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Land Suitability Analysis Using Geographic Information System (GIS) for Hillside Development: A case study of Penang Island

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Abstract. Rapid development geared towards hillsides has been a challenging issue for developing Asian countries such as Malaysia due to limited flat land. It creates various urban environmental problems, namely landslide susceptibility, soil and coastal erosion and deforestation. Therefore, it is very crucial that their location should be carefully chosen. The objectives of this study are to design a conceptual framework of understanding land evaluation using land suitability multi-criteria decision analysis (MCDA) approach considering accessibility, to develop GIS-based land suitability analysis model and to formulate effective strategies for locating optimal sites to the hillside development against environmental threats and economic pull factor. In this study, the Penang Island is selected for land suitability analysis using Geographic Information System (GIS). MCDA is the basic base for land suitability analysis in the rational land-use planning using GIS. In order to determine suitable site, the important factors/criterions are incorporated i.e. accessibility and topography, land cover, and economic. In this paper, pair-wise comparison using analytic hierarchy process (AHP) method in Expert Choice software were analyzed to get priority weights gathered by the expert opinions. 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 suitability model for hillside developments in Malaysia as well as other developing countries.

Keywords: Analytic Hierarchy Process, GIS, Land suitability analysis, Multi-Criteria Decision Analysis

1. 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 (Yaakup et al. 2005, Pardhand 2009). However, the unplanned physical development is a big issue in developing countries Lotfi et al. 2009). 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 (Chan 1998), 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 environment challenges due to its hilly topography and limited flat land (OLshansky 1998, Perkins 2006, Ahmad et al. 2010). The Geographic Information System has proven practical throughout the world and effective when used for determining suitable lands for a built environment (Baban 2007).

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 and land cover (Baban 2007). Furthermore, hillsides built developments have a big constraint of accessibility because hillsides contain elevation and

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slope contours (Amiruddin, 2006). 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 [10]. This can be achieved in the beginning stage with a sustainable development (Hyman 2000, Ahmad et al. 2010, Jovanovic 2010) 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" (Jovanovic 2010). 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 (Zolfaghari 2008, Dai 2010). 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 (Malczewski 2004). No research work has investigated a land suitability analysis incorporating accessibility (Route network analysis modelling) in hillside development using GIS-based Multi-criteria approach.

2. Background

Hazard vulnerability has increased because of the pressure of development (Nicoll 2010) encroaching to the hillsides (Chan 1998). Landslides are always susceptible for the population (Nicoll 2010), particularly in developing countries (Van westen 2000). There have been many landslide issues in Malaysia reported in past, i.e. 1993, 1995, 1999, 2000, 2001, 2002, 2004, 2006, 2007, 2008 and 2009 (Chan 1998, Jamludin 2006, Pardhan 2009). However, in this regard, there have been many studies carried out on landslide susceptibility evaluation using GIS with statistical methods (Van westen 2000, Ayalew 2004, Lee 2007, Gaghah 2009). Frequency ratio, logistic regression and neural network models are applied by (Lee 2007) in which the researchers concluded that frequency ratio and logistic regression models have a higher efficiency than implementing a neural network model. In addition, qualitative and quantitative methods are also applied by (Van westen 2000) and considered as deterministic models. The qualitative and quantitative methods are heuristic approaches in the GIS based on Expert knowledge and the parameters are described by (Van westen 2000, Jamaludin 2006). Using GIS, weighted-models (Dai, 2007, Gaghah 2009) are adopted to mitigate a geo-environmental problem for land-use planning and to determine factors that cause landslides. It is reported with a high degree of satisfaction that, the GIS application is an excellent technique providing extensive assessment for landslide prone areas (Van westen 2000, Nicoll 2010). There are mainly two major triggers of landslide hazards, namely rainfall and human activities as stated by (Lee 2007, Nicoll 2010).

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 (Miller 1998, Joerin et al. 2001, Malczewski 2006) for land development. The AHP was introduced by (Saaty, 1980) as referred in (Saaty 2008). It has been widely used as a multi-criteria evaluation process (Saaty 1985, Saaty 2003) and MCE is also one of the most viable methods addressed in many studies on the land suitability analysis through GIS (Steiner 2000, Store 2001, Youssef 2010). 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 (Collins, 2001, Mohit 2006, Chandio 2009). 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.

3. Methodology

The analytic hierarchy process was developed by (Saaty 1980) for solving complex problems. It involves synthesis of prioritization as well as ideal prioritization (Saaty 2008) 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 (Saaty 1985). 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.

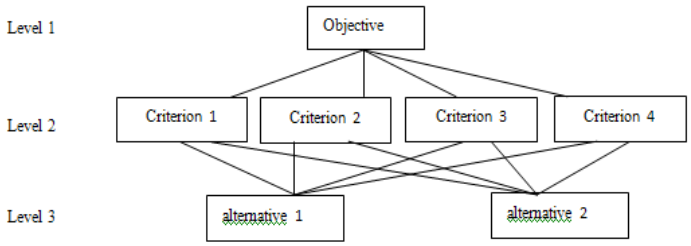

Figure: 1. Structured problem with three different hierarchy levels

Source: Malczewski 1999

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

3.1. 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 in this study and 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 spatial database layers and non-spatial data based on 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) (Chandio 2009) 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 (Saaty 1985, Chandio 2009). In this article, the important criterions are incorporated i.e. accessibility and topography, land cover, and economic.

4. Results and Discussion

4.1. 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 (Saaty 2008). Currently, the obtained weights can be computed automatically in IDRISI (Eastman 1995) as well as in Expert Choice (Expert Choice Quick Start Guide, 2000-2004) softwares called MCDA tool. The results of relative weightage of land suitability criterion Scenario 1 Accessibility and Scenario 2 Environment are shown in Table 1 and 2 based on criterions. 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: 1. 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 : 2.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

As, the calculation all the pair-wise comparison matrix to find the maximum Eigen value, the consistency is determined through Expert Choice, λmax, to calculate the consistency index, CI as follows: CI= (λmax-n)/(n-1), where n is the matrix size. Judgments consistency can be checked taking the consistency ratio (CR) of CI. 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 (Saaty 2008). 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.

5. 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 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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7. References

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