J Coast Conserv (2013) 17:1–10
DOI 10.1007/s11852-012-0213-4

Application of geographic information system technique and analytical hierarchy process model for land-use suitability analysis on coastal area

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Received: 7 March 2012 / Revised: 24 April 2012 / Accepted: 15 August 2012 / Published online: 11 September 2012

Abstract Land-use suitability is the ability of a given type of land to support a defined use. GIS is known as a powerful tool for handling spatial data in land-use analysis. Application of this tool alone cannot overcome the lack of consistency in opinions given by experts when trying to assign relative importance to each of the several criteria considered in a suitability analysis. The combination of GIS and Multi-Criteria Decision Analysis (MCDA) is a powerful approach used to assess land suitability. To address this issue, the Analytical Hierarchy Process method is used in combination with the GIS tool. The aim of this study is to demonstrate how GIS tools and AHP model can be used for integrated coastal resource planning and management. Based on the information from final map/suitability map, we can define the best area. The findings indicate that the area 1 (2111 m) from class 3 is the most appropriate one because it has good facilities and wide open areas. This study indicates how the integrated tool is handled effectively in a land use suitability analysis for building hotels in the coastal areas of Terengganu in Malaysia. This research develops a framework for integrating GIS and AHP to incorporate the decision maker's preferences on a range of factors in finding land areas suitable for coastal development.

Keywords GIS · AHP · Land-use suitability · Coastal management

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Introduction

Land suitability assessment is similar to choosing an appropriate location and the goal is to map a suitability index for the whole study area (Joerin et al. 2001). It is the fundamental work and the essential content of overall landuse planning, which requires a scientific approach, in addition to guide development, avoidance of errors in decision-making and over-investment, for sustainable utilization of land resources (Yu et al. 2009). Suitability techniques allow decision makers and environmental managers to analyze the interactions among locations, development actions and environmental elements. This enables analysts to map the interactions in different ways (Collins et al. 2001).

The general processes for land-use suitability analysis are indicated in (Fig. 1). These processes involve evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The principles of sustainable development make land-use suitability analysis more complex due to the different criteria taken into consideration (Duc 2006). It is often difficult to allocate relative weights to the different criteria involved in making a decision on suitability of land mapping unit for a land-use type. Hence, it is very important to adopt a technique that allows an estimation of weights. Analytical Hierarchy Process (AHP) is one of these techniques which is considered as one of the Multiple Criteria Decision Analysis (MCDA) methods especially in the problems with spatial nature or GIS-based (Vahidniaa et al.

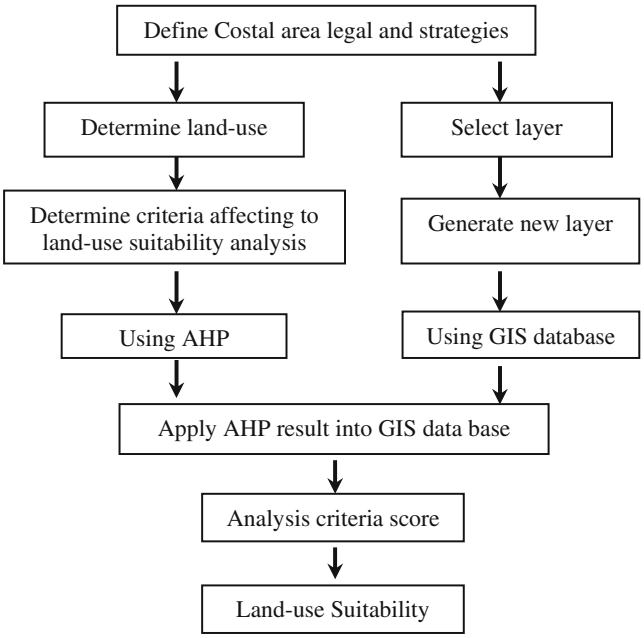

Fig. 1 Land-use suitability analysis process

2008). MCDA is a decision-making tool applied to assess the problems, which are encountered along the way. It provides a number of different alternatives in order to find optimal solutions regarding different criteria (Antunes et al. 2006).

In fact, choosing a suitable area for an activity is related to MCDA and the decision support system. Previous studies also show that the combination of MCDA and Geographic Information System (GIS) is a powerful approach to land suitability assessment (Carver 1991; Eastman et al. 1993; Joerin et al. 2001). Geographical Information System (GIS) technology can be used to assess the criteria requested to define the land suitability map for the most important land uses such as housing, agriculture and manufacturing. Land suitability maps should integrate all the relevant data for the analysis of the given area. Since a significant amount of work would be necessary to develop these types of maps, they would be useful for several years and for many future decisions. Updating the maps require less work than was originally required to produce them (Joerin et al. 2001).

Although Malaysia is almost a new entrant into tourism activities as compared to its ASEAN neighbors, the tourism industry has grown extremely over the years. Tourism industry is a key foreign exchange earner for Malaysia, contributing to over 40 % of the country's balance of payment (EPU 2006). Malaysia's marine assets have always been major drawcards for attracting tourists to the country. The building of resorts, hotels, chalets and other types of accommodation in coastal areas is the most profitable sub-sector of the marine tourism sector. However, development in coastal area needs the long term sustainability of the sector from an economic, social and environmental point of view (Basiron 1994).

In fact, the main attraction of a coastal area is its natural assets such as scenic beauty, clean beaches, unpolluted water and undisturbed coral reefs. An unsuitable selection of an area that has potential for sustainable activity could cause many environmental, social and economic damages. Hence, it is very important that in the development and operation of coastal areas, environmental management and nature conservation be given priority. The objective of this study is to apply AHP and GIS techniques for land-use suitability analysis on coastal areas of Terengganu. To illustrate the feasibility of this approach, the study would apply AHP as a model for obtaining expert knowledge on environmental systems and identifying the key barriers within such a model. Eventually, a land suitability map for building a hotel in the most suitable area of Terengganu will be realized.

Method

The implementation of the whole methodology is illustrated in Fig. 2. It shows the integration of GIS and AHP techniques in decision making for land use suitability.

Study area

This study was conducted in Kuala Terengganu (Marang), Malaysia in the year 2008–2009. Kuala Terengganu (103° 12 E, 5°18 N) considered within the Peninsular Malaysia is shown in (Fig. 3). Terengganu has sandy beaches, islands, tropical forest, and fishing villages. It has a 200-mile (320 km) long coastline along the South China Sea, extending from Besut in the north to Kemaman in the South. Its people mostly live in coastal towns and fishing villages. Terengganu state has been considered as a part of East Coast Economic Region (ECER) in Malaysia and government has target to develop this region by 2020. It has been grouped as the ECER due to its richness in cultural diversity, and its potential for development. Its beaches, resort islands, natural resources and special cultural elements have made it a haven for travelers from all over the world. Terengganu is strategically positioned to be a dynamic tourism gateway to the ECER. It offers various and special tourism attractions in the areas of mainland coastal tourism, sustainable island tourism, ecotourism, urban tourism, and cultural and heritage tourism (ECER 2009).

Geographic information systems (GIS)

GIS is a potential tool, for monitoring the changes in land use at regional as well as global scale in developing

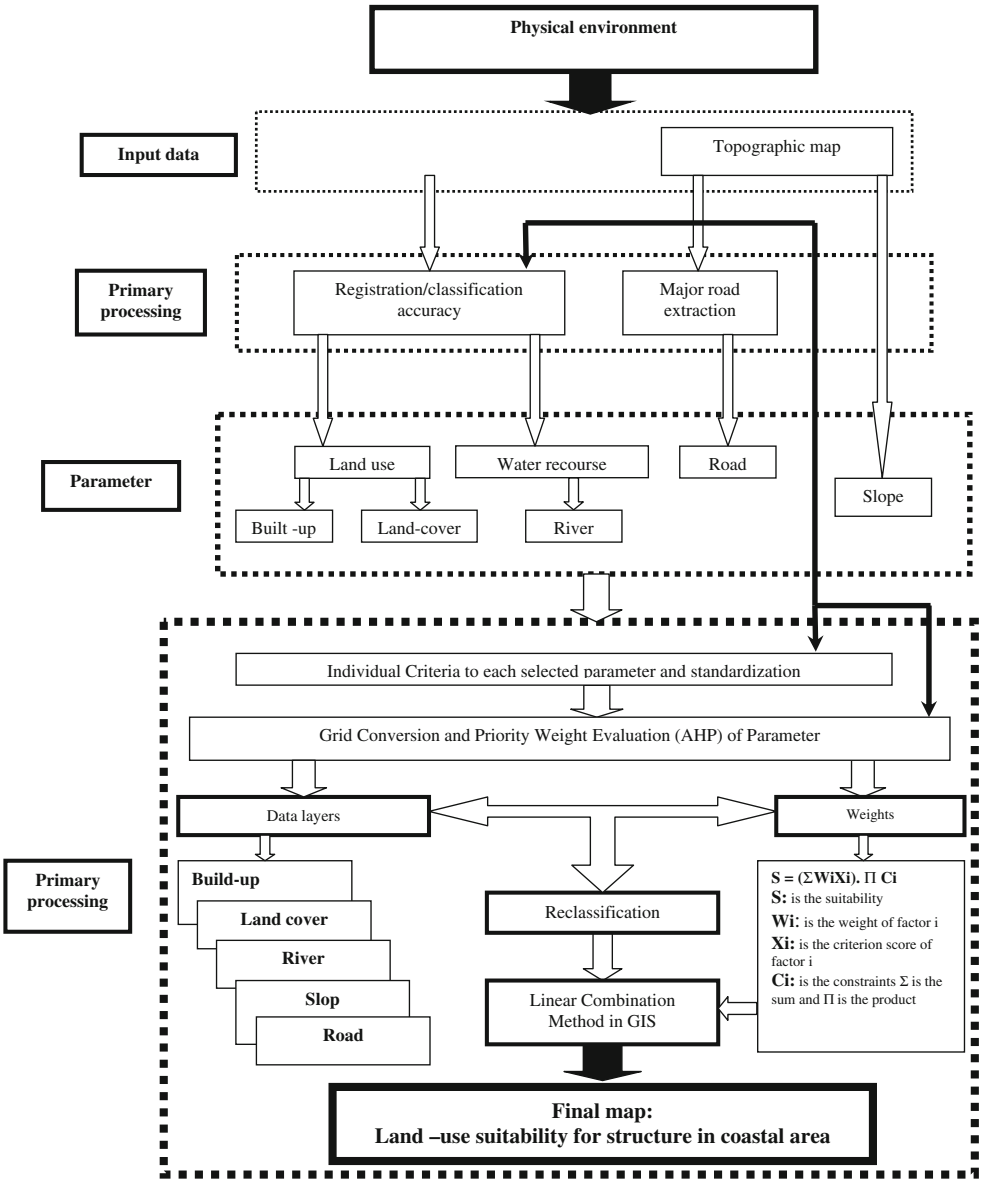

Fig. 2 General flow of study procedure

countries (Kumar 2011). It emerged as a useful computer-based tool for spatial description and manipulation. Although often described as a decision support system, there has been some disputes regarding whether the GIS decision-supporting capabilities are sufficient (Jankowski 1995). The use of GIS allows for multiple spatial variables to be incorporated in the analysis. The datasets representing these variables are based on regulations, current population trends and the increased cost of development. GIS could be an ideal solution to developing a model of land suitable for sitting building in the coastal area development. It was used for combining maps of study area and also for analyzing the land use change, realization of preference, preference change and preference conflicts. It is a powerful tool for input, storage and retrieval, manipulation and analysis and the output of spatial and attributes data. Land-use suitability analysis requires the management of both spatial and attributing data in many data layers. Therefore, an integration of GIS and AHP to analyze the land suitability is supposed to produce promising results. This study presents results obtained through application of GIS and AHP in analyzing land-use suitability, in the case of setting up a hotel building in the coastal area of Terengganu. The process of ARC-GIS spatial analyst for land-use suitability is shown in (Fig. 4).

Analytical hierarchy process (AHP)

The Analytic Hierarchical Process (AHP) is one of the methodological approaches that may be applied to resolve highly complex decision-making problems involving multiple scenarios, criteria and actors (Saaty 1980). AHP proposed in the 1970s by Thomas L. Saaty, constructs a ratio

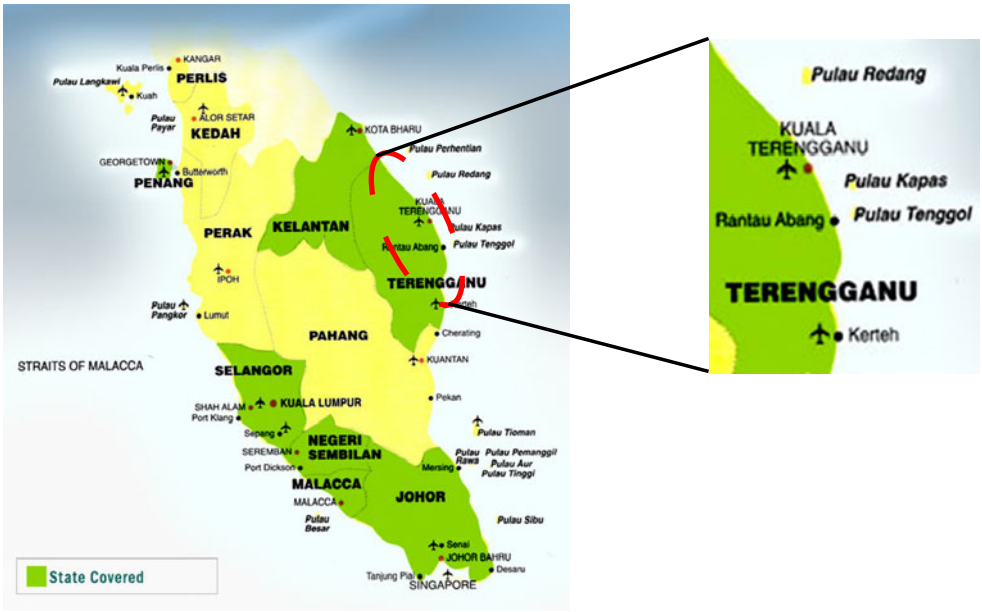

Fig. 3 Specification of Terengganu location in Malaysia

scale associated with the priorities for the various items compared. Saaty, in his initial formulation, proposed a four-step methodology comprising modeling, valuation, prioritization and synthesis. At the modeling stage, a hierarchy representing relevant aspects of the problem (criteria, sub-criteria, attributes and alternatives) is constructed. The underlying goal or mission is placed at the top of this hierarchy. Other relevant aspects (criteria, sub-criteria, and attributes) are placed at the remaining levels (Altuzarra et al. 2007). In the AHP method, obtaining the weights or priority vector of the alternatives or the criteria is required. This study focuses on the utility of the AHP as a model for obtaining expert knowledge on environmental systems where data may be lacking. The AHP method commonly used in multi-criteria decision making exercises was found to be a useful method to determine the weights, in comparison with other methods used for determining weights. When applying AHP, constraints are compared to each other to determine the relative importance of each variable in accomplishing the overall goal. The AHP has three basic steps which are applied to land-use suitability analysis (Fig. 5).

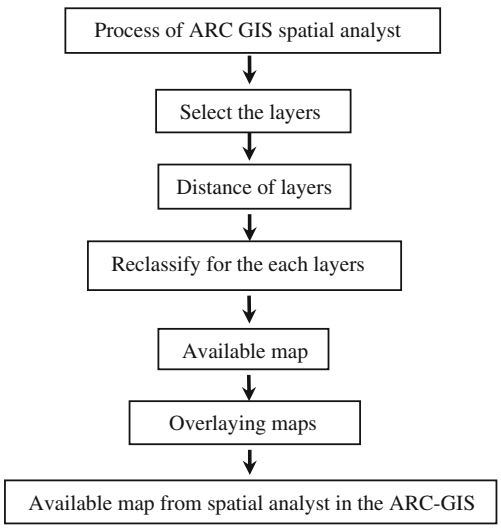

Fig. 4 Process of ARC-GIS spatial analyst for land-use suitability

Scale for pair wise comparison

All identified criteria are compared to each other in a pair–wise comparison matrix, which is a measurement to express the relative preference among the factors. Thus, numerical values express a judgment of the relative preference of one factor against another. Saaty (1977) suggested a scale for comparison consisting of values ranging from 1–9 which describe the intensity of importance, by which a value of 1 expresses "equal importance" and a value of 9 is given to those factors having an "extreme importance" over another factor (Saaty and Vargas 1991; Marinoni 2004). The data in (Table 1) shows the scale used for the comparison; the factors were compared to each other using the pair–wise comparison matrix.

In order to determine the relative preferences for the two elements of the hierarchy in the constraints matrix, an underlying semantical scale is employed with values from 1–9 (Table 2). The sum of each column within the matrix is normalized and weights are calculated. In developing a hierarchy, the top level is the ultimate goal of the decision. The hierarchy decreases from general to more specific until attributes are reached. Each level must be linked to the next higher level. The alternatives are represented in GIS database. Each layer consists of the attribute values assigned to the alternatives, which are related to the higher-level elements (Sener et al. 2004). Numerical values are assigned to

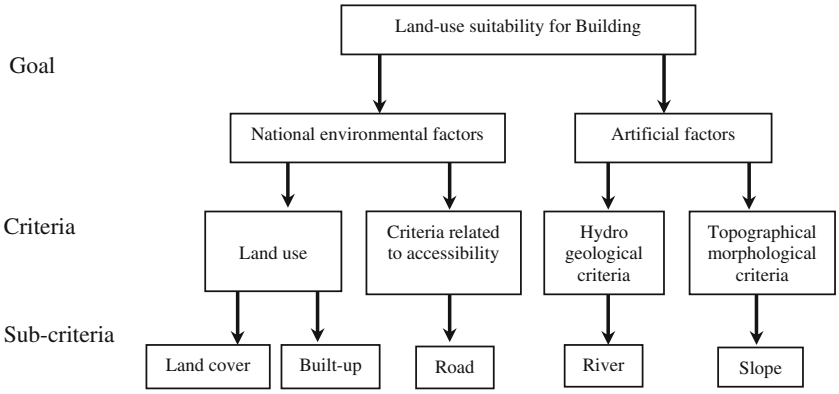

Fig. 5 Land-use suitability analysis hierarchy

each pair of constraints by using the guidelines established. Based on (Fig. 6), the most important AHP weights in land-use suitability analysis are slope, land-cover and built-up respectively with the highest percentage and then road and river with the lowest effect. It also shows that the slope has the highest sensitivity in comparison to others.

Weighted linear combination

Two of the most common procedures for multi-criteria evaluation are weighted linear combination and concordance-discordance analysis. In this study, weighted linear combination was used. Suitability map was derived from Eq. 1:

$$S = (\Sigma W_i X_i).\Pi C_i \quad (1)$$

where:

S the suitability value
W_i the weight of factor i
X_i the criterion score of factor i
C_i the constraints, Σ is the sum and Π is the product

Throughout "Analysis/Decision Support/Weight", weights were developed by providing a series of "Pair wise Comparisons" of the relative importance of factors to the suitability of pixels for the activity being evaluated. In fact, it is the derivation of weights within the context of the decision objective that provides a major challenge.

Calculation of score value for each criterion

The suitability value for constructing buildings and housing complexes in coastal areas and the criterion for each land mapping unit is determined through the maximum limitation method that affects the land use. The five natural physical characteristics represented are used in the calculation, including: river, slope, land cover, built-up and road. Before applying weighted linear combination equation to calculated suitability index, these calculated scores are standardized to the measured scale 1 (Low), 5 (medium), 7 (High) and 9 (very high suitability). All of the classifications and ranking values in spatial analysis are obtained according to some the studies of Al-Shalabi et al. (2006) and Kordi (2008). This is based on visits to the study area. The detailed conversion is shown in (Table 3).

Sensitivity analysis and correlation between IV and DV

A sensitivity analysis is the process of varying model input parameters and observing the relative changes in model response, which attempts to provide a measure of the sensitivity of parameters. In this study, a cross-comparison

Table 1 Example scale for comparisons

Intensity of Relative Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment another slightly favour one activity over
5	Essential or Strong	Experience or judgment strongly favours one activity over another
7	Importance Demonstrated	An activity is strongly favoured and its dominance is demonstrated in practice
9	Extreme (Absolute)	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Source: Saaty (1977) and Saaty and Vargas (1991)

Table 2 Constraints matrix

	Slope	River	Road	Built-up	Land cover
Slope	1	2	5	5	1
River	"1/2"	1	"1/2"	"1/3"	2
Road	"1/5"	2	1	"1/3"	5
Built-up	"1/5"	3	3	1	3
Land cover	"1/1"	"1/2"	"1/5"	"1/3"	1

technique was employed to evaluate model performance: testing for close agreement between Independent Values (IV), which is for land use index of the model, and Dependent Value (DV), which is for land use suitability. Here, a 1: 50 000 scale land-use map (topography map) from JUPEM (Department of Survey and Mapping Malaysia) was employed as a performance standard. This scheme employs five indexes (1–5), as the limitations increase, the area of land use suitability for building hotel also decreases. In this study, slope and land cover are the suitable criteria for environmental land use because they have higher AHP weights compared to other criteria. Figure 7 shows the correlation between the IV and DV. It also reveals the sensitivity of the weights given and the variation of land suitability indexes within each land-use suitability class.

Table 3 Standardized score corresponding to criteria attribute values

Level 1's criteria	Level 2' criteria	Attribute values of criteria	Score (Xi)
Environment	Slope	Class 1:0-20	9
		Class 2:20-40	5
		Class 3:above 40	0
	River	Class 1:0-100 m	1
		Class 2:100-200 m	2
		Class 3:200-300 m	4
		Class 4:300-400 m	6
		Class 5:400-500 m	8
		Class 6:500-600 m	9
	Road	Class 1:0-400 m	9
		Class 2:400-800 m	7
		Class 3:800-1200 m	5
		Class 4:1200-1600 m	3
		Class 5:above 1500 m	1
	Built-up	Class 1:0-300 m	9
		Class 2:300-600 m	6
		Class 3:600-900 m	4
		Class 4:900-1200 m	2
		Class 5: above 1200 m	1
	Land cover	Class 1:0-200 m	1
		Class 2:200-400 m	8
		Class 3:400-600 m	9
		Class 4:600-800 m	4

Results

Suitability maps resulting from Multi-Criteria Evaluation (MCE) and Multi-Objective Land allocation have shown different classes for which the degree of sensitivity is in accordance with the infrastructure of the new building, for example, hotel estates and urban settlements, vary from extremely prone areas to weakly prone. Based on relative weights of the suitability factors for development, suitability ranges were identified as shown in (Table 4).

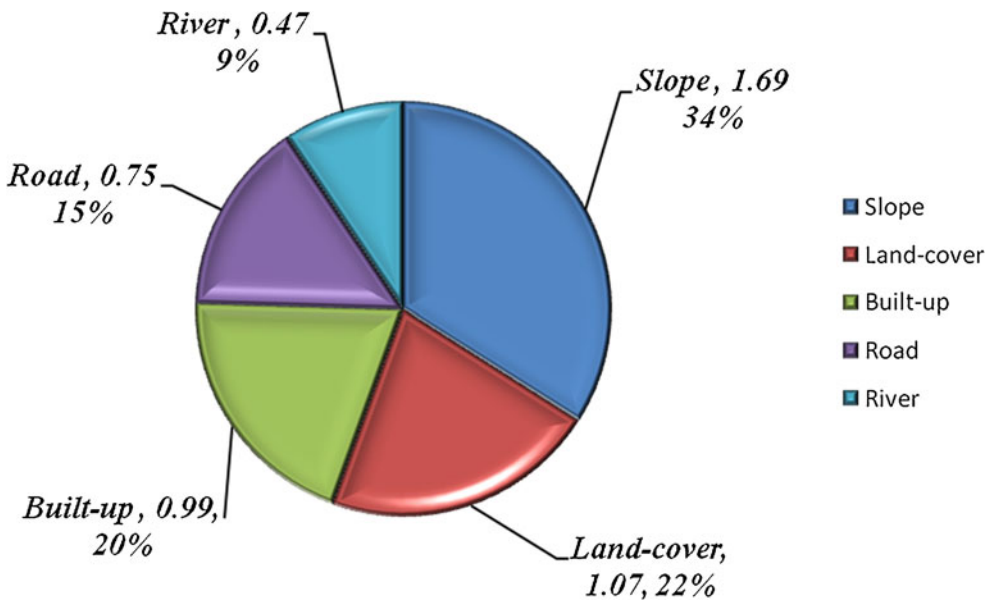

Fig. 6 AHP weights of criteria in land-use suitability analysis

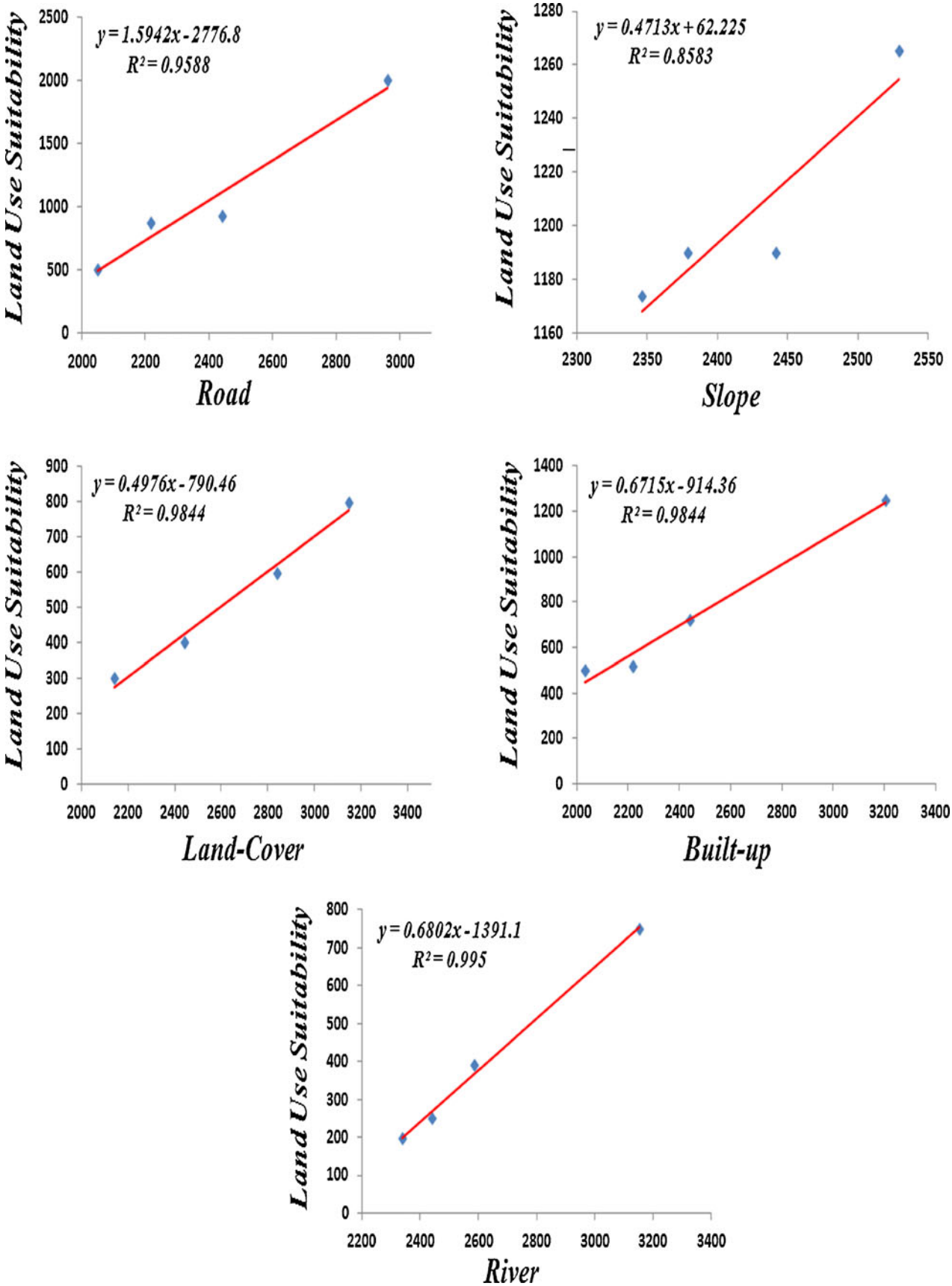

Fig. 7 Correlation between the IV and DV

Table 4 Suitability classification

Level of Suitability	Range of scores
Highly Suitable	Class 3 (Blue)
Moderately Suitable	Class 2 (Green)
Not suitable	Class 1 (Black)

Table 5 Land suitability for Terengganu in Malaysia

Land suitability classes	Area (%)
Highly suitable (Class 3)	8.94
Moderately suitable (Class 2)	43.52
Unsuitable (Class 1)	29.12
Unclassified area	13.68
Water body	4.74
Total area	100

The suitability area in addition to the map is shown in Table 5. Areas with high suitability are concentrated in the surroundings of main urban settlement zones. The final map (suitability map), which is divided into five best areas, is shown in Fig. 8. Based on this map, there are three colors (classes): black, green and blue. The blue color (class 3) is considered the best area. Among the five suitability map, we have to select one, as the most suitable area. Two factors are very important when selecting the best area among these sites. The first factor determines to what extent the area can provide more facilities to tourists and the second one is the distance to the beach because tourists prefer to stay near the beach. In conclusion, the best area among these five areas based on the existing information is area 1 (2111 m) from class 3, as it is the most appropriate due to its good facilities and wide open areas.

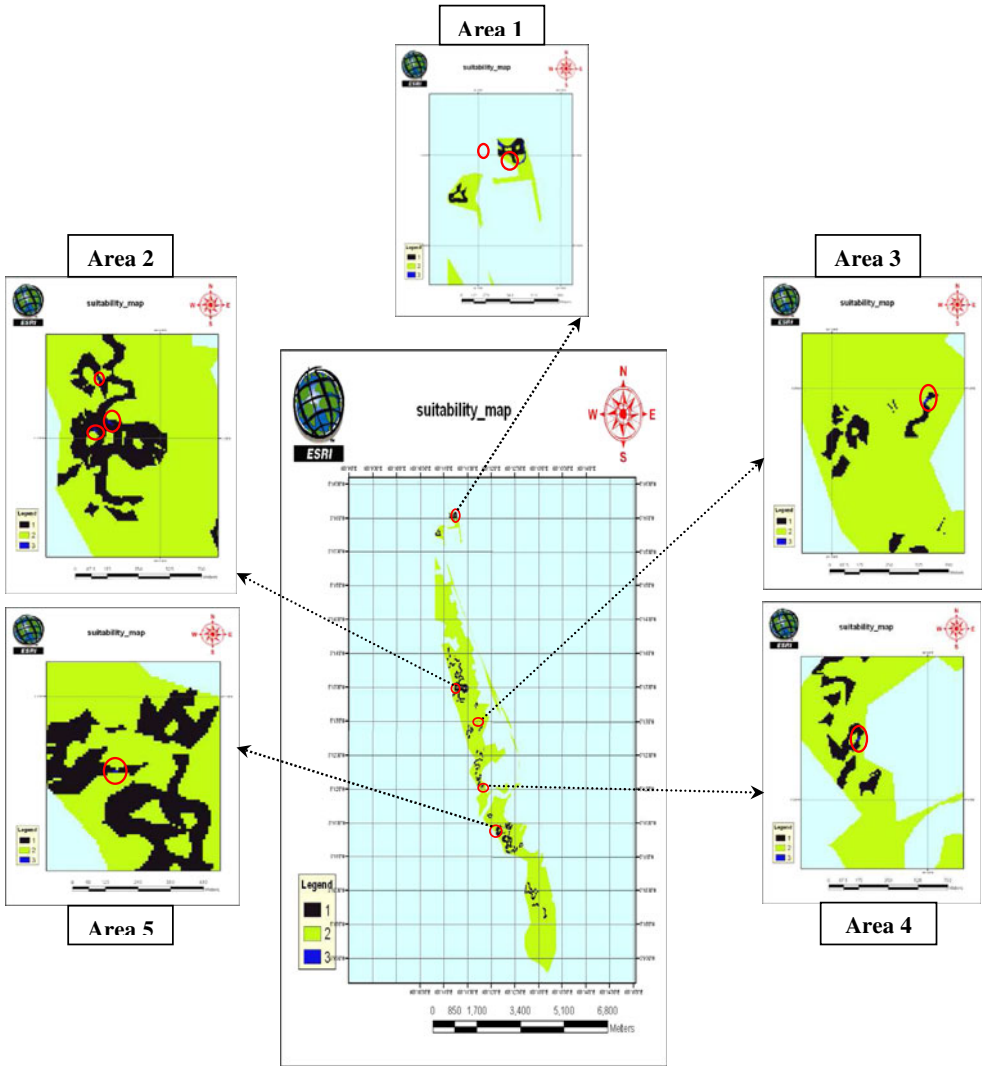

Fig. 8 Land-use suitability map for building hotel

Discussion

Application of GIS and AHP in the process of land suitability analysis is an effective way for the residential land suitability assessment. The findings of this study confirm that the combination of AHP method with GIS could be a powerful combination to apply for land use planning. This result is consistent with the findings of Weerakoon (2002), Duc (2006), Al-Shalabi et al. (2006), Javaheri et al. (2006), Chen et al. (2008) and Thap and Murayama (2008). This assessment creates an index of the influencing factors for the land-use suitability based on the literature review. Overlay mapping is the basic method applied in GIS and helps the planners to obtain the final suitability map. On the other hand, the AHP method is one of the methods used to combine attribute scores with weights or preferences that should be used in the process of weight value calculations, so we can avoid some subjective ideas affecting the results and combine the quantitative and qualitative methods. As a result, it can be concluded that the land-use suitability assessment for setting up hotels in coastal areas is a technical basis for sensible land-use planning at the regional level.

Basically, the environmental protection areas are always areas of concern for land use planners. These areas have top protection priority in comparison to other areas. For instance, the prime land cover and key hydrologic features are mostly defined as protected areas. Even if they are suitable for land uses, they cannot be used as building areas, because of their environmental protection priority. Hence, the land suitability assessment process will assess remaining areas to find the best area to build a hotel. These efforts will help the government to find a suitable area for future urban development by effectually using limited land resources.

Conclusion

The analysis of this study focused mainly on highly suitable places in coastal area as these areas have the highest potential for building hotels. We integrated GIS and AHP techniques for land-use suitability analysis based on five criteria layers and the AHP method was found to be a useful method to determine the weights. The sensitivity utility of the model helps to analyze the decision before making the final choice. The AHP method can deal with inconsistent judgments and provides a measure of the inconsistency, so it is more superior. But, the important drawback of the model is its application process, as it needs the right people with sufficient knowledge and expertise with regard to participation in decision-making groups.

For land use planning in coastal areas, researchers have found out that GIS is a technique, which provides great flexibility. Although the land use planners have conducted similar exercises in the past using manual methods, the GIS can perform these tasks much faster. This study indicates that the integration of AHP method and GIS provides a powerful combination in applying for land-use suitability analysis in coastal areas. This assessment is useful for land-use decision-making and urban development. This is very important for planners who want to decide whether land should be developed or conserved. This integration can also help to consider the strategic urban land development framework and in addition, the short-term land use policies can also be formulated. The approach, therefore, helps to monitor the land-use development which planners and policy makers can use for formulating urban growth policies and strategies for city plans in coastal areas.

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