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GIS-based integrated evaluation of environmentally sensitive areas (ESAs) for land use planning in Langkawi, Malaysia

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ABSTRACT

Extensive economic growth, tourism activities and over-exploitation of resources have become the common causes of environmental degradation in Langkawi. The sudden development leap resulting from UNESCO's recognition of Langkawi Archipelago as a Global Geopark in 2007, leads to continuous conflicts between enhancing environmental protection and meeting tourism and development needs. Environmental sensitivity evaluation is a basis upon which the concept of environmentally sensitive areas (ESAs) can be practised in order to protect the environment, regulate development activities and promote sustainable land use planning. This study embarks on evaluating and classifying environmental sensitivity as well as comparing different ESA approaches applicable for land use planning in Langkawi. A GIS-based integrated evaluation model was performed on two assessment sets (Set A and Set B) using a standard grading system and weights determined with analytic hierarchy process (AHP) method. Of these sets, the former consists of selected indicators from the Malaysian integrated ESA instrument while the latter are derived from previous eco-environmental studies conducted in China. The projected final ESA maps of Langkawi indicate spatial distribution of four environmental sensitivity classes. More highly and moderately sensitive areas are observed in Set A, accounting for 339.15 km^2 or 72.24% of the total land area compared to Set B with only 259.04 km^2 or 55.18% respectively. The results also reveal large proportion of low sensitivity areas in Set A, covering areas of 117.42 km^2 (25.01%). In contrast, more areas with non-sensitivity are widely distributed in Set B, occupying areas of 123.02 km^2 (26.20%). Taking into consideration the natural and cultural characteristics of the islands, it is suggested that Set A is a better approach to portray current environmental concerns and to coordinate future land use planning as well as fits Langkawi's aspiration in becoming a sustainable, world-class Global Geopark. This study provides beneficial information and opportunity for reasonable rearrangement of zoning and development guidelines and strategies within sensitivity areas. It promotes effective utilization of the natural resources, minimizes negative tourism impacts and adequately highlights ecosystem functions to prosper local socio-economic growth. It also represents an early step for the design of universal ESA instruments to regulate local development activities and promote sustainable land use planning in vulnerable areas at global levels.

1. Introduction

The environment provides us with all the goods and services structuring the base of our economic, social, cultural and spiritual life. Our well-being depends on the continuing capacity of ecosystems and the environment as a whole to provide their multitude of benefits. However in reality, too much focus are given on how much we can take, giving inadequate regard to the impacts of our actions on the ability of the environment to sustain itself. Over-exploitation and utility of resources due to extensive economic growth have now become the common causes of environmental degradation (Yaakup et al., 2006; Su et al., 2011; Bakr et al., 2012) and lead to continuous conflict between maintaining environmental sustainability and meeting the need for development (Dai et al., 2012). Furthermore, the interconnectivity of ecosystems is increasingly jeopardized by the uncontrolled development, land use conversion, tourism activities and endless disturbances caused by anthropogenic agents (Wang et al., 2008). These

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disruptions invariably act as impetus to habitat loss, reduction in biodiversity, ecosystem damage and worse, leading ecosystem failure (Huang et al., 2010; Li et al., 2010; Parvari et al., 2011). On the other hand, when well-connected, the diverse ecosystems could form greenway corridors consisting of linked landscape networks that provide ecological, recreational and cultural benefits to a community (Ndubisi et al., 1995).

Land use involves the process of biologically and technically reshaping, converting and managing land for socio-economic benefits (Xie et al., 2015). This alteration of land into various land use types often triggers degradation of the environment and led to a series of environmental problems such as soil erosion, wetland destruction, land contamination and pollution (Xie et al., 2015). These unceasing great pressures on the environment have alerted international organizations, government agencies and scientific communities that deterioration entails sustainable land use planning and zoning in order to regulate human activities and promote effective utilization of natural resources (Jia and Zhang, 2006; Dai et al., 2012). Common practice adopted and applied to facilitate this effort is through the implementation of environmentally sensitive areas (ESAs) concept within the context of land use planning and management.

ESAs are landscape elements, ecosystems, areas or places which are imperative to the long-term maintenance of biodiversity, soil, water and other natural resources (Ndubisi et al., 1995), which could be threatened by development (Selangor State Government, 1999; TCPD, 2010). They include among others: forests and wildlife habitat areas, steep slopes, wetlands, mangroves, and agricultural lands. ESAs occur within all landscapes, but their significance and role in ensuring environmental integrity and maintaining the health of locality are relative to their ecological values, type of land uses, planning mechanisms and management regimes (Ndubisi et al., 1995; TCPD, 2010).

The need to identify ESAs is of immensely significance for seeking balanced development within and around such areas based on the concept of sustainable development (Steiner et al., 2000; Pereira et al., 2006; Hashim et al., 2007; Liang and Li, 2012). ESAs should be recognized through environmental sensitivity evaluation, as it will enhance understanding of the various trade-off between land development, environmental protection and social well-being, and this facilitates effective planning for future development (Pereira et al., 2006; Hashim et al., 2007; Dai et al., 2012). ESAs therefore should be one of the priority issues in current land use planning and a pressing concern for local authorities to steer development away from these fragile lands (Yaakup et al., 2006).

This study therefore aims at evaluating environmental sensitivity of Langkawi using GIS-based integrated evaluation model, performed on two assessment sets comprising of selected indicators respectively from Malaysian integrated ESA instrument and eco-environmental studies conducted in China. The study embarks on the following objectives: (1) to classify environmental sensitivity into four sensitivity classes, and (2) to compare two different ESA approaches applicable for future land use planning and management in Langkawi. This will then provide opportunity for better development and planning strategies, mitigation measures to be applied, and revised procedures and guidelines to be enforced by the relevant authorities.

1.1. Contextualizing ESA approaches and methods

In general, there is a multitude range of approaches and methods used around the world to evaluate and identify ESAs (Yaakup et al., 2006; Salvati, 2012), designed from diverse contexts and performed at different spatial and temporal scale (Steiner et al., 2000; Liang and Li, 2012; Liu et al., 2012). Some ESA studies were conducted and viewed from the perspective of river quality, watershed management, agricultural activities, protection of national parks, wetlands preservation, tourism islands as well as coastal and marine environment, whereas others evaluated ESAs to a larger scale, involving districts or provinces. Frequently, these studies and many evaluation methods were carried out on the platform of GIS or remote sensing or the combination of both compared to field evaluation (Liu et al., 2012) and sometimes coupled with other environmental models or methods (Huang et al., 2010). This is mainly due to the fact that these techniques are cost-effective, easily-compared, time-efficient and ideal for mapping and monitoring trends of environmental degradation and spatial changes (Mukhlisin et al., 2010; Bakr et al., 2012). Among the varied methods used to evaluate ESAs include layer cake model (Steiner et al., 2000), multi-criteria evaluation model (Huang et al., 2010; Mashayekhan and Honardoust, 2011), fuzzy-matter-element model (Zhang et al., 2011) and decision support system (DSS-ESI) (Salvati et al., 2013).

On top of that, the Mediterranean desertification and land use (MEDALUS) model (Kosmas et al., 1999) remains the most common and widely used method to date (Salvati, 2012) and appeared in many studies (Basso et al., 2000; Contador et al., 2009; Benabderrahmane and Chenchouni, 2010; Abdel Kawy and Belal, 2011; Basso et al., 2012; Bahreini and Pahlavanravi, 2013; Jafari and Bakhshandehmehr, 2013; Salvati et al., 2014; Symeonakis et al., 2014). It focuses on recognition of ESAs through multi-factor approaches, resting on its four quality indices namely soil, climate, vegetation and management quality that define the final environmental sensitivity area index (ESAI). Three groups of ESAs can be distinguished in this model including critical ESAs, fragile ESAs and potential ESAs (Bakr et al., 2012). As this approach is simple, highly flexible, robust, widely applicable, and adaptable to new information and updates, the standard MEDALUS model was often being modified or adjusted over the years in several studies with introduction of new parameters (Ferrara et al., 2010; Bakr et al., 2012). Despite its broad acceptance, the application of the standard or adjusted MEDALUS model is generally limited to areas experiencing desertification and land degradation (Salvati, 2012) particularly in the Mediterranean region and Western Asian countries such as Iran and Egypt.

Another ESA approach available and commonly found in literature is the GIS-based eco-environmental sensitivity evaluation. It is widely applied in many ESA studies in China (Li et al., 2003; Pan and Dong, 2006; Liu et al., 2008; Dong et al., 2011; Pan et al., 2012; Zhou et al., 2012; Wu et al., 2013) with only few in South and Southeast Asian countries such as India (Gadgil et al., 2011) and Taiwan (Huang et al., 2010). This comprehensive index method views the importance of ESAs from the broader issues of ecological functions and is generally employed in areas with reasonably large or provincial scale (Dai et al., 2012). It is also occasionally performed with a combination of other models such as LUCC method, fuzzy-matter element model and factor-overlay model (Zhang et al., 2011; Liu et al., 2012). It measures the degree of sensitivity of an area to human activity which reflects its potential for causing environmental problems (Pan et al., 2012; Xie et al., 2015). It usually comprises of ecological indicators ranging from soil condition (erosion and salinization), water condition (security), land desertification, atmospheric conditions, natural or geological disasters, natural recreation and biodiversity or habitat (Wu et al., 2013; Xie et al., 2015) in order to classify ecological sensitivity into five ESA ranks: insensitive, slightly sensitive, moderately sensitive, highly sensitive and extremely sensitive (Zhang et al., 2011; Liang and Li, 2012; Pan et al., 2012).

In Malaysia, there was no ESA evaluation index been developed prior to 2010. The concept of ESAs was initially brought into attention in the early 1990s only to provide operational framework and guideline for conservation of natural resources and the

Table 1
Groups of ESAs.

ESA functions	Definition
Heritage value	Areas that has historical, cultural or scientific value
Disaster risk	Areas that are associated with high risks of natural or man-made hazards
Life support systems	Takes into account the present and future needs of society to ensure adequate quality of life based on resources available

Source: Hashim et al. (2007) and TCPD (2010).

Table 2
ESA ranking and criteria in National Physical Plan (NPP).

ESA ranking	Ranking criteria
Rank 1	All protected areas (PA), wetlands, turtle landing sites, catchment areas of existing and proposed dams, and areas with contours above 1000 m above mean sea level
Rank 2	All other forests, wildlife corridors, buffer zones around ESA Rank 1 areas and areas with contours between 300 and 1000 m above mean sea level
Rank 3	All marine park islands, buffer zones around ESA Rank 2 areas, catchment areas for water intakes, areas for groundwater extraction (well fields), areas with erosion risk greater than 150 ton/ha/year, areas experiencing critical or significant coastal erosion and areas between 150 and 300 m above mean sea level

Source: Sime Darby (2007) and Reza and Abdullah (2010).

environment (Pereira, 2007). However, most of the times it was used to assist in the environmental impact assessment (EIA) prior to the approval of development projects (Pereira et al., 2006). This broad idea of ESAs then evolved in 1998 into ten sectoral ESAs with widened scope based on land use planning perspective (Selangor State Government, 1999; Pereira et al., 2006). Several attempts were made the years onward to harmonize various concepts and definitions relating to ESAs and enlarge the scope to incorporate other environmental aspects. Concerns were also highlighted on the need to resolve the issue of overlapping sectoral ESAs for practical implementation within the planning process as well as the need to identify sensitivity level of ESAs that would enable the setting of limits for development activities (Selangor State Government, 1999). The sectoral approach of ESAs was later clustered and modified based on the three pillars of sustainable development to be more integrated for its implementation taking into account the importance of an area from the perspective of its major functions in terms of providing life support systems (economic), heritage value (social) as well as risk associated with hazards (environment) (Yaakup et al., 2006) (Table 1).

Based on these functions, an integrated ESA evaluation index for land use planning and management was then developed in 2010 with the inclusion of new relevant indicators, ideal for application by state and local authorities. It comprises of lists of ESA elements and indicators as well as unified national grading system and detailed explanation on procedures used to conduct GIS-based environmental sensitivity evaluation (TCPD, 2010). However, until now the integrated ESA practices and evaluation are confined only to the state of Selangor (Ali and Unjah, 2010; TCPD, 2010). The use of previous sectoral ESA concept is still embedded in most regional, state or local development plans, following ESA classification and ranking specified at the federal level in the National Physical Plan (Table 2), with no specific act or policy been regulated to guide ESA management (TCPD, 2010).

The same sectoral ESA classification can also be observed in Langkawi District Local Plan 2020 (Kedah State Government, 2011b). It has been used all this while to identify ESA zones for the purpose of guiding land use planning in the islands (Fig. 1). It does to some extent bring benefits through an automatic recognition of certain areas or ecosystem as ESAs but less successful in highlighting the strength and significance of ecosystem functions and current environmental conditions and problems (Hashim et al., 2007). This has led to growing concerns on the possibilities of Langkawi losing its valuable natural and cultural heritage, geological landscape and agricultural lands, mostly due to the removal of resources in order to support economic growth (Leman et al., 2007; Mohamed et al., 2011). Furthermore, there is no sensitivity assessment has been conducted to date, to monitor the current condition of ESAs in Langkawi, to allow response measures to be made (Ali and Unjah, 2011).

2. Methodology

2.1. Study area

Langkawi is an archipelago of 99 tropical islands geographically located in the state of Kedah (spanning from 6°10′N to 6°30′N and 99°35′E to 100°E), far northwestern corner of Peninsular Malaysia, covering an area of approximately 478.4 km^2 (Fig. 1). The islands are rich in unique geological and biological heritage (Ali and Unjah, 2011; Hashim et al., 2011; Ahmad et al., 2013), ranging from rock formations that are millions of years old (the oldest being more than five hundred million years old) (Leman et al., 2007; Mohamed et al., 2011); tropical rainforests enveloping the island's hills and mountains; and clean, white sandy beaches (Norhayati et al., 2011; Rahman et al., 2012). The islands are also well known for their socio-cultural heritage narrating on history and lifestyle of four main ethnic groups – the Malays, Chinese, Indians and Siamese (Hashim et al., 2011; Liu and Halim, 2011).

Remains as one of the famous tourism attractions in the country, Langkawi houses modern and world class tourist resorts and commercial enterprises; farming villages amidst the paddy fields; rubber cultivation and fruit orchards; and fishing villages which are located along the coasts of Langkawi, Pulau Tuba and Pulau Dayang Bunting (Leman et al., 2007; Hashim et al., 2011; Rahman et al., 2012). The main island, Langkawi Island (328 km^2), holds diverse ecosystems including mangrove communities, dipterocarp forests, agricultural areas and coastal vegetation, with its highest peak, Gunung Raya, reaching 881 m above sea level (Norhayati et al., 2011). Langkawi had undergone tremendous development shift in 2007 when it was endorsed as the 52nd UNESCO Global Geopark under the Global Geopark Network (GGN), the first geopark in Malaysia and South East Asia (Komoo, 2010). This recognition has brought Langkawi into greater attention and attraction from the world's community causing the island to begin receiving frequent visits from nature-loving local and international tourists (Leman et al., 2007; Liu and Halim, 2011). Together with the picturesquely natural ecosystems and landscapes and traditionally socio-economic lifestyle of its people, Langkawi become one of the leading daylight nature-based tourism destinations and experienced a rise in local economic growth in recent years (Leman et al., 2007; Liu and Halim, 2011).

2.2. Framework for environmental sensitivity evaluation

The Malaysian integrated ESA approach and principles (TCPD, 2010) served as a basis upon which the general research framework and template for environmental sensitivity evaluation was modified and outlined in this study (Fig. 2). Whilst the Pressure-State-Response (PSR) model was used as conceptual framework to provide principles for choosing ESA elements and assessment indicators. Evaluation processes were then carried out on the platform of GIS, following examples from previous studies (Zhang

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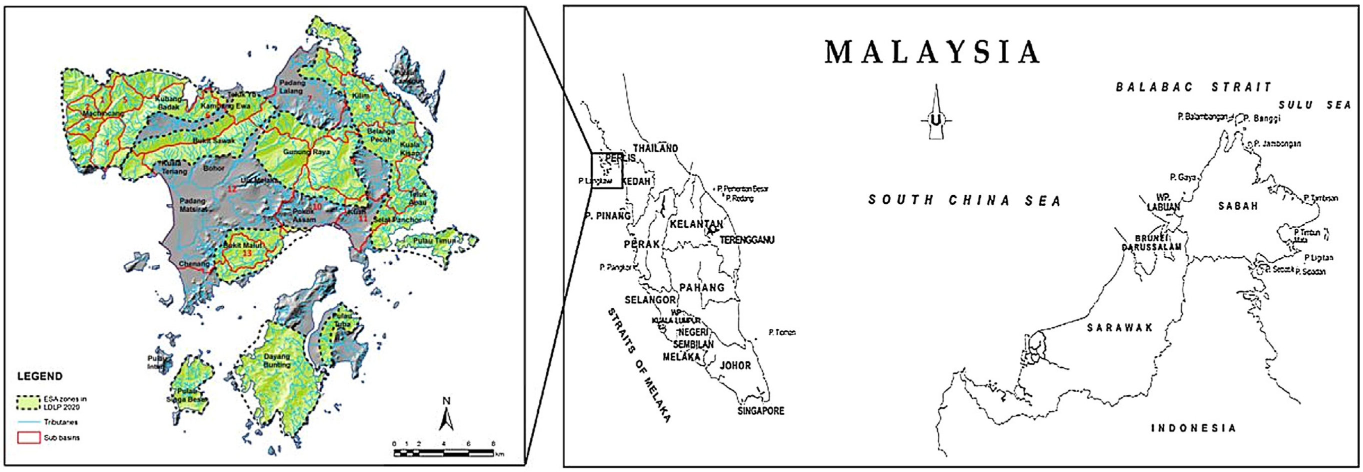

Fig. 1. Map of Langkawi.

et al., 2011; Dai et al., 2012; Liu et al., 2012; Pan et al., 2012; Xie et al., 2015). Model Builder in ArcGIS 10.1 was used to incorporate a model capable of analyzing multi-sequence sensitivity evaluation on which an integrated spatial analysis model was correspondingly designed referring to the ESA functions, elements and assessment indicators. Spatial data were collected, prepared and arranged accordingly into the model, where calculation processes took place subsequently through the application of a standard grading system formulated by TCPD (2010) and importance levels or weights determined with analytic hierarchy process (AHP) method.

For comparison purposes, two sets of assessment indicators (Set A and Set B) were prepared and used. Of these sets, the former consists of selected indicators from the Malaysian integrated ESA instrument (Table 3) (TCPD, 2010), while the latter are derived from five eco-environmental studies conducted by researchers in China (Zhang et al., 2011; Dai et al., 2012; Liu et al., 2012; Pan et al., 2012; Xie et al., 2015) but appropriately arranged into the integrated ESA model (Table 4). Eco-environmental indicators were chosen mainly due to its potential to alternatively describe and interpret ESAs from ecological point of view. ESA maps were then produced from the results generated and passed through gradual validation methods. Environmental sensitivity results were also analyzed from the perspectives of watershed management on selected river basins following recommendation made by Steiner et al. (2000). They

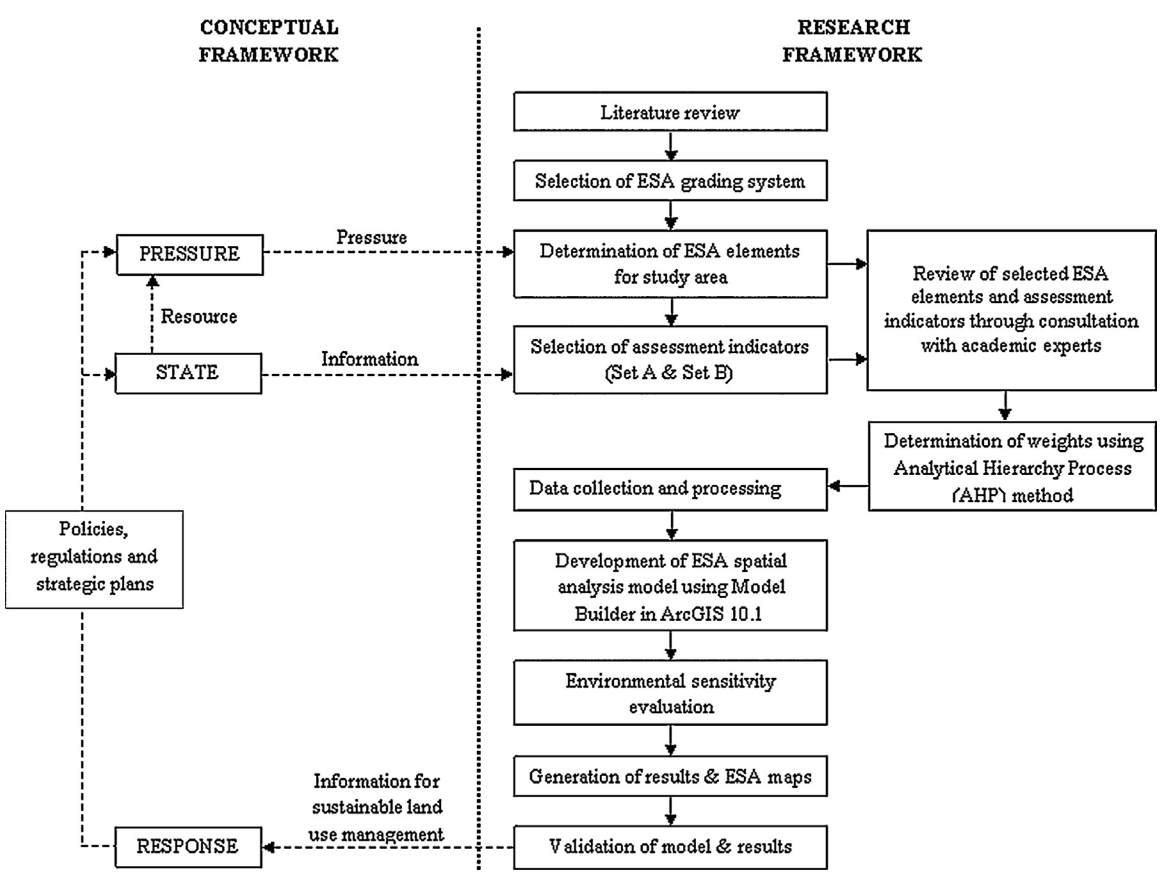

Fig. 2. Conceptual and research framework for environmental sensitivity evaluation.

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Table 3
Grading system of indicators for evaluating environmental sensitivity in Langkawi (Set A) [a]

ESA functions	Weights	ESA elements	Weights	Assessment indicators	Assigned score				Weights
					Non-sensitivity (0)	Low sensitivity (1)	Moderate sensitivity (2)	High sensitivity (3)	
Disaster risk	0.33	Topographic condition	0.25	Elevation height of $\geq$300 m (%)	<10	10–25	26–50	>50	1.00
		Landslide	0.14	Slope area of $\geq$25° (%)	<10	10–25	26–50	>50	0.75
				Soft rock/sandy soil (%)	<10	10–25	26–50	>50	0.25
		Soil erosion	0.14	High erosion potential – Levels 4 and 5 (%)	<10	10–25	26–50	>50	1.00
		Flood	0.08	Average annual rainfall (mm)	<1500	1500–2000	2000–2500	>2500	1.00
		Environmental pollution	0.25	Potentially polluted development sites (%)	<10	10–25	26–50	>50	0.33
				Pollution sources (%)	<10	10–25	26–50	>50	0.67
		Fire	0.08	Land forests (%)	<10	10–25	26–50	>50	0.25
				Bushes (%)	<10	10–25	26–50	>50	0.50
				Grass/weeds (%)	<10	10–25	26–50	>50	0.25
		Seismic tremors	0.06	Seismic tremors history	Zone I–II	Zone III–IV	Zone V–VI	Zone VII	1.00
Heritage values	0.33	Biological diversity	0.40	Forest reserves (%)	<10	10–25	26–50	>50	0.43
				Wildlife reserves (%)	<10	10–25	26–50	>50	0.19
				Special flora and fauna – Biosites	None	Low	Moderate	High	0.15
				Wetlands (%)	<10	10–25	26–50	>50	0.23
		Cultural and architectural heritage	0.20	Monuments and historical buildings	None	Low	Moderate	High	0.25
				Historical heritage sites – Culture sites	None	Low	Moderate	High	0.50
				Archeological reserves	None	Low	Moderate	High	0.25
		Natural and geological heritage	0.40	Geological monuments – Geosites	None	Low	Moderate	High	1.00
Life support system	0.33	Food resource	0.23	Paddy field (%)	<10	10–25	26–50	>50	0.75
				Other food crops (%)	<10	10–25	26–50	>50	0.25
		Water resource	0.42	Surface water bodies (%)	<10	10–25	26–50	>50	0.23
				Catchment areas (%)	<10	10–25	26–50	>50	0.43
				Aquifer (%)	<10	10–25	26–50	>50	0.19
				Groundwater abstraction sites	<1	1–2	3–5	>5	0.15
		Minerals and building materials	0.12	Rock material storage (%)	<10	10–25	26–50	>50	0.67
				Mineral deposits (%)	<10	10–25	26–50	>50	0.33
		Forest resources and functions	0.23	Multi-function forests (%)	<10	10–25	26–50	>50	1.00

[a] All assessment indicators and parameter are selected and adopted from TCPD (2010).

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Table 4
Grading system of indicators for evaluating environmental sensitivity in Langkawi (Set B) [*]

ESA functions	Weights	ESA elements	Weights	Assessment indicators	Assigned score: Non-sensitivity (0)	Low sensitivity (1)	Moderate sensitivity (2)	High sensitivity (3)	Weights
Disaster risk	0.33	Topographic condition	0.26	Elevation height (m)[c,d]	0–100	100–200	200–500	>500	1.00
		Landslide	0.26	Slope area (°)[a,c,d]	0–5	5–15	15–25	>25	1.00
		Soil erosion	0.26	Vegetation cover[a,b,c,e]	Water, swamp, paddy field	Forest, shrub	Grassland, meadow, garden	Non-vegetation, bare areas	0.33
				Vegetation coverage rate (%)[a,b]	Thick (>30)	Moderate (20–30)	Less (10–20)	Sparse (<10)	0.33
				Soil texture[a,b,d]	Gravel, sand	Clay	Loam	Silt	0.18
				Soil erosion potential[c,d]	Slight	Moderate	High	Severe, Extreme	0.16
		Flood	0.14	Average annual rainfall (mm)[a,c]	<1500	1500–2000	2000–2500	>2500	1.00
		Seismic tremors	0.08	Seismic intensity[d]	IV	V	VI	VII–VIII	1.00
Heritage values	0.33	Biological diversity	1.00	Forest coverage (%)[d]	36–78	29–36	21–29	6–21	0.43
				Distribution of wetlands and natural reserves[d]	Other areas	Fringe areas	Buffer	Core areas	0.23
				NDVI[b,d]	>0.72	0.63–0.72	0.54–0.63	0–0.54	0.15
				Biodiversity index/biosites[a,d]	None	Low	Moderate	High	0.19
Life support system	0.33	Water resource	1.00	Supply function of resource[a,d]	Other used water zone	Used water zoned of ecological forest and grass	Industrial used water zone	Used water zone of forest, fruits, animals, fishery, drinking water	0.50
				Distance to water source (m)[a,e]	>150	100–150	50–100	<50	0.50

[*] Assessment indicators and their parameters are selected and modified from:
[a] Zhang et al. (2011)
[b] Pan et al. (2012)
[c] Liu et al. (2012)
[d] Dai et al. (2012)
[e] Xie et al. (2015) and arranged into three ESA functions within the national integrated ESA model.

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were selected and preformed through automated watershed delineation on topographic map (Fig. 1), covering 13 river basins that fall within the original ESA zones in Langkawi.

2.3. Selection of indicators

Choosing proper assessment indicators and grading systems are a basis and vital for sensitivity evaluation (Zhang et al., 2011). They should reflect the current environmental problems and the strength of physical and environmental characteristics of a study area (Dai et al., 2012; Liu et al., 2012; Pan et al., 2012). In relation to this, PSR model was used as theoretical background in this study to provide hypothesis for the causal-relationships between selected ESA elements and assessment indicators. 'Pressures' on environmental elements of fundamental importance to Langkawi were first reviewed and identified based on literature as well as verified by expert panels. Available 'state' indicators in both sets were then listed for selection. Following examples from Yaakup et al. (2006), TCPD (2010) and Xie et al. (2015), the criteria for indicators selection are mainly based on the availability and operationality of data as well as their relevance to signalize current environmental conditions in Langkawi and to showcase the uniqueness of local natural ecosystems. Assessment indicators meeting these criteria were then chosen for data collection and analysis. Set A comprises of final 28 indicators from out of 52 listed in the Malaysian integrated ESA instrument (TCPD, 2010), encompassing 14 ESA elements. In contrast, only 14 assessment indicators commonly used in eco-environmental evaluation method in China were selected for Set B (Zhang et al., 2011; Dai et al., 2012; Liu et al., 2012; Pan et al., 2012; Xie et al., 2015) and accordingly adjusted into 7 ESA elements due to data limitation. The final list of assessment indicators for both sets is detailed out in Tables 3 and 4.

2.4. Determination of weights

There have been no uniform standards used to determine weights for assessment indicators to date (Liang and Li, 2012). The most common technique to underpin multi-criteria decision making is AHP and it is widely used by researchers (Huang et al., 2010; Dai et al., 2012; Wu et al., 2013; Wang et al., 2014). Whereas other varied techniques can also be found in literature including DEFINITE (Yaakup et al., 2006) and entropy method (Zhang et al., 2011; Dai et al., 2012; Wang et al., 2014). This has led to disadvantages observed in many studies in terms of subjectivity and complexity associated with the weight identification process (Su et al., 2011). Subjectivity of the decision would inaccurately reflect the environmental conditions in study area (Liang and Li, 2012). In this study, weight for each assessment indicator and ESA elements was determined with AHP technique following example from Chen et al. (2010) based on inputs from selected field experts who deal directly and regularly with current environmental issues and problems in Langkawi. These expert panels were gathered and requested to provide insights particularly related to pair-wise comparison, importance levels, ranking and hierarchy structure of the indicators and elements for further weight calculation processes using AHP (Tables 3 and 4). Emphasis on the involvement of experts was also frequently employed by other researchers including Xie et al. (2015). Liang and Li (2012) further advocates this idea by articulating that expert estimation is useful for reducing the deviation caused by subjectivity.

2.5. Data collection

This study was presented by incorporating and analyzing GIS spatial data including amongst others topography, slope, land use, geology, soil type, forest reserves and wetlands as well as statistical data such as average annual rainfall at district level that was integrated into spatially extensive data. Digital base maps in shape file format were mainly gained from local, state and national government agencies in Langkawi and Kedah, as specified in Table 5. Other maps such as the location of biosites and archeological reserves were derived and digitized from official government documents amongst others Langkawi District Local Plan 2020 (Kedah State Government, 2011b), Langkawi Geopark Management Plan 2012–2030 (LADA, 2013), Kedah Structure Plan 2002–2020 (Kedah State Government, 2011a) and Northern Corridor Economic Region Socioeconomic Blueprint (Sime Darby, 2007). Some existing maps such as heritage sites and geological monuments were also updated with additional locations digitizing based on the latest information set out in those documents. Certain information is also verified and gathered through observation on geological, ecological and physical characteristics of Langkawi. A GIS database was developed in this study to enable gathering and analysis of spatial as well as to facilitate access to spatial analysis model designed. Vector layers that are composed of points, line or polygons were first converted into raster grid format. Grid cells of 10 m × 10 m size was uniformly set and adjusted for all raster layers to harmonize maps with different scales as well as to simplify the grading process and overlay analysis in Model Builder. A Digital Elevation model (DEM) with grid size of 30 m × 30 m was also generated from contour map of Langkawi and is the basis for hydrologic modeling used in this study to delineate river basins areas.

2.6. Grading, calculation and evaluation process

Environmental sensitivity evaluation performed in this study involves GIS-based processes of grid computing, classifying, grading, overlaying, calculating and analyzing spatial data on raster layer sets using scoring standards (TCPD, 2010) and predetermined weights. First, grid data on raster layer corresponding to each indicator were categorized into four sensitivity levels respectively, derived from Malaysian integrated ESA instrument (TCPD, 2010), i.e. non-sensitivity, low sensitivity, moderate sensitivity and high sensitivity with an assigned score of 0, 1, 2 and 3 (Tables 3 and 4). Calculation was then performed for every grid cells based on the weights of each assessment indicator through superposition analysis to obtain the sensitivity value and grading result of ESA elements. The same calculation and analysis processes were continued onwards using the weights of ESA elements and functions to obtain final sensitivity value and grade of the study area based on the following formula (TCPD, 2010; Zhang et al., 2011; Dai et al., 2012):

$$SV_j = \sum_{i=1}^{\delta} IL_i \times r_{ij} \quad (i = 1, 2, 3;\ j = 1, 2, \ldots, n)$$

where SV_j is the final sensitivity value for the jth unit, IL_i is the importance level of the ith ESA function R_i, and r_{ij} refers to the sensitivity value of R_i for the jth unit, which is determined using similar formula:

$$r_{ij} = \sum_{S_k \in R_i} IL_k \times S_{kj}$$

for $S_k \in R_i$ ($i = 1, 2, 3$; $j = 1, 2, \ldots, n$) is used for both Set A and Set B, where IL_k is the importance level of the kth ESA element S_k corresponding to ESA function R_i, and S_{kj} refers to the sensitivity value of S_k for the jth unit, which is again determined using similar formula:

$$S_{kj} = \sum_{T_m \in S_k} IL_m \times t_{mj}$$

Table 5
Source of GIS and statistical data.

Source	Type of data	Year
Department of Survey and Mapping Malaysia	Topography, slope	2012
Town and Country Planning Department of Peninsular Malaysia	Land use	2010
Mineral and Geoscience Department Malaysia (Kedah/Perlis/Penang)	Geology, minerals, aquifer	2010
Department of Agriculture, Kedah	Soil type, erosion, agriculture	2010
Kedah State Forestry Department	Forest reserves, wetlands	2010
Department of Wildlife and National Parks, Kedah	Wildlife reserves	2008
Department of Irrigation and Drainage Malaysia, Kedah	Rivers, dams, flood	2010
Department of Environment, Kedah	Rainfall	2013
Langkawi Development Authority	Land use	2010
Langkawi Municipal Council	Land use	2010

for $T_m \in S_k$ ($k = 1, 2, \ldots, 28$; $j = 1, 2, \ldots, n$) is used for Set A, for $T_m \in S_k = (k = 1, 2, \ldots, 14$; $j = 1, 2, \ldots n)$ is used for Set B, where IL_m is the importance level of the mth ESA indicator T_m corresponding to ESA element S_k, and t_{mj} refers to the sensitivity value of T_m for the jth unit. The overall analysis processes for both Set A and Set B were carried out using the Model Builder in ArcGIS 10.1. Final sensitivity value, grade and results were then projected onto ESA maps of the study area.

2.7. Validation of models and results

Evaluation model used in this study as well as the projected ESA maps were validated by passing through map spatial comparison procedures. Hagen (2002) stressed that these procedures are important for validation and calibration of spatial model's efficacy in producing reliable maps. Among them, Kappa index of agreement for categorical data is the much frequently adopted statistical analysis for GIS application and considered as a useful measure of classification accuracy (Caeiro et al., 2003). Kappa statistics is particularly used to evaluate and compare similarity or magnitude of difference on a grid size level between two categorical thematic maps. The level of agreement derived from the comparison is expressed in the form of overall single value of similarity (between 0 and 1) indicating poor to almost perfect agreement. Hence, Kappa statistics was used in this study to analyze similarity between the previous ESA zones in LDLP 2020 (Fig. 1) and the two projected ESA maps (Set A and Set B). These validation processes were performed using SPSS 22.0.

Other than that, Whinam et al. (2003) emphasized that every assigned sensitivity classes must be supported by ground-testing to ensure accuracy. Thus, ESA maps projected in this study were also subsequently and visually inspected by expert panels to ensure consistency of results and are going through ground truthing processes gradually to allow comparison and validation with field data. Three main phases were focused and briefly described in Fig. 3 in order to frame and ensure continuity of the processes. However, only Phase 1 will be covered in this study since we are currently in the process of collecting and analyzing field data (e.g. aerial photo, water quality) particularly related to the important base maps used in this study (e.g. elevation, slope, forest reserves, geosites, water resources) to determine sensitivity borders. Therefore, two ESA zones in Langkawi Island were selected for preliminary analysis namely Machincang-Kubang Badak and Kilim-Selat, where series of preliminary field surveys and observation works were then conducted through close collaboration with field experts, local agencies and local community to map current environmental problems, locations of important resources and people's environmental priorities. Scientific information, research findings and related news were collated to identify and provide overview of characteristics or criteria that contribute toward sensitivity within the two areas.

3. Results

3.1. Spatial distribution of ESAs based on functions

It is observed from the projected maps of both sets (Fig. 4a and b) that highly sensitive areas in relation to disaster risk are widely distributed at hilly and mountainous ecosystems of the three Geoforest Parks namely Machincang Cambrian, Kilim Karst and Dayang Bunting as well as Gunung Raya and Bukit Sawak, covering 13.47% (63.25 km^2) and 9.73% (46.61 km^2) of the total area in Set A and Set B respectively (Table 6). These are areas either at higher elevation (>300 m) or constitute high erosion potential with slope degree of more than 25°. It is then followed by moderate sensitivity areas surrounding or near to the highly sensitive areas, accounting for more than 30% of the total land area in both Set A (190.28 km^2) and Set B (158.81 km^2). The results also indicate more or less the same low sensitivity level observed from both maps, accounting for nearly 200 km^2 plain areas in the middle part of Langkawi Island, outspreading from Pokok Assam, Ulu Melaka, Chenang and Bohor to the large area of Padang Matsirat. In terms of heritage value, the results show that large proportion of the land area in both assessment sets are highly sensitive, occupying areas of 232.43 km^2 (49.51%) and 245.10 km^2 (52.21%) in Set A and Set B respectively (Fig. 4c and d, and Table 6). Among areas that fall into this category include protected forest reserves at three Geoforest Parks, Gunung Raya, Bukit Sawak and Bukit Malut; wildlife reserves at Pulau Singa Besar; and additional areas facing north in Set A from Padang Lalang and Teluk Yu to Kampung Ewa.

This is mainly due to the biologically rich and diverse forest ecosystems as well as mangrove areas that serve as natural habitat for many species located within these areas. However with less indicators used in Set B, the results indicate clear distinction between the proportion and size of areas classified into moderate sensitivity, low sensitivity and non-sensitivity among those two sets. 31.44% of the total land area (147.59 km^2) in Set B is classified as not sensitive due to the fact that the indicators used are limited only to matters related to biological richness. In contrast to that, more areas in Set A are observed with moderate sensitivity, accounting for 19.91% (93.49 km^2) of the total area, taking into account the denseness of additional invaluable geological and cultural heritage sites.

Unlike the two ESA functions, different results are portrayed in Fig. 4e and f, referring to areas that provide natural resources for people's socio-economic life. Less areas of high sensitivity are revealed, representing not more than 10.00 km^2 or 2.00% of the total land area in both assessment sets (Table 6). More areas with lower sensitivity level (287.40 km^2 or 61.22% of total area) are distributed across Langkawi with only small proportion of moderately sensitive areas (38.37 km^2 or 8.17% of total area), found in the middle part of the main island, comprising of paddy fields at Ulu Melaka and catchment area near Padang Matsirat in Set A. Similar observation also occurs in Set B, where approximately 433.61 km^2 or

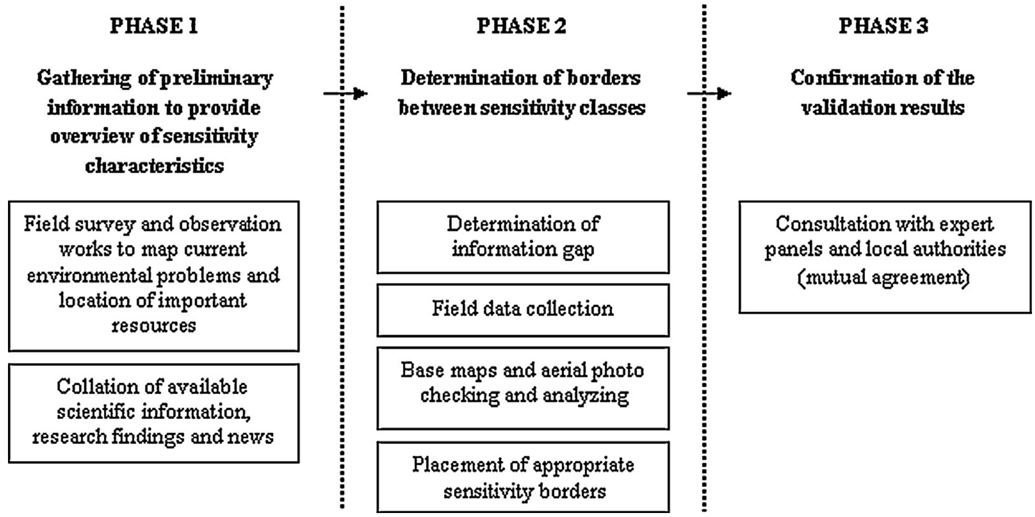

Fig. 3. Phases of ground-truthing processes.

Table 6
Results of environmental sensitivity evaluation in Langkawi based on ESA functions.

ESA functions	Classification	Set A		Set B	
		Areas (km^2)	Percentage of total area (%)	Areas (km^2)	Percentage of total area (%)
Disaster risk	High sensitivity	63.25	13.47	46.61	9.93
	Moderate sensitivity	190.28	40.53	158.81	33.83
	Low sensitivity	193.76	41.27	188.18	40.08
	Non-sensitivity	22.20	4.73	75.86	16.16
Heritage value	High sensitivity	232.43	49.51	245.10	52.21
	Moderate sensitivity	93.49	19.91	41.17	8.77
	Low sensitivity	108.06	23.02	35.59	7.58
	Non-sensitivity	35.51	7.56	147.59	31.44
Life-support system	High sensitivity	8.76	1.87	8.54	1.82
	Moderate sensitivity	38.37	8.17	14.14	3.01
	Low sensitivity	287.40	61.22	13.22	2.82
	Non-sensitivity	134.95	28.74	433.61	92.35

92.35% of the total land area are classified as non-sensitivity and 13.22km2 or 2.82% as low sensitivity respectively, resulting from the used of indicators specifically limited to water zones.

3.2. *Integrated ESA maps of Langkawi*

The overall spatial distribution and zoning of environmental sensitivity in Langkawi are illustrated in Fig. 5 (Set A) and Fig. 6 (Set B). It can be seen from both ESA maps that high sensitivity areas are mainly distributed at five major forest reserves locations in Langkawi namely Machincang Cambrian Geoforest Park, Kilim Karst Geoforest Park, Dayang Bunting Geoforest Park, Gunung Raya and Bukit Sawak, accounting for about 141.24 km^2 or 30.08% of the total land area in Set A and 46.40 km^2 or 9.88% in Set B respectively (Table 7). Additional highly sensitive areas are also observed at Pulau Singa Besar, Pulau Tuba and near Bukit Malut, partly influenced by existing diverse forest ecosystems within the areas. Whereas, nearly half of the land area in both ESA maps is occupied by moderate sensitivity areas acting as buffer zones surrounding these highly sensitive ecosystems, covering areas of 197.91 km^2 or 42.16% of the total land area in Set A and 212.64 km^2 or 45.30% in Set B respectively, up from the middle to northern part of the main island. On the other hand, the results also indicate lower level of environmental sensitivity in Set A (117.42 km^2 or 25.01% of total land area) or non-sensitivity in Set B (123.02 km^2 or 26.20% of total land area) at the southern part of the island, outspreading from the large areas of Ulu Melaka and Bohor to Padang Matsirat. These are mostly plain areas that have undergone rapid development and favor multiple agricultural practices.

Viewing from the perspective of watershed management, environmental sensitivity at selected river basins in Langkawi Island is slightly different between the two assessment sets. Zonal statistics analysis performed on the results showed that at least 10 river basins at core areas in Set A are classified as highly sensitive leaving only 3 river basins near Kuah, Pokok Assam and Bukit Malut, which are considered as moderately sensitivity (Fig. 7a). In contrast to that, not more than 5 high sensitivity river basins are observed in Set B (Fig. 7b) mainly at Machingcang Cambrian Geoforest Park, with another 4 are classified as less sensitive (near Kubang Badak, Kilim, Padang Lalang and Belanga Pecah) and 4 as not sensitive (in the middle part of Langkawi).

Table 7
Final results of environmental sensitivity evaluation in Langkawi.

Assessment sets	Classification	Area (km^2)	Percentage of total area (%)
Set A	High sensitivity	141.24	30.08
	Moderate sensitivity	197.91	42.16
	Low sensitivity	117.42	25.01
	Non-sensitivity	12.92	2.75
Set B	High sensitivity	46.40	9.88
	Moderate sensitivity	212.64	45.30
	Low sensitivity	87.39	18.62
	Non-sensitivity	123.02	26.20

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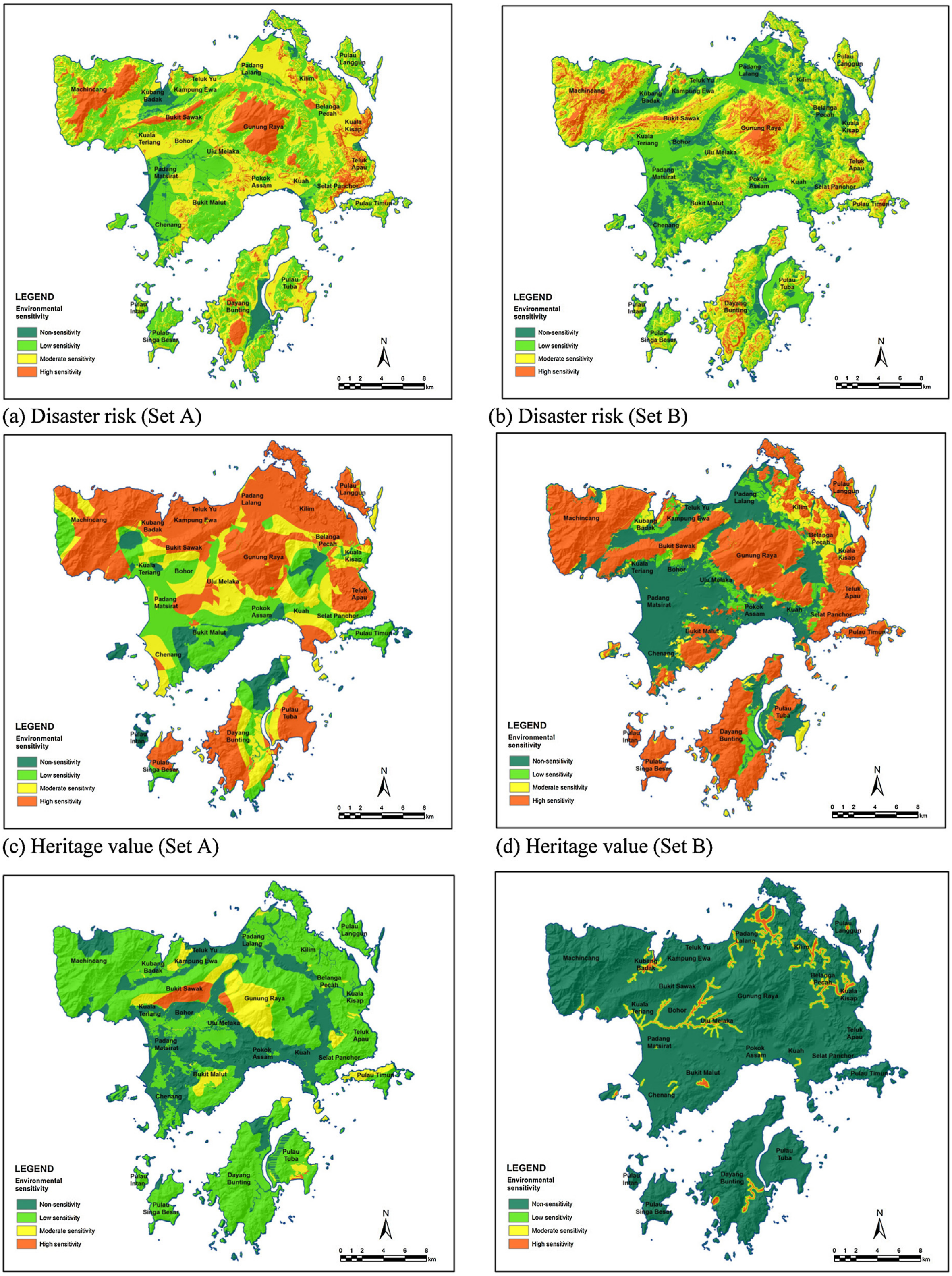


(a) Disaster risk (Set A)
(b) Disaster risk (Set B)
(c) Heritage value (Set A)
(d) Heritage value (Set B)
(e) Life-support system (Set A)
(f) Life-support system (Set B)

Fig. 4. Environmental sensitivity map of Langkawi based on ESA functions.

In terms of map similarity, visually observed results of Set B reflect relatively matching patterns and distribution of sensitivity when compared to the original ESA zones in LDLP 2020 (Fig. 6). Spatial distribution of moderate and high sensitivity areas are seen to be centered in eight zones. This was further confirmed statistically with result derived from the analysis of Kappa value. The result indicates moderate strength of agreement on the similarity between the two maps ($K = 0.54$, $p < 0.001$). This finding however was expected mainly due to mechanism used in both maps were largely revolved on ecological perspectives despite the use of

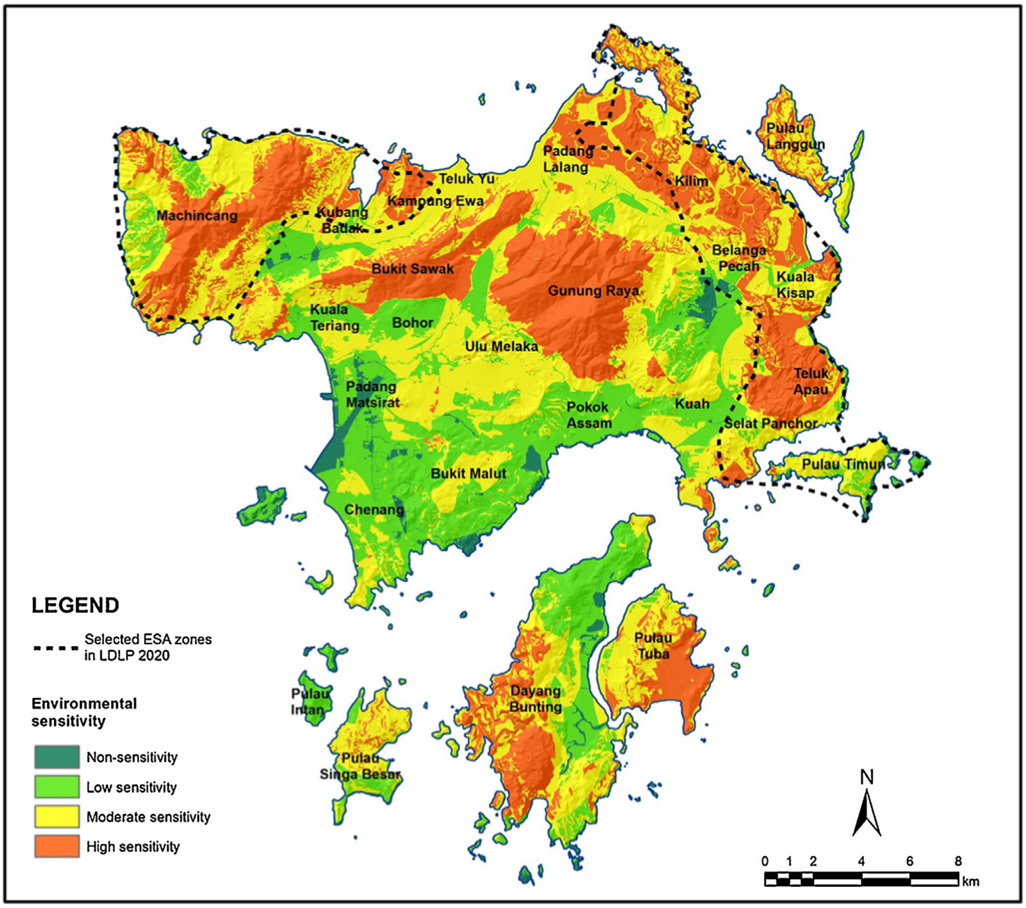


Fig. 5. Integrated ESA map of Langkawi (Set A).

different indicators and criteria. On contrary, slightly different results and patterns are portrayed in Set A (Fig. 5) where additional sensitivity areas are distributed up from the middle to northern part of the main island apart from the eight ESA zones. Kappa value also shows fair agreement on the similarity between projected Set A map and the original ESA zones in LDLP 2020 ($K = 0.34$, $p < 0.001$). The use of additional different indicators from various environmental aspects arguably has contributed toward higher magnitude of difference between the two maps. However, the difference observed in Set A provides useful opportunity for better understanding on how the current environmental problems and concerns in Langkawi have determined and shaped the sensitivity borders.

Therefore, the projected final ESA map in Set A is also used for ground truthing purposes, to ensure consistency of results with the field data. Overview of some characteristics that may contribute toward sensitivity was constructed during Phase 1 of the ground truthing processes using the preliminary findings from series of field surveys and observation works. It was conducted at two selected ESA zones and was being updated with various research findings and studies conducted by Leman et al. (2005), Wong (2008), Ali et al. (2010), Wan Juliana et al. (2010), Norhayati et al. (2015) and Ali et al. (2015). This overview indicates some dominant environmental elements that constitute the uniqueness of the local ecosystems and play important roles in continuously providing services to the community, as specified in Table 8.

4. Discussion

There is yet to be a universal environmental sensitivity evaluation index system or model for application at national, state, provincial, city or district levels (Liu et al., 2012). Regardless various ESA approaches applied, Jia and Zhang (2006) suggested that index used in sensitivity evaluation should considers and be based on physical, natural and environmental characteristics of the study area. On top of that, it should also reflect and provide insights on the current local environmental problems and concerns (Yaakup et al., 2006; Dai et al., 2012; Liu et al., 2012; Pan et al., 2012).

As previous studies conducted in Malaysia were mostly focusing only on a single environmental element such as landslide and soil erosion (Ramli et al., 2005; Mukhlisin et al., 2010), environmental sensitivity evaluation performed in this study on two different assessment sets was indeed designed and intended to provide example and to find the better ESA approach and method that are able to showcase the uniqueness and functions of ecosystems in Langkawi. As both ESA maps projected in this study roughly show different distribution of environmental sensitivity classes, it proves that selection of appropriate assessment indicators is a vital part of sensitivity evaluation, as similarly suggested by Dai et al. (2012). Different indicators used will deliver new perspective for land use planning, but often it could also lead to misinterpretation of the actual state of the environment if unsuitable indicators and grading system are used (Xie et al., 2015).

Based on the results, this study argues that Set B is less favorable and suitable to be adopted for Langkawi due to several reasons. Firstly, the indicators are generally used in different context. Most studies in China were conducted from the perspective of maintaining ecological functions rather than environment as a whole and often emphasized on fundamental natural elements such as water, atmosphere, land and habitat. As stated by Dai et al., 2012, these studies neglected the interaction between other correlative economic, cultural and eco-environmental factors. This has resulted

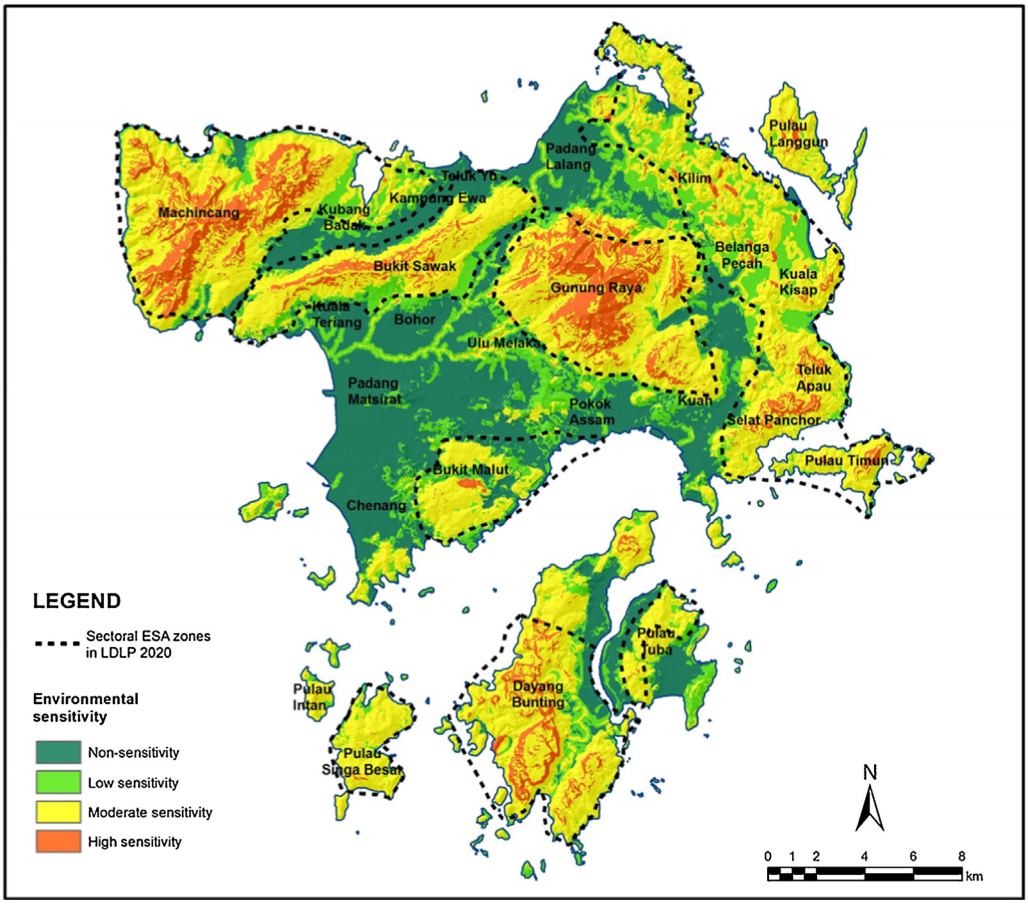
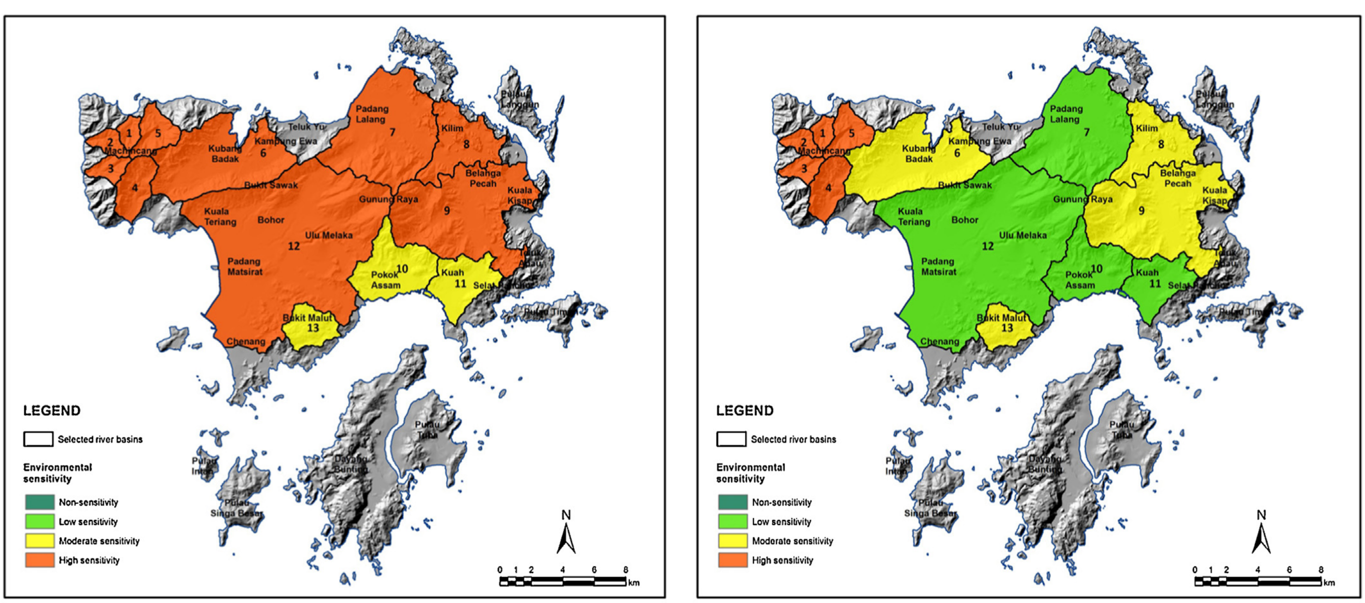


Fig. 6. Integrated ESA map of Langkawi (Set B).

in limited distribution of highly and moderately sensitive areas, observed only at forest ecosystem areas in Langkawi. It has also led to the portrayal of ESA map (Fig. 5) that was quite similar to the original sectoral ESA used in the Langkawi District Local Plan 2020, covering all eight ESA zones. Secondly, the list of indicators used in those studies was also limited. Most evaluation model and instrument in China comprised of not more than 15 indicators. It has led to difficulties in arranging them equally into the three ESA functions. Majority of the indicators used fitted into 'disaster risk' functions and its respective elements. Apart from that, no indicators



(a) Set A (b) Set B

Fig. 7. Environmental sensitivity map of selected river basins at Langkawi.

Table 8
Overview of environmental sensitivity characteristics in selected ESA zones.

ESA functions	Environmental sensitivity characteristics	
	Zone 1: Machincang-Kubang Badak Total area: 62.96 km^2	Zone 4: Kilim-Selat Panchor Total area: 81.13 km^2
Environmental risk	•Comprises of mountainous landscapes with the sequence of sandstones interbedded with siltstones, mudstones and conglomerates •Highest peak reaches 708 m above sea level with steep landscapes and near-vertical slopes •Consists of weak areas that are highly vulnerable to weathering and erosion at the peak area as well as wave erosion at the rocky beach area •Situated in the equatorial zone which experiences high rainfall events (average annual rainfall is 2413.3 mm) and high temperatures (between 27.5 °C and 29.8 °C) •Low bifurcation ratio in few river basins indicates a high probability for local flood episodes •Development of premium hotels and luxury villas could potentially cause pollution	•Comprises of karst landforms made of limestone, sandstone and shale •Steep surface, near-vertical limestone hills and overhanging cliffs are the dominant features •Consists of areas that are vulnerable to erosion by ground water, surface runoff and waves •Experiences high rainfall events (average annual rainfall is 2548 mm) and high average temperatures (27.2 °C) •Mangroves ecosystems act as natural coastal defence from high waves and heavy storms •Increasing human activities and boat traffic could potentially cause significant adverse environmental impacts
Heritage value	•One of the oldest regions in Southeast Asia, consists of the oldest rock formation (Machincang Formation) in Malaysia (550 million years old) •High seascape diversity including sea-fountains, sea-cliffs, sea-scarps, sea caves, headlands, remnant islands, rocky beaches and sandy beaches •High mountainous landscape diversity including crested ridges, deep narrow gorges, valleys, steep cliffs, pinnacles and waterfalls •High number of identified and potential geosites and biosites •Presence of trace fossils and numerous trilobite and brachiopod fossils •Consists of mangroves, virgin forests, recreational forests and forest reserves including the Machincang Cambrian Geoforest Park •Natural habitat for high diversity of plant and animal species •Existence of unique and rare mountain plants species including 11 endangered species and 27 Peninsular Malaysian endemics species •Existence of unique and rare animal species such as Great hornbill (*Buceros bicornis*) and threatened animal species such as *Limnonectes blythii* •Existence of legendary sites such as Telaga Tujuh and Pasir Tengkorak	•Consists of the oldest carbonate rock formation (Setul Formation) in the region (490–370 million years old), Singa and Chuping Formation •Various karstic and coastal landscapes that are of great value for scientific study such as pinnacles, caves, lakes, limestone hills and cliffs •High fossil diversity including trilobites, gastropods, brachiopods, byrozoans, cephalopods, bivalves, graptolites, crinoids and cnidarians •Coexistence of coastal karst and mangrove ecosystem (the only place in Malaysia) •High number of identified and potential geosites and biosites •Consists of pristine mangroves and forest reserves including the Kilim Karst Geoforest Park •Natural habitat for high diversity of plant and animal species •Unique and rare plants species such as Limestone cycad (*Cycas clivicola*) •Unique and rare animal species such as Brown kingfisher (*Halcyon amauroptera*) •Existence of areas with Malay traditional vernacular house built in 1950s •Existence of legendary sites such as Gua Cherita
Life support resources and systems	•Contains five main river basins namely Datai, Tama Kecil, Tama Besar, Perangin and Temurun •Perangin river basins serves as the main source of water supply in Langkawi Island through water storage plant located at Telaga Tujuh •Exceptional quality of beautiful clear quartz crystals •Abundance of ground herbs species •Ideal for nature recreational and ecotourism activities •Consists of tourism hotspots that support generation of socio-economic incomes for the local community	•Contains three main river basins namely Kilim, Ayer Hangat and Kisap •Potential additional source of water supply for Langkawi •Existence of traditional agricultural practices of paddy growing and rubber tapping •Existence of traditional cottage industry of harvesting sea cucumber by the local fishing community •Ideal for nature recreational and ecotourism activities •Ecotourism is the major source of socio-economic incomes for the local community

related to geological and cultural heritage elements were found, with most of them measured heritage value only from the perspective of biological aspects. In terms of providing life support services, there was also limited indicators related to water functions, with no emphasis was given on agricultural or food, mineral or forest resources. Thirdly, the projected ESA map does not represent the real assessment mechanisms applied in those studies, as most listed indicators and some relatively new desirable indicators are unable to be selected and used for Langkawi due to data unavailability.

Whereas Set A, theoretically fits well with Langkawi and germane for highlighting environmental characteristics of the islands within the Geopark concept and aspirations. The results successfully reveal different type of map from wider environmental perspective and point out the strength and uniqueness of Langkawi's diverse natural and cultural heritage. It covers majority of the previously identified ESA zones, while areas essential in providing environmental services and goods are also adequately highlighted in the map. It reasonably represent the current environmental sensitivity of Langkawi in a broader scope that could lead to better understanding of the trade-offs between development activities and the need to preserve and conserve valuable sites. This study argues that evaluation template and mechanism used in Set A could be considered for future land use planning in Langkawi, preferably with several improvements.

First, the selection of ESA elements and indicators should be revised with greater consideration on their relevance to Langkawi. For example, elements related to fire, seismic intensity and mineral deposits that received lower importance level in this study could be removed, as less indicators used will result in a more precise ESA map (Pereira et al., 2006; Hashim et al., 2007). Second, the target for parameters used in the grading system should not be based only from the perspective of river basin (Pan and Dong, 2006). In relation to this, it can be observed that most parameters are applied in terms of percentage of an area to facilitate analysis in the context of river basin boundary. For example, 'percentage of areas with slope >25°' is used for grading the landslide sub-elements. However, this type of parameters always tends to give the same score or value for every single grid cells in a river basin and may not present the actual condition. Instead, different parameters that are more comprehensive could be considered for grading the same elements such as '0–10°, 10–20°, 20–25° and >25°', as applied by Zhang et al. (2011). Such parameters are frequently used, preferable and will generate a more accurate result since every grid cells is given the exact score and they reflect the actual condition on the ground. Third, the instrument should also consider additional new or common indicators that are widely used at the international level (Zhang et al., 2011). In relation to this, most studies conducted abroad used vegetation cover as one of their main indicators to assess disaster risk (Zhang et al., 2011; Liu et al., 2012; Dai et al., 2012; Xie et al., 2015) and thus, it could also potentially be used in the future sensitivity analysis. Despite all these improvements, this study agrees on suggestion by Steiner et al. (2000) that planning of ESAs should be conducted from the perspective of watershed management. Most environmental management concepts at present are geared toward maintaining the quality of the environment and achieving sustainable development at a watershed or basin scale. Hence, it would also be beneficial if the management of ESA is aligned with those concepts, as this will better facilitate protection and conservation efforts within and around ESA (Basso et al., 2012; Salvati, 2012). As stated by Pan and Dong (2006), strengthening environmental management at a basin scale is a prerequisite for achieving social and economic sustainability.

In terms of spatial analysis technique, this study shows that GIS is a useful and convenient tool applicable for environmental sensitivity evaluation by efficiently collecting, storing, processing, transforming, mapping and analyzing spatial data from the real world (Yaakup et al., 2006; Mukhlisin et al., 2010). GIS was able to quickly and accurately extract a variety of basic environmental data and information, generate and update thematic maps of different factors as well as present complex scientific data in a user-friendly format (Zhang et al., 2011).

ESA classification can be a very useful tool for the local authority to practice sustainable land use planning and zoning when categorized based on integrated environmental sensitivity evaluation. It provides beneficial information for reasonable rearrangement of development strategies within sensitivity areas to steer development away from fragile ecosystems and promotes effective utilization of the natural resources. Negative impacts caused by anthropogenic disturbances could also be further minimized as well as ecosystem functions are strengthened to support socio-economic growth. It is holistic in approach and provides reasonably alternative for local decision makers to enhance land use management.

Thus, the sensitivity evaluation carried out in this study could provide early scientific inputs for local planners in moving toward it. The areas of high sensitivity, moderate sensitivity, low sensitivity and non-sensitivity distributed across Langkawi resulted from the evaluation process should then serve as guidance for them in determining the types of development activities that may be considered in the future. Multiple types of development zones such as prohibited, restricted, optimized, general or key development zones can be constructed based on this classification as well as physical, biological and cultural characteristics of the areas. Appropriate zoning of agricultural areas, industrial zones and human settlement areas could also be made. Areas that are of great significance in preserving the diversity, continuity and functionality of the ecosystem should be maintained to ensure the stability of natural landscape and surrounding environment. Conservation efforts should also be emphasized to preserve these valuable natural resources for the benefits of current and future generations.

5. Conclusions

Langkawi has experienced rapid development resulting from the growing tourism industries and extensive local economic growth. More areas are expected to be further developed in the future surpassing the island's carrying capacity in order to cater the tourism demand and to prosper additional socio-economic income of its people. Despite of great devotion to prevention and restoration, the trend of environmental deterioration has not been effectively managed through the use of sectoral ESA concept in current land use planning. As new integrated ESA approach has yet to be adopted by local planners in Langkawi, environmental sensitivity evaluation is a pressing need to halt further irrational damages.

Environmental sensitivity evaluation performed in this study on two different assessment sets was indeed designed and intended to provide example and to find the better ESA approach and method that are able to showcase the uniqueness and functions of ecosystems in Langkawi. The projected final ESA maps indicate and reflect spatial distribution of four environmental sensitivity classes: high sensitivity, moderate sensitivity, low sensitivity and non-sensitivity, for the entire areas. Taking into consideration the natural and cultural characteristics of the islands, it is suggested that Set A is a better ESA approach for Langkawi and should be widely considered in directing future development activities. It portrays current environmental concerns and appropriately highlights the current local environmental problems from a wider environmental perspective as well as fits Langkawi's aspiration in becoming sustainable, world-class Global Geopark. It also successfully showcases the strength and synergy between environmental functions of the various ecosystems as well as natural, geological and cultural characteristics of Langkawi.

The results offered direction into how development activities should be oriented within these zones. Rearrangement of development strategies can be made by the local planners as well as planning and zoning of principal functions in order to promote sustainable land use planning and management. The management of integrated ESAs incorporates the concept of conservation, optimization of resource use and controlled development. Since the current Langkawi District Local Plan is expected to be revised in 2015, this study offers opportunity and provides scientific input and reliable information for making appropriate planning and management measures as well as conservation strategies in protecting and preserving Langkawi's ecosystems and resources. Sustainably managing and protecting ESAs will not only preserve the ecosystems but at the same time will secure the livelihoods, socio-economic and socio-cultural of local communities in Langkawi. It will also maintain their uniqueness as an important natural heritage to be enjoyed by the current and future generations.

Ultimately, this study represents an early step for the design of universal ESA instruments, highlighting the need of site-specific indicators selection for the production of scientifically rigorous and politically-relevant assessments in order to regulate local development activities and promote sustainable land use planning in vulnerable areas at global levels.

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