



## Article

# Application of Multi-Criteria Decision-Making Model and Expert Choice Software for Coastal City Vulnerability Evaluation

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**Abstract:** Climate change is regarded as a serious threat to both environment and humanity, and as a result, it has piqued worldwide attention in the twenty-first century. Natural hazards are expected to have major effects in the coastal cities of the globe. At the same time, about two-thirds of the world's human population lives in the coastal margins. One of the fundamental issues for coastal city planners is the coastal cities' environmental change. This paper presents the application of a model framework for the management and sustainable development of coastal cities under a changing climate in Kuala Terengganu Malaysia. The analytic hierarchy process (AHP) is performed in the Expert Choice software for coastal city hazard management. This approach enables decision-makers to evaluate and identify the relative priorities of vulnerability and hazard criteria and sub-criteria based on a set of preferences, criteria, and alternatives. This paper also presents a hierarchy erosion design applied in Kuala Terengganu to choose the important sustainable weights of criteria and sub-criteria as well as the zone as an alternative model.

**Keywords:** MCDA; sensitivity; climate change; erosion; coastal city



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## 1. Introduction

Climate change is often regarded as the world's most persistent environmental concern in the twenty-first century. At the same time, almost two-thirds of the world's population lives along the shore [1]. Any long-term significant change in the average weather experienced by a specific location is referred to as climate change. The term "average weather" refers to average precipitation, temperature, and wind patterns. It includes changes in atmospheric variability or average across timescales spanning from decades to millions of years [2]. Coastal city regions are always undergoing broad changes in shape and morphologic characteristics due to natural processes such as heavy rainfall, waves, wind, sea level rise, erosion, flood, and human activity [3]. Furthermore, expansion along cities' coastlines has resulted in issues such as increasing erosion, siltation, flooding, loss of coastal resources, and harm to the sensitive marine ecosystem [4]. Because of coastal zone management (CZM) and the creation of climate change impact assessments, coastal zone susceptibility to hazard is an important topic for study, according to [5].

Uncertainty in projecting climate remains one of the barriers to managing changes in the coastal environment caused by global warming, according to many coastal planners [6]. Similarly, uncertainties arising from human aspects of global change have a substantial influence on the evaluation and response to climate change consequences such as sea-level rise, flooding, and erosion [7]. Nonetheless, in order to create suitable adaptation

measures that would limit the possible consequences of sea level rise on coastal cities, a comprehensive evaluation of the effect of sea level rise on the coastal city is necessary [8,9]. The knowledge of coastal city vulnerability raises scientists' and policymakers' capability to forecast the effect which might arise because of a rise in sea level as well as other climate change effects. Thus, it might assist in prioritizing the efforts of management which should be taken in order to decrease risks or its possible effects [10].

Because of climate change, the increase in global sea levels that happened in the twentieth century might likely accelerate in the twenty-first century and beyond; however, the degree of acceleration is unknown [11]. According to research on long-term sea level rise, the rate of global sea level increase caused by climate change is +3.32 mm/year [12]. Despite the expected significant scale of the consequences of sea-level rise [13], it is emphasized that the application and effectiveness of adaptation remain enormous uncertainties that demand further attention and evaluation. Variations in sea level, wave conditions, and river flow caused by climate change are expected to have an impact on the stability of the world's hundreds of tiny tidal inlets [14].

Littoral transport, sediment supply, and secular sea-level fluctuations are all variables that impact long-term coastal city changes [15]. Furthermore, due to river mouth processes, near-shore hydrodynamics, the structure of coastal landforms, and storm surges, the coastline undergoes recurring alterations [16]. Human activity in the coastal area inside watersheds, river catchments, and offshore is another element that promotes coastal city erosion [17]. The current beach sediment transport through littoral drift in Peninsular Malaysia's east coast is caused by the oblique technique of south-westward-directed sea swell and waves emanating from the South China Sea during the period of the northeast segments, and the existence of near shore islands and coastline protrusions, according to the conclusion of [18] regarding sediment transport in Kuala Terengganu. This sort of inlet is prevalent in developing countries, where data availability is typically sub-optimal and community resilience to coastal changes is low, due to its presence in tropical and sub-tropical zones [14]. Coastal erosion is generally exacerbated by a mix of human activity and natural factors, notably development in coastal regions [19]. One of these risks is coastal erosion, which is defined as an undesirable landward shift of the coastline [20]. Coastal erosion caused by rising sea levels is a major problem in Malaysia, according to some research [21], because the country has a long coastline and numerous cities located along the ocean. The major sources of erosion along the coastline are natural processes and human activities, both of which can have significant consequences for the natural environment and socioeconomic situations in coastal areas [22].

The coastline of Peninsular Malaysia spans for over 4800 km and is rich in natural coastal resources [23]. From November 1984 to January 1986, the Malaysian government conducted a study on national coastal erosion, which found that erosion had impacted about 29 percent of the country's coastline, or 1380 km [24]. Along the eastern coast of Peninsular Malaysia, particularly the location of the South China Sea, flooding and coastal erosion constitute severe problems [25]. Nonetheless, in order to create suitable adaptation measures that would limit the possible consequences of sea level rise on the coastal zone, a holistic evaluation of the effect of sea level rise on the coastal zone is necessary. Flooding, coastal erosion, and shoreline alteration are major issues along Peninsular Malaysia's eastern coast, particularly in the South China Sea [26]. Flooding has always happened in Terengganu, which is located on Peninsular Malaysia's east coast, according to [27,28]. Floods, for example, occur often every year in Terengganu's Dungan region, especially when the river level reaches a few meters beyond the danger threshold. highlighted that flooding has always occurred in Terengganu, which is located on Peninsular Malaysia's east coast. For example, floods occur often every year in the Dungan district of Terengganu state, especially when the river level rises a few meters beyond the danger threshold. Dungun was badly flooded by a monsoon flood in 2012, caused by significant rains, and the region was inundated by flood water as high as 1.5 m [29]. The floods were caused by either direct river flow or tidal surges from the ocean [30,31]. According to [32], about 70%

of Terengganu is categorized as a low-lying coastal territory with a height of less than 200 m, and around 30% of the area is prone to flash floods.

Due to the northeast monsoon's stronger effect in comparison to the southwest monsoon, Peninsular Malaysia's east coast is more sensitive to environmental changes [25]. Coastline erosion has long been a problem in Kuala Terengganu's Marang Kechil to Kuala Merang coastal area [33]. The Kuala Terengganu coast in the South China Sea (SCS) has grown dramatically as a result of the development of breakwaters, jetties, trading hubs, residences, hotels, and coastal resorts [34]. The majority of the development in this area had a negative impact on the shoreline and the coastal environment. For example, jetties along the Kuala Terengganu coastline held sediments, producing erosion at lower littoral drift and acceleration at greater littoral drift [35]. The majority of development along Kuala Terengganu's coasts occurred without regard for the need to gather quantitative and qualitative data on coastal city regions [36]. There are no sound coastal city setbacks or other mitigating measures in Kuala Terengganu because of a lack of coastal change data [37].

Furthermore, in this location, inadequate sediment delivery to beaches and coastal flooding are two variables that contribute to coastal city erosion. The necessity of coastal assessment and analysis of environmental change and coastline position projection for coastal development in Kuala Terengganu [38] are justified by this dangerous scenario. In addition, to improve and expand management strategies in this sensitive sector, proper tools and scientific databases are required. Coastal city vulnerability assessment is critical for coastal change research because it helps to avoid choices based on inadequate data and inaccurate assessments, which might lead to the loss of coastal resources and infrastructure [39]. As a result of the fast growth of coastal regions in recent years, coastal city change studies are becoming increasingly relevant in Malaysia. Prior research and experiences have projected that the repercussions of coastal change, particularly on the East Coast, will be severe and costly [40]. However, there is a lack of a precise and reliable assessment of the annual rate of change that might be used to enact preventative measures and describe the probable future coastline layout.

The study's ultimate objective is to look into the vulnerability and erosion control of Peninsular Malaysia's east coast. The project aims to do the following: (1) Estimate experimental data using subjective information and expert views in order to treat the topic as an MCDA problem. (2) On a local scale, identify the essential and sensitive criteria as well as an alternative for coastal city erosion.

As a result, using multi-criteria spatial decision analysis (MCSDA) models, this research can forecast the future of coastal city vulnerability erosion for decision-makers and planners, which is equivalent to information gathered by various Malaysian ministries and agencies [41]. MCDA provides better-supported methodologies for comparing project options using decision matrices, resulting in a significant improvement in the environmental decision-making process. It also provides formal methods for incorporating project stakeholders' perspectives into the ordering or ranking of options [42]. The MCDA method has been widely used in environmental management and planning, as well as stakeholder participation [43]. One of MCDA's most important features is its capacity to bring out the similarities and potential conflict areas among stakeholders in collective decision-making, allowing for a better understanding of others' views [44]. The analytical hierarchy process (AHP) is the most widely used and widest procedures in the MCDA approach [45,46]. Reference [47] agreed, claiming that AHP is the most widely used as well as the fastest evolving decision analytic technique in a variety of disciplines, including environmental and resource planning, environmental management, and so on.

The AHP process is a reasonable method to conduct vulnerability, hazard, and risk criteria weight of erosion because it displays a choice problem and then advances precedence for the criteria, sub-criteria, and alternatives. The ANP technique, which is distinct from AHP, is a generalized variant of AHP that allows for outer-dependencies, inter-dependencies, and feedback among decision components in hierarchical or other structures.

In other words, the more complicated the situation is, the more work it takes to prepare the decision structure [48]. The AHP is a particular instance of the ANP since there are no feedback loops between the components. As a result of paired comparisons of elements under identical conditions, both the ANP and the AHP obtain ratio scale priority for every component or element and cluster of components or elements [49].

AHP techniques have a number of advantages, including being relatively simple to use, the ability to integrate qualitative and subjective factors, the ability to withstand rapid preplanning, the ability to estimate the greatest judgmental decisions from a large number of credit analysts, and the ability to assess the consistency of these judgments [50]. AHP has been used in a variety of complex decisions, including challenges in natural resource management [51], integrated coastal zone management (ICZM) [52], environmental issues [53], social science and technology [54], economic studies [55], risk management process [56], land use planning [57], urban planning [58], and the business and tourism industries [59].

## 2. Methodology

### 2.1. Study Area

Terengganu is a Malaysian constituent state on Peninsular Malaysia's east coast. Kelantan is to the northwest of the state, Pahang is to the southwest, and the South China Sea (SCS) is to the east. The largest city in the state is Kuala Terengganu, which is located at the mouth of the Terengganu River. It is located between  $5^{\circ}27'58.31''$  N and  $5^{\circ}11'42.36''$  N, and  $102^{\circ}57'06.10''$  E and  $103^{\circ}13'18.69''$  E in latitude and longitude, respectively. Figure 1 presents the sandy coastal beaches that cover the whole of the city's eastern coast, which confronts the South China Sea. The research region is the Kuala Terengganu coastline, which stretches over around 69 km from Merang to Rusila.

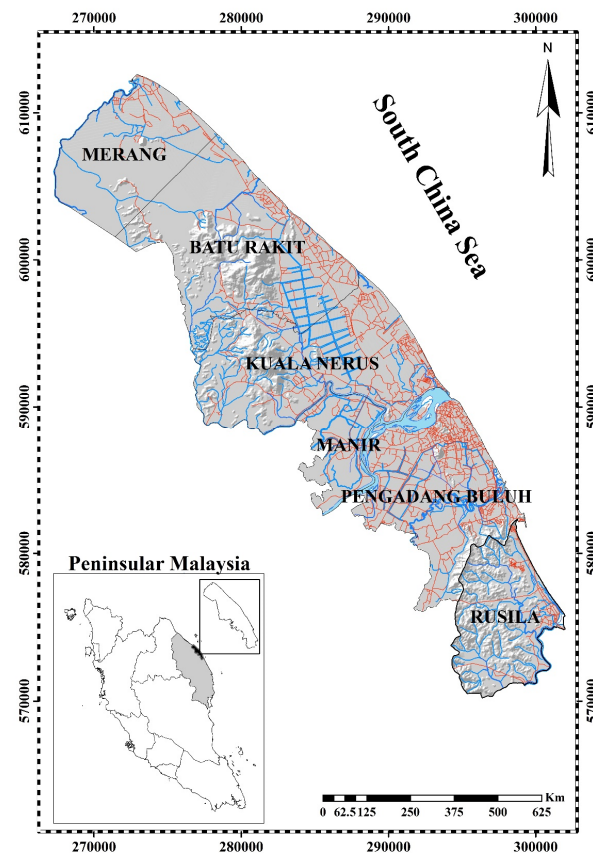


Figure 1. Kuala Terengganu study area.

The majority of the activities in this region are focused along the shore; monitoring is critical in order to identify locations inside the coastal city that are particularly vulnerable

to erosion and accretion. Due to its constant exposure to significant coastal erosion as well as its unique location as an active tourism gateway to the East Coast Economic Region, Kuala Terengganu was chosen as a research region (ECER). Sustainable island tourism, ecotourism, urban tourism, and traditional culture and historical tourism are also popular tourist activities, particularly along the mainland's coasts [60]. The ECER covers the states of Terengganu, Kelantan, and Pahang, as well as the Johor and Mersing districts [61]. It was developed as an economic corridor to help the east coast of Peninsular Malaysia undergo socioeconomic changes.

## 2.2. Understanding the AHP Framework

This research applies the AHP method to assess the vulnerability and hazard index criteria and sub-criteria coastal city region's erosion that necessitates qualitative and semi-quantitative analysis of the coastal region's information. In AHP, it is important to create a hierarchy by shaping the problem into its basic elements. This model ascribes weights to the variables with the use of pairwise comparison at every hierarchy level. AHP consists of two main parts, qualitative design (QD) and semi-quantitative design (SQD). These designs in the AHP model improve the consistency of the system as well as ease weight computation for criteria and sub-criteria. The four phases of qualitative AHP are: (1) problem modeling, (2) weights valuation, (3) weights aggregation, and (4) sensitivity analysis, which will be explained briefly in the next section.

The QD utilizes two criteria for the measurement of erosion area, namely vulnerability index (VI) and hazard index (HI). VI can involve qualitative factors, namely, soil types, plantation and cultivation, regions without slope, sediment rate, average height, distance to coast, geology era, and density in rural and urban regions as well as road location to coast. Hazard index (HI) ratios can also involve qualitative risk factors, namely, amount of rainfall, coastline historical changes, wind speed, and flash flood area as well as environmental natural hazards such as sea-level rise.

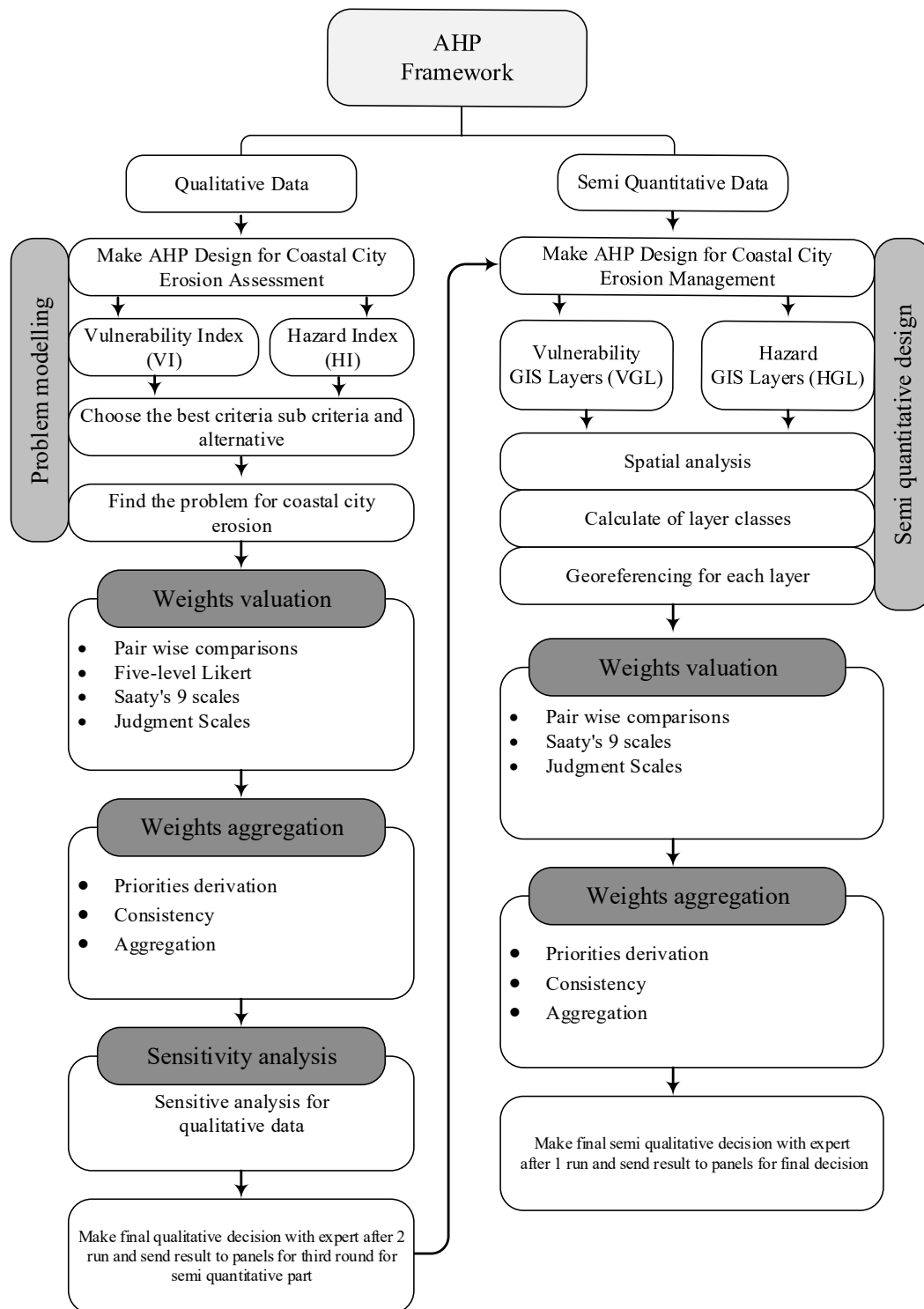
On the other hand, SQD erosion risk is assessed with two criteria, namely vulnerability and hazard GIS layers. The vulnerability GIS layers include classes of land use, geology, soil, etc. Similarly, hazard GIS layers consist of classes of rainfall, flood, sea-level rise, etc. In SQD AHP design some steps are like QD without sensitive analysis. Figure 2 shows the levels and constituents of AHP for the coastal city erosion management (CCEM) model. The AHP method is organized hierarchically at diverse levels with each level containing a finite amount of decision components. The general goal of the CCEM model is represented by the upper level of the hierarchy whereas one or more intermediate levels symbolize the decision criteria and sub-criteria. Hence, the lower level comprises all potential options (zones) [62].

The first stage in any decision-making process is to organize the problem, which may be broken down into three parts: goal, criteria, and sub-criteria. The breakdown of the choice issue into components based on their common properties and the construction of a hierarchical model with several levels make up the structuring of the decision hierarchy [63].

### 2.2.1. Data Collection by Using Experts

We gathered two sorts of data for this post based on issues and options. The AHP technique requires both primary and secondary data. The expert choice matrix is included in the source data (ECM). ECM was provided to 12 Malaysian specialists from various agencies (DID, SMART, NAHRIM). ECM was on the scene for six months (for three rounds). The first round took place from 14 February to 17 April 2018, the second round from 22 August to 20 September 2018, and the third round from 3 October to 7 November 2018. Secondary data from relevant departments were obtained for semi-quantitative data. Topographic map (2002), land use map (2008), and MUKIM map (2010) from JUPEM, geology map from the Geology department, flood map (2008) from DID, population map (2010) from the Department of Statistics, and soil map (2008) from the Department of

Agriculture were the most common secondary spatial data for GIS layers (DOA). We developed two types of hierarchy designs, QD and SQD, based on the issue description, alternative, and expert knowledge for coastal erosion in Kuala Terengganu. We gathered primary data for the AHP approach based on issues and options. ECM is included in the primary data as numerical data.



**Figure 2.** AHP framework, showing the four computational parts for qualitative data analysis and three computational parts for semi-quantitative data analysis.

### 2.2.2. Pairwise Comparisons

The second step is associated with the collection of input data by pairwise comparisons of decision components as well as obtaining the judgment scales. Having arranged the problem in a hierarchical technique, the next step is to appraise the relative significance of the criteria and sub-criteria with the general goal. The study applies two designs, namely the five-level Likert with the expert choice questionnaire (ECQ) which enables the selection of the best and essential criteria from the expert’s point of view, and the Saaty’s 9-point scales with ECM which is utilized for the qualitative and semi-quantitative data criteria and sub-criteria. For the quantification process in AHP, the pairwise comparisons of criteria use a scale of unconditional judgments generally known as the Saaty’s 1-9 scale that specifies the degree at which one item prevails over the other regarding certain features. By utilizing pairwise relative comparison, the preference between criteria and sub-criteria would be asked for deriving weights by the AHP model. The relative significance of every variable is evaluated through the application of Saaty’s 9-point scales, as indicated in Table 1.

**Table 1.** The fundamental AHP important scale.

For Any Pair of Objectives $i, j$	
Verbal Judgment of Preference	The Intensity of Importance Numerical Rate
The equal importance of both components	1
Judgment slightly favors one component over another (moderate difference of importance)	3
Judgment strongly favors one component over another (strong difference of importance).	5
Very strong favoring of one component concerning another.	7
Evidence of extreme difference of importance of one component concerning another.	9

Note: 2, 4, 6, 8 are intermediate values between the two adjacent judgments (Source: [64]).

A matrix collects the pairwise comparisons of the decision-maker at each node of the hierarchy. AHP applies a ratio scale that does not need any units in the comparison. The judgment indeed is a quotient  $a / b$  of two quantities  $a$  and  $b$  which have the same units.

The transitivity criterion (1) holds for all  $a_{ij}$  comparisons if the matrix is consistent:

$$a_{i,j} = a_{i,k} \cdot a_{k,j} \tag{1}$$

$$a_{i,j} = \frac{1}{a_{j,i}} \tag{2}$$

### 2.2.3. Priorities Derivation

After filling the comparison matrices, priorities could be computed. The traditional AHP utilizes the eigenvalue technique. A consistent matrix is known as priorities  $w_i$ . The comparison of the alternatives  $i$  and  $j$  is denoted as  $w_i/w_j$ , which is multiplied by the priority vector  $\vec{w}$  gives:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \tag{3}$$

For a consistent matrix, we can demonstrate that:

$$= \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \times \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \tag{4}$$

or in a matrix form:

$$A \cdot \vec{w} = n\vec{w} \quad (5)$$

where  $\vec{w}$ : The eigenvector;  $n$ : The dimension of the matrix;  $A$ : The comparison matrix.

The formulation of an eigenvector issue is seen in Equation (5). The estimated priorities are exact for a consistent matrix, but based on perturbation theory, when small inconsistencies or discrepancies are inserted, the priorities should only vary minimally [65].

#### 2.2.4. Consistency

This part is concerned with the evaluation of the weight consistency of comparisons. It offers an index for the measurement of inconsistency for every matrix of comparisons as well as for the whole hierarchy in every set of judgments. It is necessary to apply a consistency check since priorities are meaningful only if obtained from consistent or proximate consistent matrices.

This step conducted the calculations to determine the maximum eigenvalue, Consistency Index ( $CI$ ), Consistency Ratio ( $CR$ ), and normalized values for every alternative and criteria [66]. The AHP determines the general consistency of judgments through a  $CR$ . As noted by some studies [67], the judgmental matrix's consistency can be accomplished through the examination of total  $CR$ , the ratio of  $CI$  denoted as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

where  $\lambda_{max}$  = maximal eigenvalue; or the scores that attained a certain level of consistency were accepted as demonstrated by a  $CI$  calculated by [68]. A  $CI$  was proposed that is denoted as follows:

$$CI = \sum_{j=1}^{\lambda} W_j \times CI_j \quad (7)$$

The  $CR$  allows determining the number of errors that were generated when offering expert judgments.

The  $CR$ , the ratio of  $CI$  and Random Indices ( $RI$ ), is given by:

$$CR = CI / RI \quad (8)$$

where  $RI$  signifies the random consistency index of a reciprocal matrix that was randomly created from the 9-point scale, with reciprocals forced (the average  $CI$  of 500 randomly filled matrices). The calculated  $CI$  can be compared with the created paired comparison matrix's  $RI$  to examine  $CR$ . The  $CR$  indicated whether the judgment weights of the decision-maker were accepted. A  $CR$  below 10% reveals that the matrix could be considered as possessing an acceptable consistency and the errors are relatively small and considered acceptable. Thus, [69,70] computed the random indices as indicated in Table 2.

**Table 2.** Random consistency indices.

$n$	3	4	5	6	7	8	9	10
$RI$	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Some judgment matrices require stimulation from decision-makers; one for the estimation of the local weights of criteria regarding the objective and another one for the calculation of the local weights of alternatives with each of the criteria and sub-criteria. The extra judgments are required for the estimation of an index for ascertaining the consistency of judgments. One of the considered strong points of AHP is its ability to ascertain consistent judgments via the computation of consistency ratio.



### 2.2.5. Aggregation

This step calculates the local weights of the components by utilizing Expert Choice software and deals with the additive aggregation of weights through several levels to obtain the ultimate weights of alternatives. After obtaining the local weights of components, they are combined or aggregated to obtain the ultimate weights of the decision options. Thus, the criteria's weights and the alternatives' scores known as local priorities are decision components in the decision process in Step Two. The decision-maker must offer his preferences or priorities by pair-wise comparisons with the weights and scores. The weights ( $w_j$ ) and scores ( $S_{ij}$ ) values are stimulated from these comparisons and denoted in a decision table. The final step of the AHP combines or aggregates all preferences from the decision table with a weighted summation of the kind in reference [71] and establishes local priorities based on all factors to determine global preference or priority. The ultimate criteria and alternative (zones) weights in qualitative and semi-quantitative data will be calculated using a formula as follows:

$$Z_i = \sum_j w_j \times S_{ij} \quad (9)$$

where  $Z_i$ : Represents global priority of the alternative  $i$ ;  $S_{ij}$ : Denotes weight of the criterion  $j$ ;  $w_j$ : Signifies local priority.

Thus, the global priorities ( $Z_i$ ) attained in this research are ultimately utilized for normalization through the division of the score of every alternative solely by the alternative score and the choice of the optimum alternative in each criterion [72].

### 2.2.6. Sensitivity Analysis

The sensitivity analysis of the AHP model is the final stage. The sensitivity analysis is the final phase in the decision-making process, and it involves making minor changes to the input data to see how they affect the outcomes. Hence, the results are considered robust if there is no change in the ranking [73]. The major goal of sensitivity analysis is to determine the sensitivity of the choices about the criteria weights' changes [74].

## 3. Results and Discussion

### 3.1. AHP Approach and Structure for CCEM Model

Two AHP hierarchy designs including QD and SQD are presented in Figure 3. QD is used for appraisal of erosion assessment in experts' knowledge setting, whereas qualitative design is used for management of erosion in expert and GIS settings. The study chose the optimum criteria based on experts' knowledge, visits to the study area, fieldwork, and literature review.

The evaluation criteria in multi-criteria spatial decision-making (MCSDM) are linked with geographical entities as well as the association between them. Therefore, maps or GIS layers could be used to represent the evaluation criteria. The study gathered and analyzed the GIS maps which encompass geographical characteristics. We applied four criteria, based on the expert survey and review of literature, namely climatic criteria, human activities criteria, environmental criteria, and coastal hazard criteria. One of the key goals is to choose one specific alternative from a variety of known alternatives. Highlighting the criteria, sub-criteria, and options in the spatial decision problems is indeed very challenging due to the vast number of alternatives.

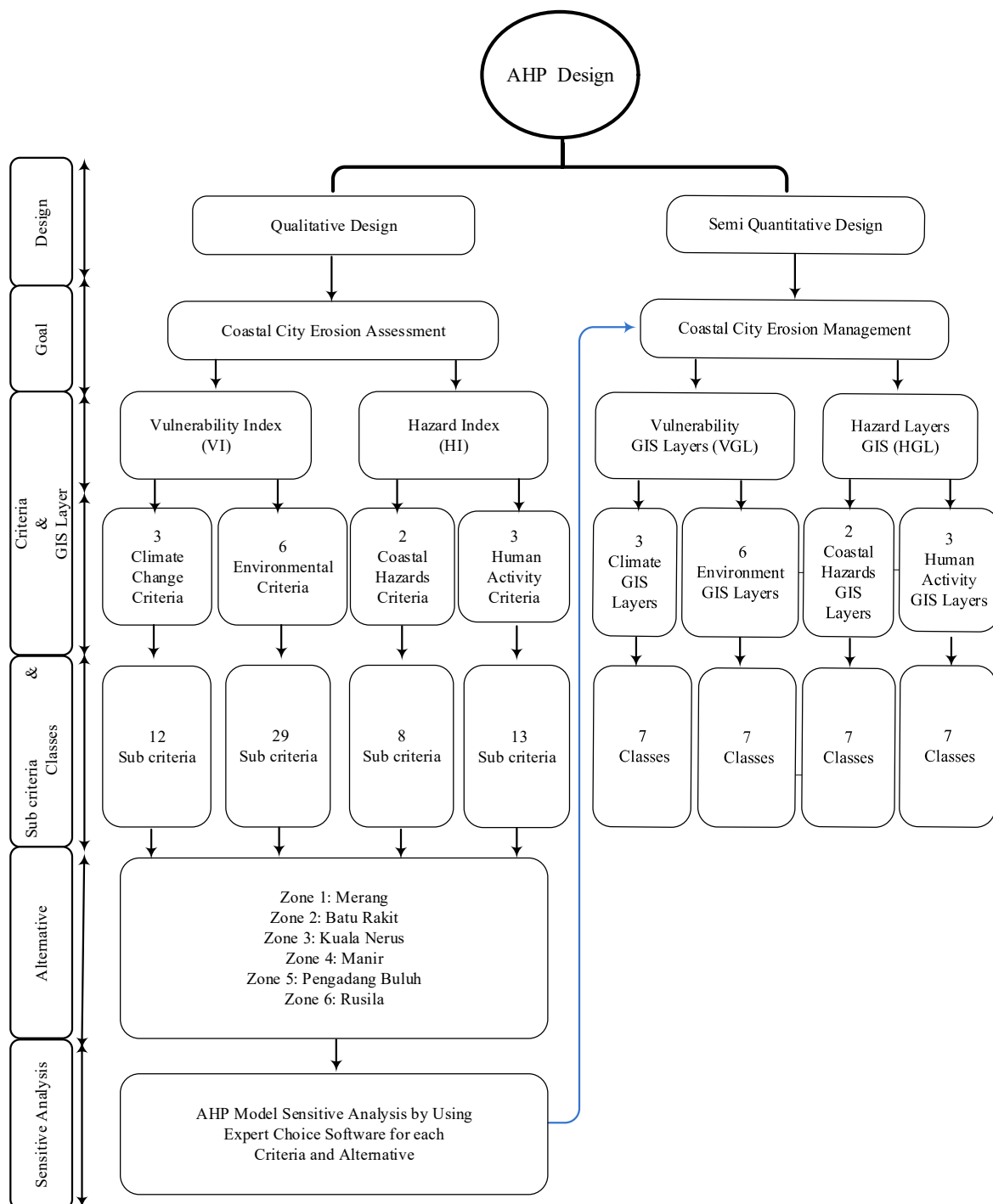


Figure 3. Analytical hierarchy process design.

The main goal of this structure is to assess the coastal city risk. We have designed 6 environmental, 3 human activities, 3 climatic, and 2 coastal hazard criteria as well as 29 environmental, 13 human activities, 11 climatic, and 8 coastal hazard sub-criteria.

Based on the sensitivity of areas, the study area was classified into six regions, namely, Zone (1): Merang; Zone (2): Batu Rakit; Zone (3): Kuala Nerus; Zone (4): Manir; Zone (5): Pengadang Buluh; and Zone (6): Rusila, with every region presented as an alternative layer and every region type signified as (VI) and (HI) zones.

### 3.2. AHP Expert Choice Team and Weights

The study team designed all the criteria, sub-criteria, and alternatives by applying the AHP model and ECM. Weights were assigned to a range of criteria based on experts' opinions. They were calculated for all criteria and sub-criteria in Expert Choice software for qualitative and semi-quantitative design. The ranking results of the first and second rounds were used in the third round to calculate the weight for the GIS layers class for semi-quantitative design. Areas that were ranked with the "highest" vulnerability should be the focus of future management efforts (Table 3).

The analytical results of the AHP-Expert Choice matrix from experts' opinions are shown as numerical values in Tables 3 and 4 which signify the weights of relative erosion vulnerability and hazard qualitative index. They are represented by numbers from 0 to 1. AHP weights are not the probabilities of erosion but comparative criteria, sub-criteria, and alternatives of erosion vulnerability and hazard qualitative index.

Within environmental criteria (EC), six criteria were selected based on erosion in the coastal area by using ECM from experts' (some government agency of Malaysia) opinion and AHP model. The estimated final weights for each criterion, sub-criteria, and alternatives are as follows: Zone 5 is more sensitive to river criterion, because of the presence of a big river in the middle of this region, with a weight of 0.232, CR of 0.09, and high alternative weight of 0.439, while Zone 1 is less vulnerable to river criterion, because of the absence of river in this zone, with a low alternative weight of 0.053.

In the human activity criteria (HAC), the study has three criteria selected by the Expert Choice matrix. Among all the criteria in HAC, the built-up criterion has the highest weight of 0.071 with a CR of 0.09. Zone 5 has the highest alternative weight of 0.434 which shows that this area is more vulnerable to construction compared to other areas, while Zone 1 has the lowest alternative weight of 0.055. This zone is in the town area of Kuala Terengganu where there is a higher density of building and coastal construction.

Table 4 shows the different criteria weights arising from the same AHP model, but with different values for the hazard index. To calculate the hazard index, the criteria are categorized into climate change hazard criteria (CCHC) which include rainfall, wind, and sea-level rise, and coastal hazard criteria (CHC) which consist of flood and coastal change.

In CCHC, the rainfall criterion has the highest weight of 0.223 with a CR of 0.09. Among all zones, Zone 5 is more vulnerable to rainfall with an alternative weight of 0.386, while Zone 4 is less sensitive to this criterion with an alternative weight of 0.061. In CHC, the environmental change criterion has a slightly higher weight than the flood criterion. Again, Zone 5 has the highest alternative weight of 0.440 while Zone 4 has the lowest weight of 0.038.

In summary, Zone 5 has a higher vulnerability value to erosion compared to other zones. This area is more sensitive to the river, built-up, rainfall, and environmental change criteria. In addition, the vulnerability of Zone 5 was mostly influenced by the presence of a big river as well as being a town center with many ongoing environmental development projects and various man-made structures. It is revealed that this region is more affected by environmental factors followed by climate change hazards. High rates of erosion could affect the land use in the coastal area as well as increase sedimentation, which in turn could be a hazard to fishermen's boats because they could get stuck in sand bars. It could also pose a threat to fishing villages and local aquaculture activities.

The protection of the region using breakwaters and revetments could be one of the most effective approaches to protect this area. There are more breakwaters and revetments in Zones 1 and 2 relative to these regions experiencing a lower rate of erosion. Furthermore, data indicated that beaches protected by breakwaters and revetments were not affected by erosion during bad weather; nevertheless, a part of the beach just a few meters away from the erosion control structures was severely eroded [75].

**Table 3.** AHP weights for qualitative vulnerability criteria.

Goal	Index	Criteria	CR	Weight	Sub-Criteria	CR	Weight	Alternative	Weight	
Coastal City Erosion Vulnerability Assessment (CCEVA)	Vulnerability Index (VI)	Environmental Criteria (EC)	River	0.09	0.232	Seasonal change	0.06	0.084	Zone 1	0.053
						Water discharge	0.06	0.207	Zone 2	0.129
						Flood intensity	0.03	0.27	Zone 3	0.199
						Sedimentology (Sediment rate)	0.06	0.123	Zone 4	0.105
						Runoff water	0.07	0.06	Zone 5	0.439
						Rainfall & runoff correlation	0.06	0.256	Zone 6	0.075
			Land Use	0.04	0.201	Plantation & cultivation	0.07	0.125	Zone 1	0.101
						Forestry	0.07	0.239	Zone 2	0.186
						Rangeland	0.07	0.046	Zone 3	0.218
						Urban, rural, industrial, and military development	0.09	0.361	Zone 4	0.075
						Watershed	0.06	0.105	Zone 5	0.237
						Cultural areas	0.05	0.05	Zone 6	0.183
			Geology	0.08	0.036	Geomorphologic scale	0.08	0.566	Zone 1	0.101
						Waterways geo-profile	0.08	0.26	Zone 2	0.066
						Tectonic process	0.08	0.086	Zone 3	0.121
						Geology era	0.08	0.08	Zone 4	0.211
									Zone 5	0.435
									Zone 6	0.067
		Slope	0.09	0.118	Slope Class	0.08	0.582	Zone 1	0.052	
					The average slope of waterway/floodway	0.07	0.161	Zone 2	0.204	
								Zone 3	0.118	
					The average slope of land use	0.09	0.197	Zone 4	0.103	
								Zone 5	0.132	
								Zone 6	0.392	
		Soil	0.09	0.088	Soil type	0.08	0.373	Zone 1	0.075	
					Soil erosion	0.07	0.337	Zone 2	0.1	
					Soil influence	0.06	0.099	Zone 3	0.267	
								Zone 4	0.038	
					Organic material	0.09	0.045	Zone 5	0.472	
					Land proportion for agriculture use	0.07	0.145	Zone 6	0.048	
		Topography	0.09	0.177	Vertical classification	0.09	0.223	Zone 1	0.104	
					Vertical classification in coastal area	0.09	0.239	Zone 2	0.163	
					Area and location of classification	0.08	0.425	Zone 3	0.096	
								Zone 4	0.138	
					Average height	0.08	0.113	Zone 5	0.267	
								Zone 6	0.232	
		Human Activity Criteria (HAC)	Road	0.08	0.030	Grid type	0.09	0.2	Zone 1	0.082
									Zone 2	0.039
						Water resource proximity to the road	0.09	0.148	Zone 3	0.093
						Road location to coast	0.09	0.607	Zone 4	0.035
									Zone 5	0.528
						Type of materials	0.09	0.045	Zone 6	0.223
Population	0.09		0.047	Density/ha	0.09	0.112	Zone 1	0.063		
				Density in land shapes	0.07	0.129	Zone 2	0.267		
				Density in coastline	0.06	0.501	Zone 3	0.207		
				Density in rural and urban zone	0.06	0.045	Zone 4	0.069		
				Density in hazardous areas	0.08	0.213	Zone 5	0.299		
							Zone 6	0.095		
Built up (BC)	0.07		0.071	Land shape	0.08	0.338	Zone 1	0.055		
				River grid location	0.04	0.184	Zone 2	0.17		
		Distance to coast		0.07	0.426	Zone 3	0.172			
		Local/non-local materials supply		0.07	0.052	Zone 4	0.072			
			Zone 5	0.434						
			Zone 6	0.097						

**Table 4.** D-AHP weights for qualitative hazard criteria.

Goal	Index	Criteria	Criteria CR	Criteria Weight	Sub-Criteria	Sub-Criteria CR	Sub-Criteria Weight	Alternative	Alternative Weight	
Coastal City Erosion Hazard Assessment (CCEHA)	Hazard Index (HI)	Climate Change Hazard Criteria (CCHC)	Rainfall	0.09	0.223	Rainfall amount	0.07	0.423	Zone 1	0.111
						Rainfall node	0.07	0.216	Zone 2	0.094
						Monsoon rainfall	0.09	0.199	Zone 3	0.239
						Max rainfall	0.08	0.162	Zone 4	0.061
									Zone 5	0.386
									Zone 6	0.109
			Wind	0.09	0.126	Wind speed	0.06	0.413	Zone 1	0.097
						Major wind direction	0.09	0.26	Zone 2	0.12
									Zone 3	0.179
									Zone 4	0.196
									Zone 5	0.279
									Zone 6	0.13
		Sea level rise	0.05	0.114	Land and sea upward coastline	0.08	0.591	Zone 1	0.076	
					Historical changes	0.09	0.135	Zone 2	0.123	
					Historical coastal erosion due to high changes	0.05	0.2	Zone 3	0.224	
					Reform of beach platform / base on changes in height	0.08	0.075	Zone 4	0.044	
								Zone 5	0.41	
								Zone 6	0.123	
		Coastal Hazards Criteria (CHC)	Flood	0.07	0.264	Flash flood Area	0.08	0.069	Zone 1	0.036
						Flood volume	0.07	0.377	Zone 2	0.117
						Flood intensity	0.08	0.219	Zone 3	0.376
						Correlation between flood and river grid	0.09	0.085	Zone 4	0.048
									Zone 5	0.375
									Zone 6	0.050
Coastline Change	0.01		0.274	coastline lithology	0.07	0.169	Zone 1	0.092		
				Coastline natural hazard	0.09	0.338	Zone 2	0.099		
				Coastal land use	0.09	0.299	Zone 3	0.267		
							Zone 4	0.051		
							Zone 5	0.440		
							Zone 6	0.051		

### 3.3. Sensitivity Analysis

A sensitivity analysis in this study shows the sensitivity of the alternatives for all the different criteria of the model on the choice of the important erosion criteria and sub-criteria in the Kuala Terengganu coastal area. The sensitivity analysis was only applied for qualitative data because experts ranked and weighted the qualitative data, and their results could be used to decide for semi-quantitative data. One of the popular sensitivity graphs in Expert Choice software is known as a dynamic graph. The sensitivity analysis results for environmental and human activity criteria obtained by using a dynamic graph through the application of AHP are presented in Figure 4.

The study presented the dynamic graph and the sensitivity analysis results in Expert Choice software in two parts; part one is the criteria and part two is the alternative. Each part has its unique menu commands and the sensitivity analysis between criteria and alternative can be compared with each other. If the priority sensitivity of each criterion or alternative is changed, the number of changes that would be necessary for other criteria or alternatives as the output of sensitive analysis could be seen. Thus, the priorities of the alternatives (zones) will change in the right column by dragging the nine criteria priorities in the left column. If a decision-maker thinks an objective might be more or less important than originally indicated, the decision-maker can drag that objective’s bar to the right or

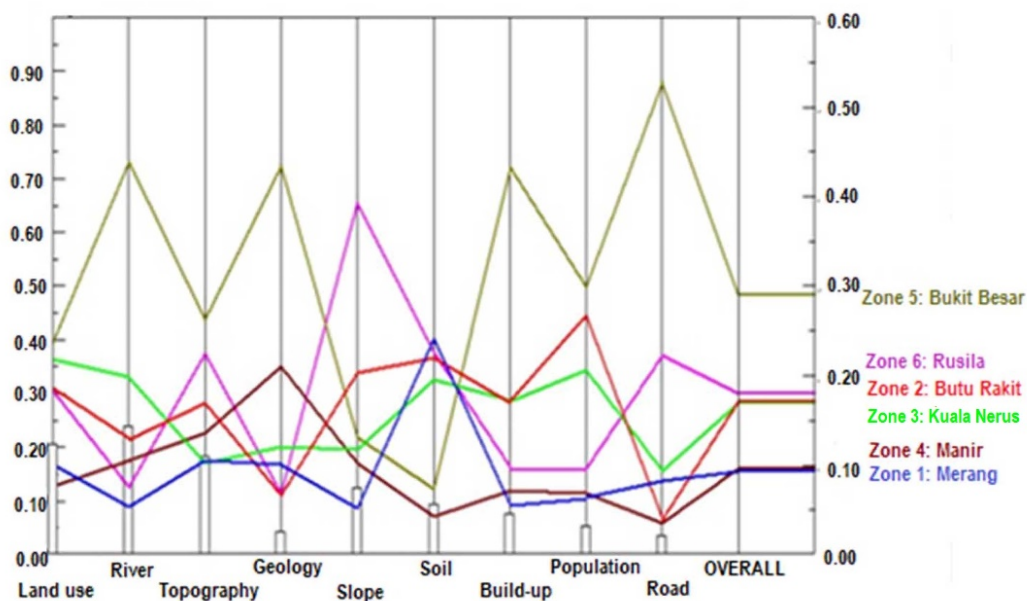
left to increase or decrease the objective’s priority and see the impact on the alternatives (Table 5).

**Table 5.** Coastal vulnerability sensitivity weights.

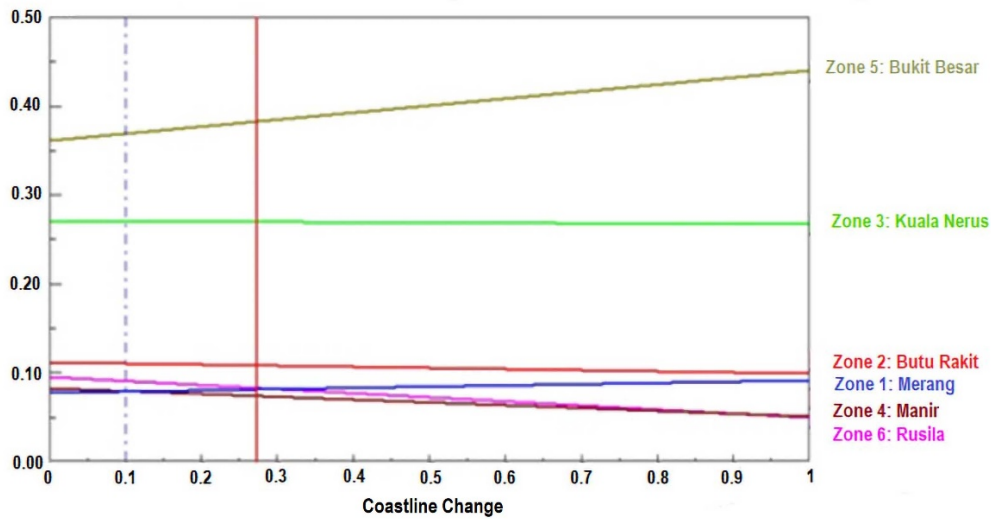
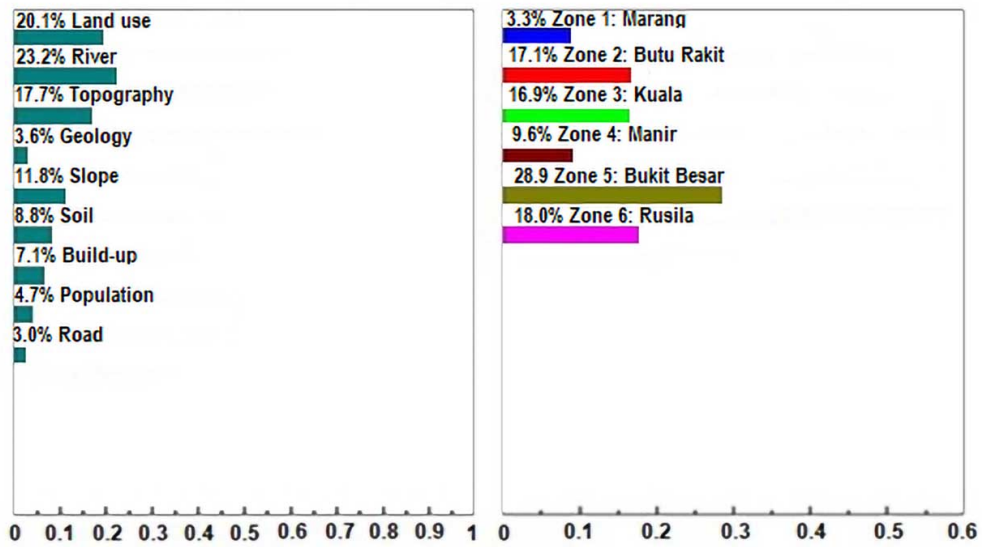
No	Criteria	River %		
		10%	50%	90%
1	Land Use	23.5	11.1	2.3
2	Topography	20.7	17.3	3.6
3	Geology	4.2	2	0.5
4	Slope	13.8	6.5	1.4
5	Soil	10.4	4.9	1.1
6	Built-Up	8.3	3.9	0.9
7	Population	5.5	2.6	0.6
8	Road	3.5	1.7	0.4
1	Zone 1 (Merang)	10.2	8.7	7.3
2	Zone 2 (Butu Rakit)	17.6	14.2	11.2
3	Zone 3 (Kuala Nerus)	16.5	17.6	19.7
4	Zone 4 (Manir)	9.5	10.4	10.8
5	Zone 5 (Bukit Besar)	26.4	34.4	42.2
6	Zone 6 (Rusila)	19.9	14.7	9.4

The study considered the river criterion from environmental criteria because the AHP results revealed that the river criterion has a higher weight among other environmental and human activity criteria.

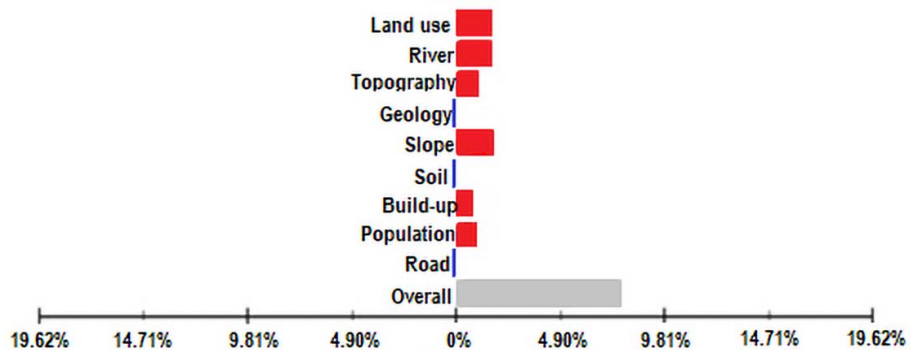
In the environmental criteria, it was found that an increase in the sensitivity of river criterion has a high weight of 0.232 with a corresponding inconsistency (CI) of 0.09 to 10%, 50%, and 90% of the main goal in the dynamic chart. This result indicates that the AHP model is still in favor of the land use criterion with scores of 23.5% of the main goal (leaving 76.5% for the others while keeping the proportionality between each), 11.1%, and 2.3%, respectively. In human activity criteria, built-up with scores of 8.3%, 3.9%, and 0.9% are more sensitive than population and road criteria. The result is relatively reasonable since more sensitivity of land use criteria in the vulnerability index is significantly greater than the other criteria. With an increase in the sensitivity of rivers in Kuala Terengganu, land use criteria will be more vulnerable than other criteria in Kuala Terengganu coastal city.



**Figure 4.** Cont.



**Zone 1: Marang <> Zone 2: Butu Rakit**



**Weighted head to head between Zone 1: Marang and Zone 2: Butu**

**Figure 4.** In Expert Choice software, an example of four different graphical coastal city vulnerability assessment sensitivity evaluations is shown.

Based on the sensitivity table, the study found that Zone 5 is more vulnerable to erosion based on the criteria. The results are comparable to the other zones, but Zone 5 remains the most vulnerable and sensitive area with scores of 26.40%, 34.4%, and 42.20%. On the other hand, Zone 1 with scores of 10.20%, 8.70%, and 7.30% remains the least vulnerable and sensitive zone for erosion in Kuala Terengganu. The result shows that Zone 5 is always in the lead with a persistent score beyond 26.4%, followed by Zones 6, 2, 3, 1, and 4, respectively.

Similarly, sensitivity analysis of the coastal change criteria still demonstrates that Zone 5 has the highest score of 36.9%. Results show that Zone 5 is always in the lead with a score higher than 30%, followed by Zone 3 (27.1%), Zone 2 (11%), Zone 6 (9.1%), and Zone 4 (8%). The result is relatively reasonable since the coastal hazard erosion in Zones 5 and 3 is significantly higher than the other criteria.

In coastal hazard criteria, an increase in the sensitivity of environmental change has the best weight of 0.274 with a corresponding inconsistency (CI) of 0.01 to 10%, 50%, and 90%. It was found that the AHP model is still in favor of the flood criteria with scores of 32.7%, 18.2%, and 3.8% as indicated in Table 6.

**Table 6.** Coastal hazard sensitivity weights.

No	Criteria	Coastline Change %		
		10%	50%	90%
1	Wind	15.6	8.7	1.8
2	Rainfall	27.6	15.3	3.2
3	Flood	32.7	18.2	3.8
4	Sea Level Rise	14.1	7.8	1.7
1	Zone 1 (Merang)	7.9	6.8	5.8
2	Zone 2 (Butu Rakit)	11	10	9.1
3	Zone 3 (Kuala Nerus)	27.1	28.8	30.6
4	Zone 4 (Manir)	8	6.9	5.8
5	Zone 5 (Bukit Besar)	36.9	44.1	51.3
6	Zone 6 (Rusila)	9.1	7.9	5.4

The situation is similar for the zones, as Zone 5 has the highest vulnerability and sensitivity area with scores of 36.9%, 44.1%, and 51.3%. On the contrary, Zone 4 with scores of 8%, 6.9%, and 5.8% has the lowest sensitive zone for erosion. With an increase in sensitivity of the coastal change in the area, a flood criterion is more vulnerable compared to other criteria in Kuala Terengganu.

The sensitivity analysis results as presented in Figure 5 indicate the degree of stability of the decision. The choice of Zone 5 remains the same even with significant changes on the criteria weights which can be justified by the consistent judgments and the pairwise comparisons. AHP analysis demonstrates an efficient knowledge-based approach to help quantify experts' knowledge to qualitative analysis. The best alternative in this study was Zone 5 for Kuala Terengganu coastal area. Qualitative vulnerability and hazard weights are final calculations in Expert Choice software for this part of the research (Figures 6 and 7). By using qualitative results and some analysis on the semi-quantitative data, the result for environmental erosion of Kuala Terengganu shows that Kuala Terengganu, Kuala Ibai, Chendering, and Kuala Marang River criteria have the highest weights, 0.282, for vulnerability layer and coastline change criteria with the highest weight, 0.275, for hazard layer as the important criteria for Kuala Terengganu coastal area (Figures 6 and 7).



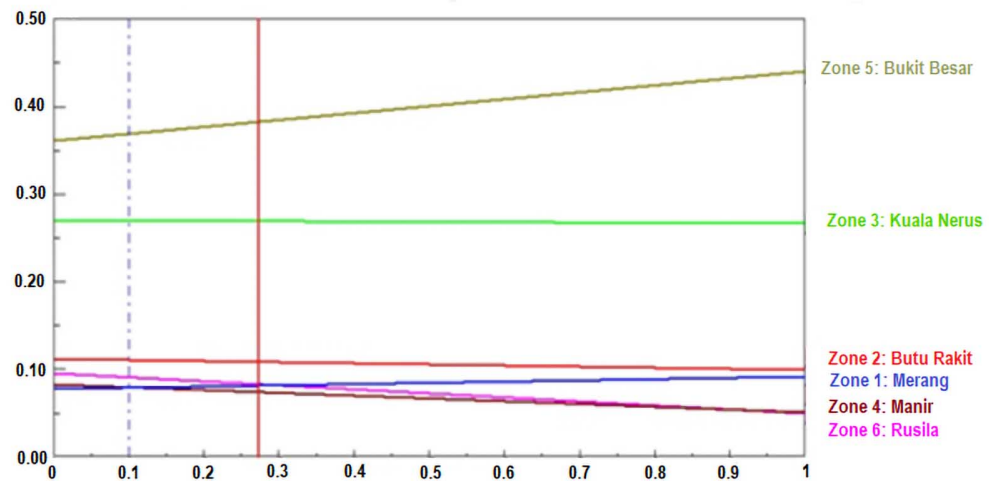
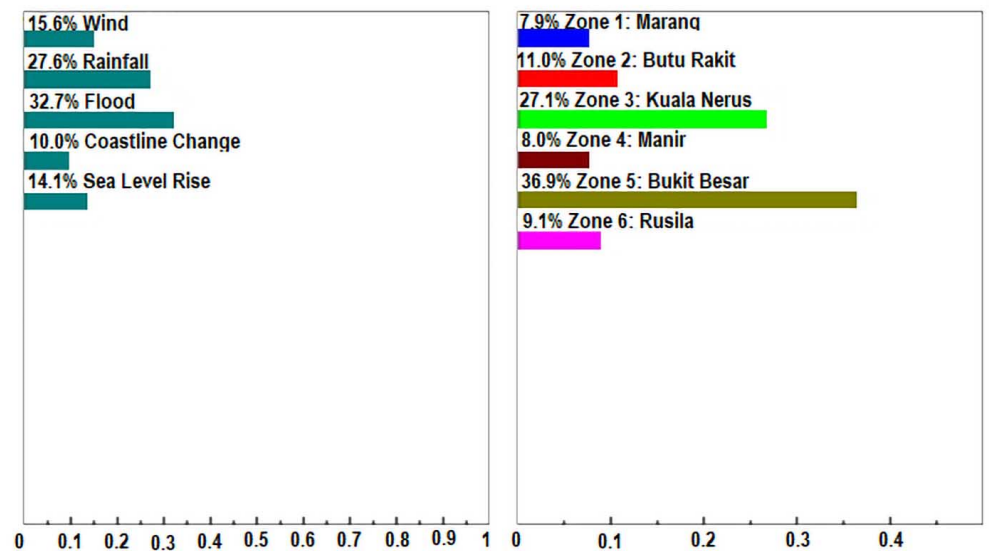
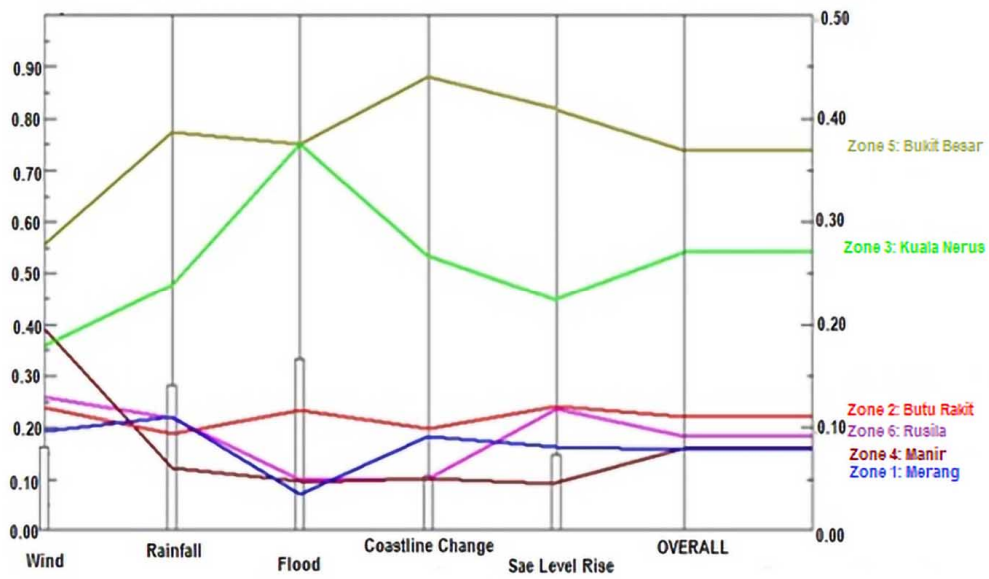


Figure 5. Cont.

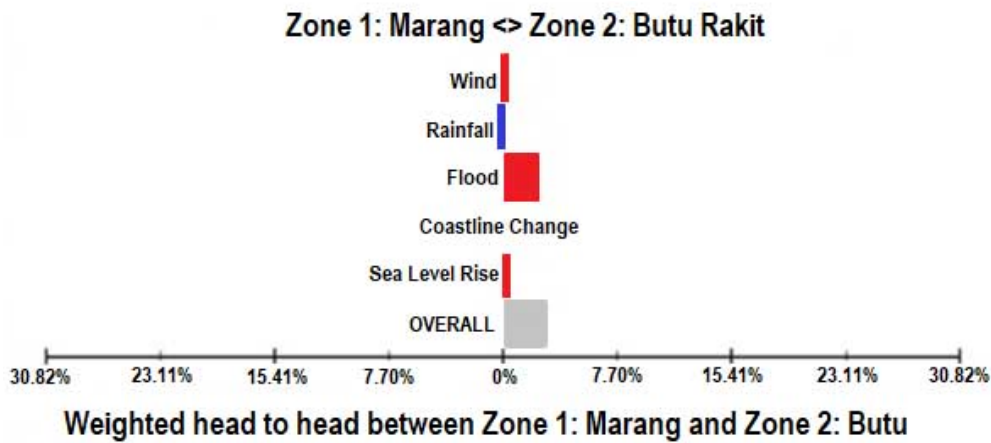


Figure 5. In Expert Choice software, an example of four possible graphical coastal city hazard assessment sensitivity evaluations is shown.

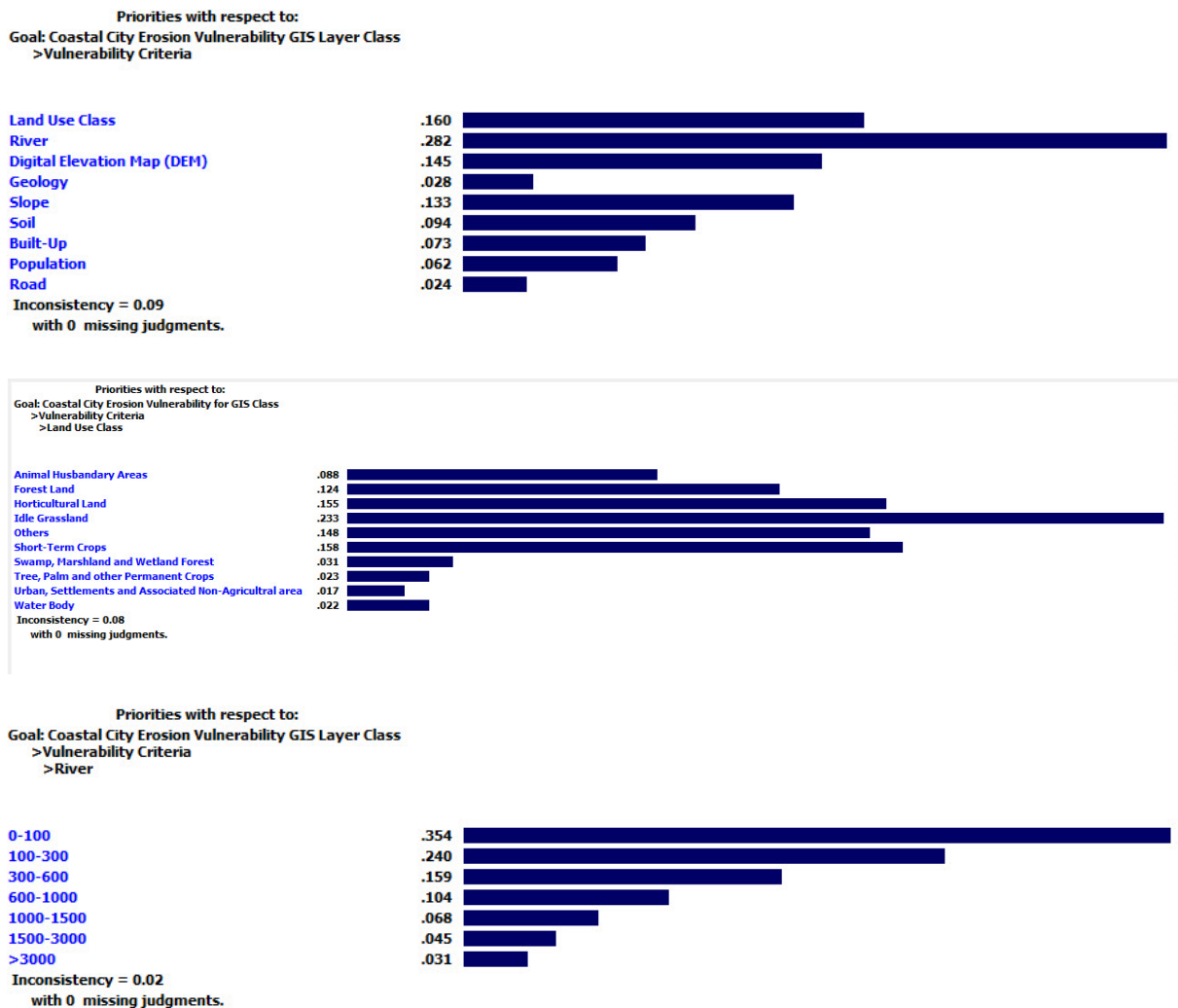
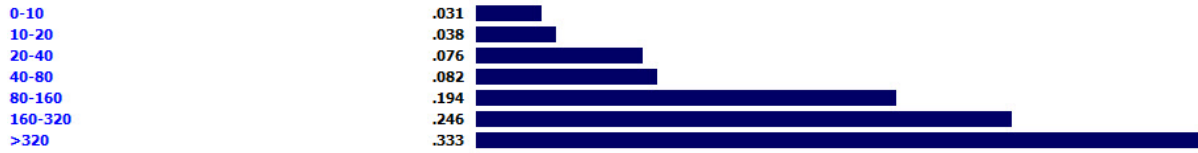


Figure 6. Cont.

Priorities with respect to:  
 Goal: Coastal City Erosion Vulnerability GIS Layer Class  
 >Vulnerability Criteria  
 >Digital Elevation Map (DEM)



Inconsistency = 0.09  
 with 0 missing judgments.

Priorities with respect to:  
 Goal: Coastal City Erosion Vulnerability GIS Layer Class  
 >Vulnerability Criteria  
 >Geology



Inconsistency = 0.05  
 with 0 missing judgments.

Priorities with respect to:  
 Goal: Coastal City Erosion Vulnerability GIS Layer Class  
 >Vulnerability Criteria  
 >Slope



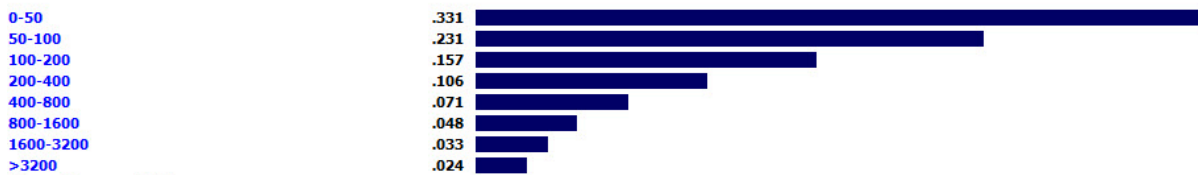
Inconsistency = 0.02  
 with 0 missing judgments.

Priorities with respect to:  
 Goal: Coastal City Erosion Vulnerability GIS Layer Class  
 >Vulnerability Criteria  
 >Soil



Inconsistency = 0.08  
 with 0 missing judgments.

Priorities with respect to:  
 Goal: Coastal City Erosion Vulnerability GIS Layer Class  
 >Vulnerability Criteria  
 >Built-Up



Inconsistency = 0.03  
 with 0 missing judgments.

Figure 6. Cont.

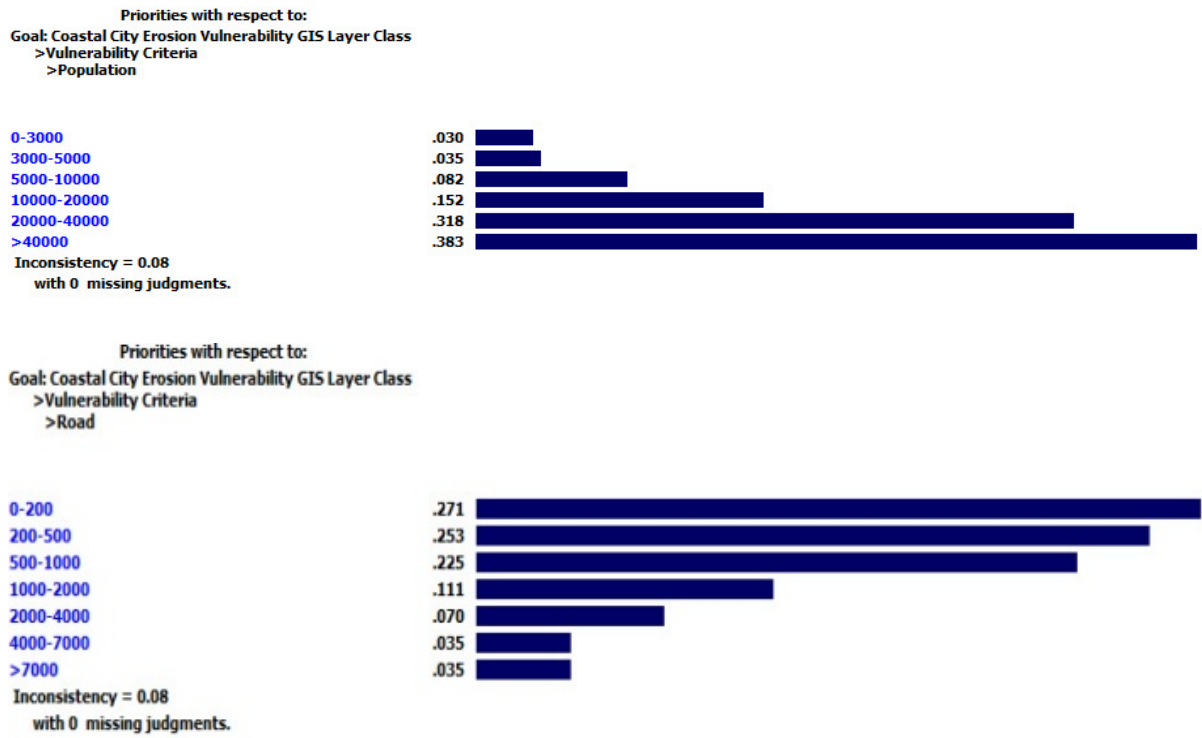


Figure 6. Final weights for semi-quantitative vulnerability layers.

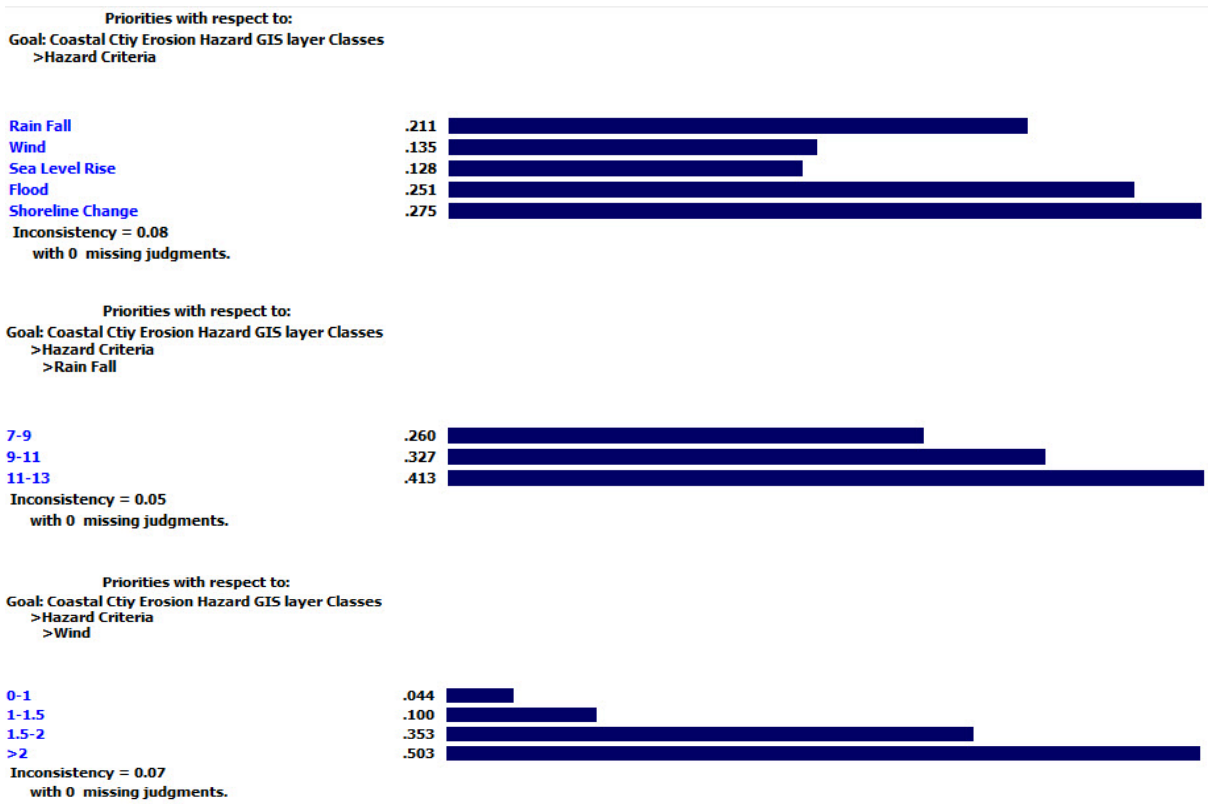


Figure 7. Cont.

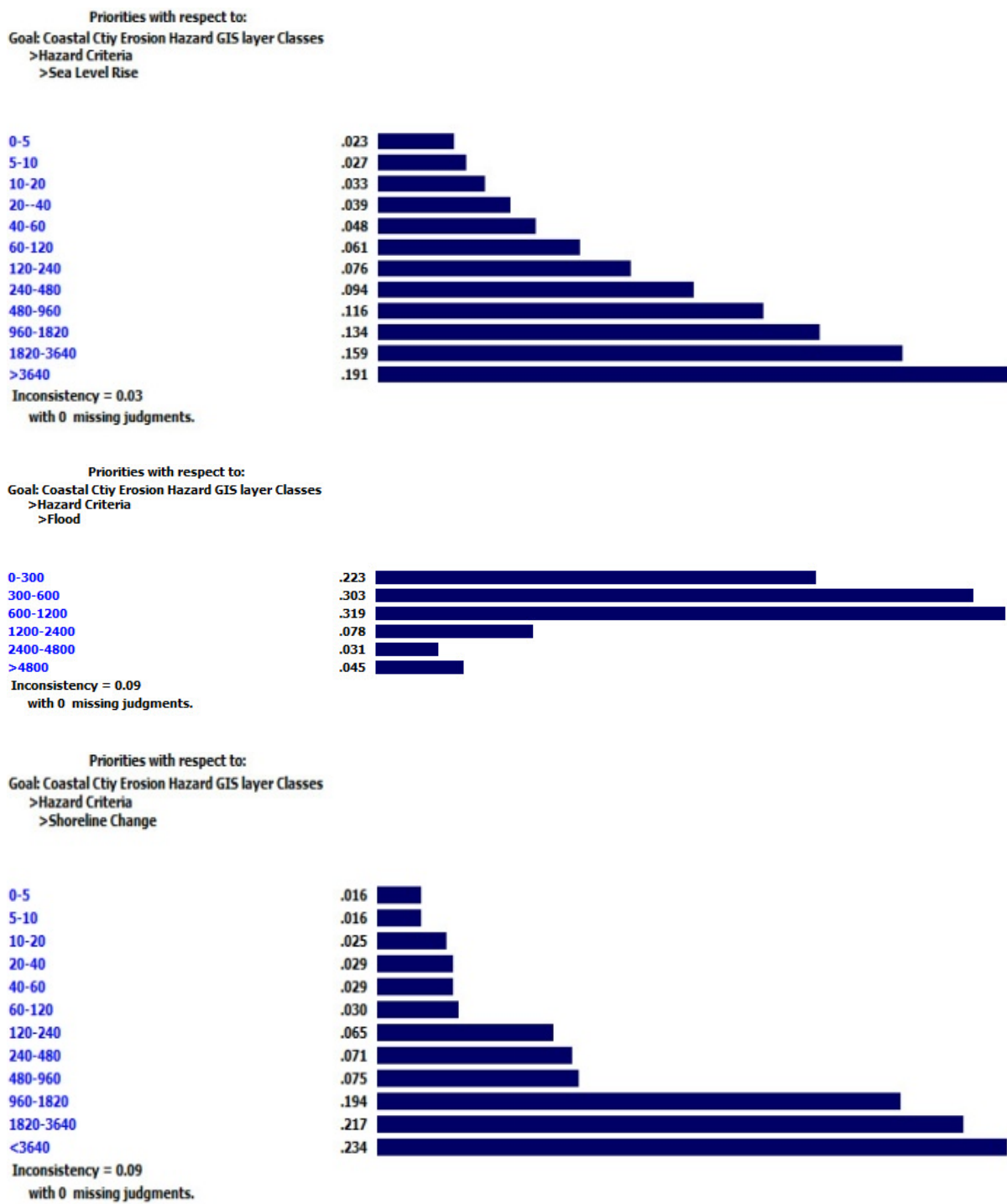


Figure 7. Final weights for semi-quantitative hazard layers.

The study found that Kg. Seberang Takir is a significant source of river sand in the Kuala Terengganu coastal area. Erosion beaches are the other major source and probably provide a larger volume of sand to the longshore transport system than do the rivers. Sand is probably lost offshore of a region between Kg. Seberang Takir and S. K. Chendring (Left Bank Bt. Chendring). In addition, some sand is probably lost in the mouth of Jalan Tok Adis (Left Bank. K. Ibai) and possibly in some closed river entrances north of Kg. Seberang Takir. Sand carried north to Right Bank Bt. Merang Kecil may be carried offshore, possibly as a result of the complex effects of offshore islands or waves which approach from the northeast. Sand is presently lost in the basin at Kampung Aur (Right Bank Bt. Chendring).

This volume is carried to the north from the new nodal reaches south of the harbor from the north around S. K. Chendring (Left Bank Bt. Chendring). The volume carried north to the harbor will decrease with time as a new hook-shaped bay evolves.

Environmental change and behavior have seen some of the most extensive recent coastal retreats along the east coast of Malaysia. The coastal retreat is notably severe south of Right Bank Bt. Merang Kecil. It is also very severe from the south side of Kg. Seberang Takir to Jalan Tok Adis (Left Bank. K. Ibai), a developed region containing new hotels and some residences. Changes in coastal orientation, the related divergent nodal region, and the presence of sheltering offshore islands near Right Bank Bt. Merang Kecil appear to be responsible for the coastal city erosion from Right Bank Kg. Merang to Left Bank Bt. Chendring. Losses are in both directions between Kg. Seberang Takir and S. K. Chendring (Left Bank Bt. Chendring). Because this region projects breakwater and seaward of adjacent shore beaches, once moved to more westerly beaches, they are probably not returned when the wave direction changes. Landward inset of the beach north of S. K. Chendring (Left Bank Bt. Chendring) and the straightness of the shore there is indicative of a low sand volume that bypasses the headland to the south. Most of the sand leaving the eroding Terengganu coasts in an along-shore direction passes to the north. Since the mean wave approach direction for this coast is about normal to this shore, losses are caused more by no return of sand across the river. Half the sand from this region may be lost offshore. Sand losses south of Right Bank Bt. Merang Kecil are the result of changes in shore orientation and sheltering of the shore by offshore islands to the north and northeast. The latter reduces the magnitude of wave energy on the coast from the north and, therefore, increases the effect of waves that arrive from south of shore as normal. The coastline from S. K. Chendring (Left Bank Bt. Chendring) to Kampung Kijing (Left Bank of Kuala Marang Terengganu) has reacted quickly to the construction of the breakwater at S. K. Chendring, beginning about 1985 (Left Bank Bt. Chendring).

The north headland has basically been relocated to the south by this breakwater. The indentation of the equilibrium embayment subsequently shifted and this shift has resulted in serious erosion. The evolution of the bay after construction can be predicted quantitatively.

The pace of coastal retreat and advance, as well as the volume of sand transported north to the harbor, may all be anticipated. This data may then be utilized to best site and design a building to avoid sedimentation in the harbor and offer a dumping location so that sand dumped south of the port does not return to the harbor but instead moves south.

The volume of sand that moves south around S. K. Chendring (Left Bank Bt. Chendring) should be bypassed to the south to prevent down-drift beach erosion. It could also be back-passed to the north to mitigate erosion problems there.

#### 4. Conclusions

For coastal vulnerability management in Kuala Terengganu, Malaysia, this study combines an MCDA model with Expert Choice decision-making software. It creates vulnerability weights and sensitivity zones for coastal region damages that might be caused by human activities, climate change, and environmental causes. A reliable erosion model and precise weights of erosion-prone regions are required to assess erosion susceptibility.

The final weights for each zone of the research area are calculated using the AHP and Expert Choice software. One of the most significant aspects of this study was the selection of the best and most relevant criterion and sub-criteria utilizing AHP model for coastal erosion in order to achieve an accurate result. Many variables may be significant for the occurrence of erosion in a particular coastal location, but they may not be important in other areas. The input data are crucial, and the technique framework used to collect them, as well as how and where they were gathered, might have an impact on the outcomes. Other significant variables include selecting the finest local agencies in the country or international agencies in other nations, as well as the quantity and quality of experts needed to construct the Expert Choice matrix and the best MCDA model.

In quality design, the flood criterion in coastal hazard criteria has the greatest weight of 0.264 with a CR of 0.07, and in semi-quantitative design, it has the highest weight of 0.251 with a CR of 0.08. Zones 5 and 4 have the greatest alternative weights of 0.375 and 0.376, respectively, indicating that they are more prone to erosion than other zones, whereas Zone 1 has the lowest alternative weight of 0.036. The rainfall criteria in climate change hazard criteria have the highest weight of 0.223 with a CR of 0.09 in quality design, and the highest weight of 0.211 with a CR of 0.08 in semi-quantitative design. Zone 5 has the highest alternative weight of 0.386, suggesting that it is more prone to erosion than the other zones, whereas Zone 4 has the lowest alternative weight of 0.061, showing that it is less prone to erosion than the other zones. In quality design, the river criterion in environmental criteria has the greatest weight of 0.232 with a CR of 0.09, while in semi-quantitative design, it has the highest weight of 0.282 with a CR of 0.09. Zone 5 has the greatest alternative weight of 0.434, indicating that it is more prone to erosion than other zones, whereas Zone 1 has the lowest alternative weight of 0.053. In quality design, the built-up criterion in human activity criteria has the greatest weight of 0.071 with a CR of 0.09, and in semi-quantitative design, it has the highest weight of 0.073 with a CR of 0.08. Zone 5 has the greatest alternative weight of 0.434, indicating that it is more prone to erosion than other zones, whereas Zone 2 has the lowest alternative weight of 0.055. The most vulnerable site, according to the research, is Zone 5, Bukit Besar. Both the hazard and vulnerable criteria are very vulnerable to it. The northern and southern districts of Kuala Terengganu have less erodible coastline regions. Environmental impact assessment (EIA) is critical in many fields, including environmental management and engineering. The results of this study reveal that the international airport in Kuala Terengganu is at moderate risk due to its location in a low-lying and flood-prone area. The findings of this study may assist managers in making better judgments and implementing new management, as well as enable the Terengganu state government to devise a strategy for addressing the erosion problem in this area. It should be mentioned that the erosion criterion used in this study should be altered in a different study area since the criteria used in Kuala Terengganu may not be relevant in other areas.

The government will need to define appropriate and unsuitable regions in order to determine whether areas are at high danger or low risk for coastal building. The findings of this study will help planners, policymakers, and decision-makers better understand the effects of climate change on coastal city regions when developing short- and long-term projections of land use appropriateness in Kuala Terengganu's coastal districts. These study findings and outputs are critical because they might be used by the government, policymakers, and planners in the future to allocate funding and plan correctly in this field. The study identified and assessed a variety of adaptation solutions for dealing with possible climate change vulnerabilities in a number of major industries in the region. The findings provide a prioritized ranking that indicates the overall preference for each of the adaptation alternatives in the research area's coastal zones. According to the findings, the government may implement new laws to safeguard this region from coastal erosion by building jetties and seawalls to protect the inland area from wave action and prevent coastal erosion.

#### *4.1. Coastal City Erosion Control*

Coastal erosion has severe consequences because it changes landforms, land use, and property ownership. Social, economic, and physical values are all affected by such changes, both directly and indirectly. Controlling coastal land erosion can help to reduce the impacts of coastal city erosion. Structural methods alter the physical features of the coastline, provide a physical barrier to the sea, and clearly identify the protected region. They always necessitate building expenditure, which is frequently substantial, and have immediate and sometimes long-term environmental consequences. For many, if not all, coastal erosion concerns, structural solutions are competing for alternatives. Seawalls, breakwaters, and jetties are structural methods that are especially suited in Kuala

Terengganu for protecting the east coast of Peninsular Malaysia from geographically Kuala Terengganu coastal erosion.

Land and water are separated by seawalls. Their main goal is to keep the upland they have taken over from being damaged by waves. Seawalls are huge, free-standing constructions that are built to withstand the full power of waves. Undermining and flanking of sea barriers must be avoided. Furthermore, the usage of seawalls frequently necessitates acceptance of increased beach erosion in front of the seawall.

Jetties are more for navigational purposes than for erosion management, although they do control erosion in a small region of the river mouth and reduce one of the consequences of erosion. Jetties are structures that extend seaward from the river mouth to limit and guide river and tidal flows, as well as to prevent the navigation channel's shoreline from being obstructed. Because accretion reduces the amount of sand delivered to the river mouth, the shoreline on the other side will erode. This accretion erosion will continue until the updraft shore has been built out to the end of the accreting jetty. When sand movement along the coast is evenly balanced in both directions, accretion may occur at both jetties for a period of time, and erosion may occur on both sides of the river mouth for a comparable period of time.

Breakwaters are structures that intercept waves before they reach a coastal region, harbor anchoring, or basin, providing protection from the elements. The traditional role of breakwaters in navigation improvement has been supplemented by the protection of coastal regions to limit erosion. Breakwaters prevent erosion by decreasing or preventing wave energy from reaching the shore. Breakwaters are free-standing, enormous structures that directly fight the power of waves. When circumstances are good, the cumulative impact is accretion, which can link breakwater and coastline. For most areas of Malaysia's east coast, particularly Kuala Terengganu, a breakwater is a functionally acceptable erosion control structure. However, in many cases, they are more expensive than other options.

#### *4.2. Control Works and Protection*

Throughout the Kuala Terengganu coastline, structural control measures have been implemented. Expert selection and fieldwork observation took appropriateness and efficacy into account independently. Works were deemed appropriate if the conceptual approach was sound, implying that the structure employed was appropriate. When surveyed, the structure was judged to be effective if it had no structural or functional flaws.

At their bases, seawalls have a tendency to increase erosion and scour. Foundation collapse is probable for most seawalls unless toe protection is provided. Seawalls also have a tendency to speed up erosion at their ends. The wall will be flanked and eventually demolished from the landward side unless it returns to allow for this erosion. These natural symbioses have been seen in numerous coastal regions on the east coast, including the Kuala Terengganu coastal districts.

The predicted socio-economic effects of critical erosion risk regions imply that the social and economic costs of erosion may soon be intolerable. For the Kuala Terengganu area, feasibility studies are needed to more clearly identify and quantify such costs, as well as the costs of control, so that protective investment choices may be taken by impacted institutions. Kuala Terengganu's leisure resorts of Kuala Nerus and Pengadang Buluh are located near Gong Merbau and Left Bank. Ibai, K.

The recreational facility is a sandy beach that is well known and has a strong brand. Erosion has already taken a toll on the beach, which is now just 30 or 40 m wide. There are other beach sites in the region where leisure use may be relocated without too much difficulty. Kuala Nerus and Pengadang Buluh in Kuala Terengganu, on the other hand, are well-known beaches that people are accustomed to visiting. They have developed support facilities and are well known.

When all of these factors are taken into account, a moderate demographic impact is predicted. It receives a modest economic effect rating based on a similar rationale. This gives the feasibility study a lot of weight and makes it a top priority. To establish the most



appropriate protection strategy, the feasibility study will examine breakwaters, jetty, and beach restoration alone and in combination.

#### 4.3. Limitations of the Study

As a result, it is determined that AHP and Expert Choice software can help with decision-making in coastal city areas like Kuala Terengganu; however, there are various challenges and constraints for integrated decision-making models. The insufficiency of sources of environmental criteria and sub-criteria for erosion in the coastal city region is one of the primary constraints of utilizing the AHP model. The insufficiency of sources of environmental criteria and sub-criteria for erosion in coastal regions, for example, was the primary restriction in utilizing MCDA models in this study. Furthermore, there was a lack of a core database for the research area's environmental and coastal cities. Finding recognizable and consistently characterized coastal land-use indicators at individual coastal city sites proved challenging, if not impossible in some circumstances. Because this study was based on limited coastal city data, it can only provide a broad picture of environmental risks in the Kuala Terengganu coastal area. However, as a study of general coastal management and planning in the Kuala Terengganu coastal area, it may point to future research directions.

#### 4.4. Recommendations and Future Work

The findings of this study indicate that mathematical MCDA models and computer software may be used to identify and estimate weights for criterion, sub-criteria, and alternatives for coastal conservation management and planning in Kuala Terengganu. Although the model can show the potential of using these integration methods and provide useful results in the study area, more research and application of this methodology are needed to test the model's transferability in a variety of criteria and alternatives with similar and different coastal hazard assessments. Coastal vulnerability, such as erosion and flooding, can impact conservation and sustainability in coastal city regions; future research on coastal environmental conservation might combine environmental sustainability and vulnerability. The geospatial model used in this study can help coastal managers, planners, and developers identify vulnerable regions and enhance the coastal land-use plan and coastal city management plan. The future sustainability of coastal city systems may then be forecasted using time series data, maps, and satellite pictures for the selected indicators, resulting in a more accurate projection of future sustainability. As a result, decision-making data may be effectively obtained, assisting government policymakers in establishing stronger, more sustainable coastal development. It should be mentioned that the erosion criterion used in this study should be altered in another study area since the criteria used in Kuala Terengganu may not be applicable in other areas. The future sustainability of coastal city systems may then be forecast utilizing a time series data map and satellite pictures for the selected criteria, resulting in a more accurate projected sustainability. As a result, decision-making data may be effectively generated to aid government policy-making in establishing stronger, more sustainable coastal development.

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