approach was used that includes a pairwise comparison questionnaire. AHP was developed by the Saaty in 1980 in order to assist in a decision-making process [13-14]. An example of the AHP problem in a hierarchical model with various three hierarchy level scan be shown in Fig. 2.

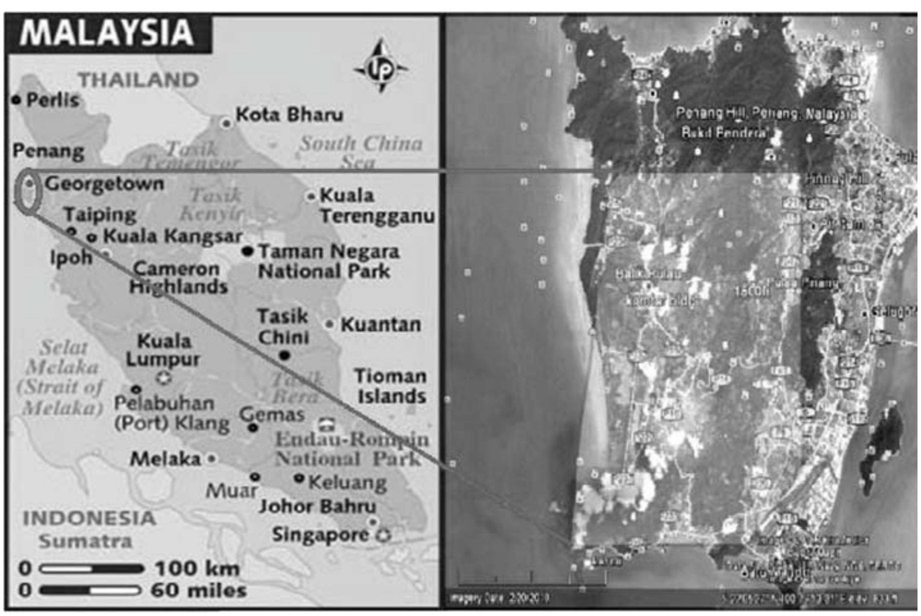

FIG. 1. LOCATION OF STUDY AREA

3.1 Data Collection and Analysis

The data were collected into two formats such as spatial from ministry of mapping and surveying, Malaysia and weights (decision) by experts. The spatial criteria and sub-criteria were selected of this study such as accessibility (primary road and secondary road); topography (elevation, slope and aspect) and land cover (agriculture land, forest land, existing residential, wet land and surface water). Data layers converted into raster format (feature to raster). Raster data layers were reclassified. Weights of criteria and sub-criteria were collected by using pairwise comparison matrix questionnaire to the experts based on AHP method by using 1-9 Saaty scale [15-17]. Collected weights were analyzed in expert choice decision support software using pairwise comparison matrix method [18]. Analyzed weights (Priority vector) were integrated into GIS using weighted summation method in ArcGIS software. This whole process was performed under the framework of AHP for the land suitability modelling of selecting sustainable hillside land for development. The outline of methodology can be shown in Fig. 3.

4. RESULTS AND DISCUSSION

Criteria and sub-criteria for site selection used in sustainable hillside land development model were accessibility (Primary road and Secondary road),

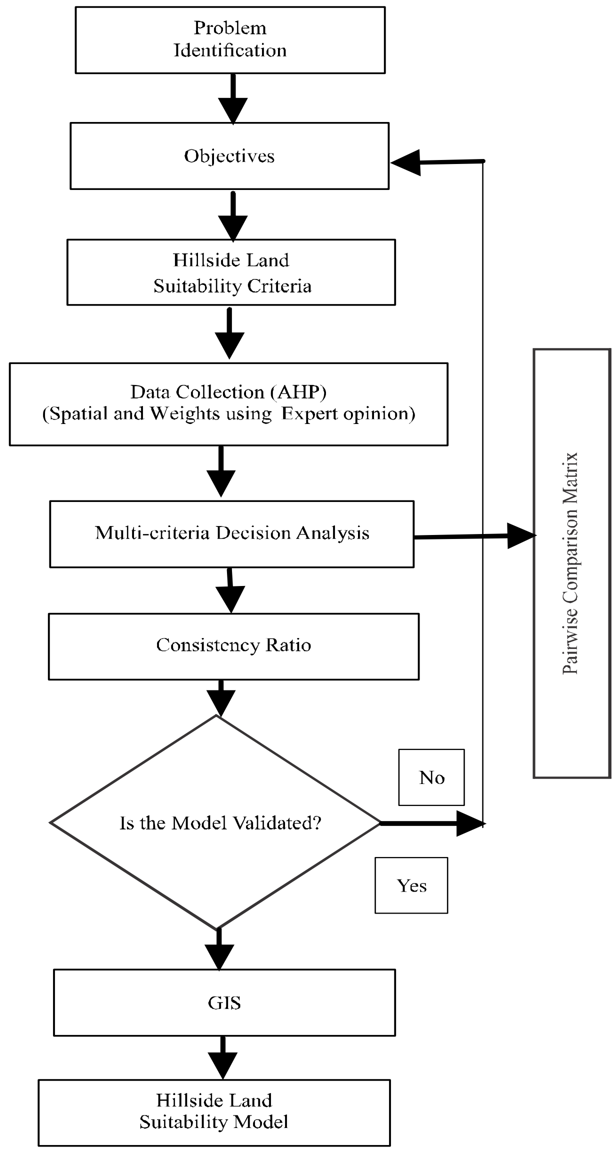

FIG. 3. FLOW DIAGRAM OF METHODOLOGY

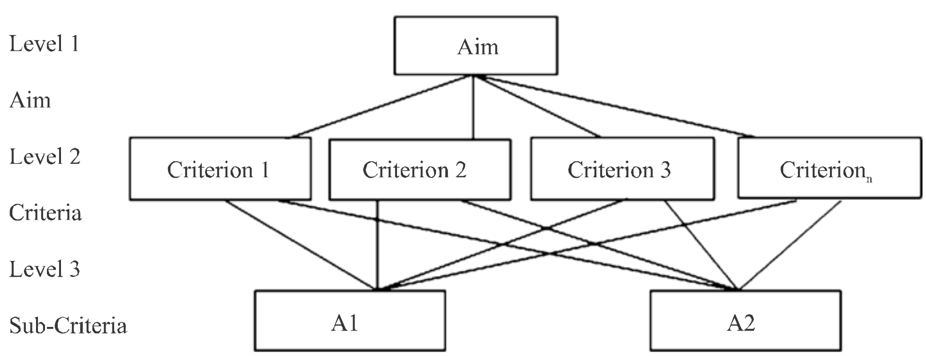

FIG.2. HIERARCHY OF THE LSA MODEL EXAMPLE

topography (Elevation, Slope and Aspect) and land cover (Agriculture land, Forest land, Existing Residential, Wet land Surface water).The derivation of relative weights of hillside land suitability criteria are shown in Table 1. In this table, three criteria were selected such as accessibility, topography and land cover. The accessibility criteria obtained the less priority (0.249) as compare to topography criteria (0.594). It means that topography is the environmental sensitive element for hillside development in terms of unstable slopes exists on the site. Hence, each criterion was classified into sub-criteria. The derivation of relative weights of land suitability sub-criteria of accessibility, topography and land cover criteria is shown in Table 2. In this table, primary road sub-criteria obtained high priority as compare to the secondary road sub-criteria. Slope sub-criteria also got high priority. Therefore, slope is an important sub-criterion because of hilly topography. Synthesising the priority vectors of criteria and sub-criteria are performed in EC software to make sum up 1 of pairwise comparison matrix as shown in Fig. 4, as an example.

The acceptable level of CR (Consistency Ratio) is less than 0.10 then the decision is given by the expert's satisfactory.

CR=CI/RI

Where CI is λmax-n/n-1, RI is Random Consistency index, N is Number of Criteria, and λ_{max} is priority vector multiplied by each column total.

Therefore, CR is derived (0.06) that shows acceptable response level collected by the experts. The WLC (Weighted Linear Combination) method [19,20] was used to produce land suitability model for sustainable hillside

TABLE 1. DERIVATION OF RELATIVE WEIGHTS OF LAND SUITABILITY CRITERIA

Suitability Criteria	Accessibility	Topography	Land Cover	Priority Vector
Accessibility	1	1/3	2	0.249
Topography	3	1	3	0.594
Land Cover	2	1/3	1	0.157
Σ				1

TABLE 2. RELATIVE WEIGHTING OF SUB-CRITERIA FOR EACH LAND SUITABILITY CRITERIA

Criteria		1	2	3	4	5	Priority Vector
Accessibility							
(1)	Primary road	1					0.667
(2)	Secondary road	½	1				0.333
							1.00
Topography							
(1)	Elevation	1					0.297
(2)	Slope	2	1				0.540
(3)	Aspect	½	1/3	1			0.163
							1.00
Land Cover							
(1)	Agri. Land	1					0.543
(2)	Forest Land	1/9	1				0.20
(3)	Existing Residential	1/7	3	1			0.190
(4)	Wet land	1/9	1/7	1/7	1		0.035
(5)	Surface water	1/7	1/7	1/5	1	1	0.031
							1.00

development. Criteria are multiplied by a weight one another followed by a summation of results to yield a suitability map in WLC method, as follows:

$$SHD = \sum_{i=1}^{n} WiCi\Pi_{j=1}^{m} rj \quad (1)$$

Where SHD (Suitability of Hillside Development), wi is the weight for a criteria i, and Ci is the criteria of suitability factor i, where rj is the criterion score of constraint j, and Ï is the product operator. Thus, weighted sum WLC, MCE (Multi-Criteria Evaluation) which is available in ArcGISsoftware [20].Site selection analysis was done by using ArcGIS software. The resolution of raster format is (45x45m) pixel. As presented in Fig. 5, the land suitability analysis results were classified into four classes for hillside development that 22.5 square km (15%) was highly suitable, 40.5 square km (27%) moderately suitable, 61.5 square km (41%) less suitable, and 25.5 square km (17%) not suitable land.

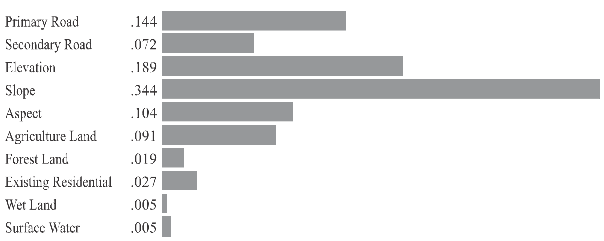

FIG. 4. AGGREGATION OF PRIORITY VECTORS (WEIGHTS)

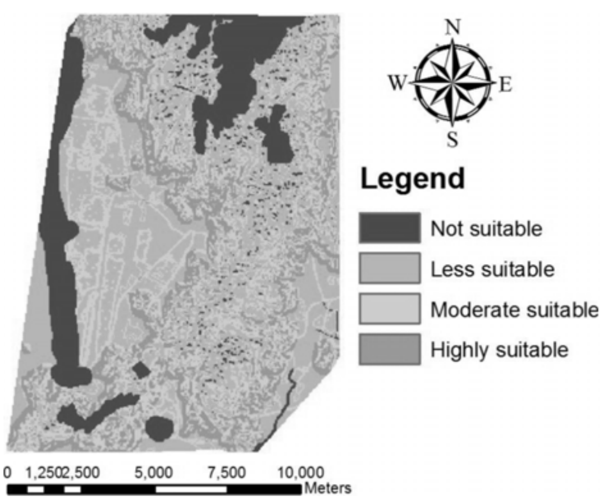

FIG. 5. LAND SUITABILITY MODEL FOR SUSTAINABLE HILLSIDE DEVELOPMENT

5. CONCLUSION

Site selection contains complexity in decision making environment that needs special attention in group making decision rather than individual decision for spatial problems. Indeed, hillside land suitability is a sensitive issue if does not get discerning methods to make appropriate decisions in order to spatial problems. This paper concludes that the integrated GIS-based multi-criteria approach can be a dynamic approach such as spatial multi-criteria AHP method as a decision-making method that allows the consideration of multiple criteria. AHP allows group decision-making approach in LSA. Integrated GIS-based MCDM method for site selection can advocate technically to determine land for sustainable hillside development. These integrated approaches can be a policy tool for researchers, urban planners and decision maker. They can consider a development tool for future scenario of land-use planning such as expansion of cities and development of hilly areas in Sindh, especially for the sustainable development of Gorakh hill station. Therefore, this research approach can be a development instrument for future urban growth towards mountainous areas in developing countries, like Pakistan. An integrated GIS-based MCDM methods reduce the subjectivity of the various kind of spatial problems.

ACKNOWLEDGEMENTS

Authors thank to University Teknologi PETRONAS, Malaysia, for financial support conducting this research. Authors also indebt Mehran University of Engineering & Technology, Jamshoro, Sindh, Pakistan, for giving opportunity to conduct this research.

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