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RESEARCH ARTICLE

AN ASSESSMENT OF ENVIRONMENTAL SENSITIVITY IN BATTICALOA DISTRICT, SRI LANKA USING GEOSPATIAL TECHNOLOGY

N. Nithiyatharsan[a], K. Rajendram[b], M.A.C Piyathilaka[a]

[a] Department of Environmental Technology, Faculty of Technology, University of Colombo, Sri Lanka
[b] Department of Geography, Eastern University, Sri Lanka, Vantharumoolai, Chenkalady, 30350.
****Corresponding author Email: skrajendram@gmail.com***

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ABSTRACT

The main objectives of the study are to identify the environmentally sensitive areas in the Batticaloa district using diverse environmental elements and assessment indicators to generate environmentally sensitive area maps and assess the environmental sensitivity based on their functions using geospatial technology. The accessibility of geospatial data related to environmentally sensitive areas provides useful information for the decision-making process in environmental planning and sustainable land management. Geospatial technology is a very powerful tool for monitoring environmental sensitivity. The multi-criteria method and the analytic hierarchy process technique were used by scholars to assess environmental sensitivity. Under this method, assigned weights and pre-established rating criteria were adopted using the weighted sum overlay technique. The present study followed the same method adopting environmentally sensitive area functional indicators of disaster risk, life support system, and heritage value. The environmental sensitivity has been assessed using different criteria such as flood susceptibility, soil erosion, surface water bodies, Land Use/Land cover, agricultural land, forest, and biodiversity index. The integrated environmentally sensitive areas are categorized as four sensitivity classes which are high, moderate, low, and non-sensitivity. The results reveal that the high sensitivity areas include about 17.87% (441 km^2), and moderate and low sensitivity areas were found as around 26.24% (648 km^2), and 35.55% (878km^2) respectively. The non-sensitivity areas covered around 20.34%. The results indicate that importance should be given to environmental conservation in the planning process in sensitive areas. The information about environmentally sensitive areas is significant for decision-making such as land use/land cover planning and sustainable land management practices.

KEYWORDS

Environmental Sensitive Area, Disaster Risk, Life Support System, Heritage Value, Analytic Hierarchy Process.

1. INTRODUCTION

The environment provides us with the goods and services that structure the foundation of our economic, social, cultural, and spiritual lives. Our well-being depends on the continuing capacity of ecosystems and the environment to provide their multitude of benefits. Overexploitation and the utility of resources due to extensive economic growth have become common causes of environmental degradation (Yaakup et al., 2006; Bakr et al., 2012). Environmental sensitivity evaluation is a basis upon which the concept of environmentally sensitive areas (ESAs) can be practiced to protect the environment, regulate development activities, and promote sustainable land use planning (Leman, et al., 2015). ESAs are landscape elements, ecosystems, and places that are imperative to the long-term maintenance of biodiversity, soil, water, and other natural resources (Ndubisi et al., 1995).

The concept of ESAs is used worldwide to protect biological diversity and natural ecosystems. The environmentally sensitive areas must first be recognized to successfully manage and protect them. Sri Lanka has distinguished biological diversity richness. Topography, soil, climate, and ecology provide favorable conditions for an extensive array of flora and fauna across the country, as a result, the country has been identified as a biodiversity hotspot in Asia. Environmental degradation is more prominent in areas within the ecosystem on the Earth because they provide many services that contribute to human well-being and poverty alleviation without a sustainable use of the ecosystem (UN Millennium Ecosystem Assessment Board, 2007). The biodiversity comprises species richness, gene pool, diverse habitat, an intense assortment of forest ecosystems, wetlands, agricultural ecosystems, coastal, marine, and freshwater, etc.

However, the rapid growth of population, climate change, urbanization, and frequent disasters are threats to the environment which persuade for decreasing the environmental quality in Sri Lanka including the study area. Environmental sensitivities are the range of effects of environmental factors. Environmental sensitivity describes the ability of an individual to perceive and process information about their environment. Environmentally Sensitive Areas (ESAs) are essential for the long-term preservation of natural resources through the policy-making for land management practices to regulate mandatory services. The growth of the population is attributed to increasing the demand for natural resources. Minimum environmental considerations in development and planning practices, infrastructure, environmental pollution, illegal trades, extreme climate conditions, and disasters are the main causes of the depletion of

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natural resources and reduction in biodiversity (Ministry of Environment, Sri Lanka, 2021).

The identification and evaluation of the ESAs are important for decision-making in sustainable environmental planning and management. However, insufficient geospatial information at the micro and meso levels related to ESA may lead to difficulty in efficiently identifying, protecting, and sustainably managing the ESAs which emphasizes the need for more research. To protect these areas and avoid negative influences has been researched and developed (Shen et al., 2011). This research aims to identify, and assess the ESA and map them to support and preserve the environment. ESAs need special protection to promote sustainability of the ecosystem balance, environmental equilibrium, and a resilient economy and society.

In Sri Lanka, various environmentally sensitive elements have been protected by adopting several policies. Protected area systems support to preservation of biodiversity and nature in the country through the legal framework of the fauna and flora protection ordinance (UNDP, 2021). The Ministry of Environment in Sri Lanka recently developed a draft of the National Policy on Environmentally Sensitive Areas in 2021. The policy aims to manage and conserve ESAs outside of protected areas by introducing mechanisms to identify sensitive land parcels and management models (Ministry of Environment Sri Lanka, 2021). GIS-based approaches are often widely used to identify ESAs and assessments. The identification and evaluation of ESAs through the application of geospatial information is significant for the decision-making process in sustainable environment and land management practices and especially the geospatial information and the database is very useful for proposed planning in the ESAs. For example, the Environmental Impact Assessment (EIA) process is the early stage of project planning. Based on the provision of the National Environmental Act the area is declared an Environmental Protection Area. Considering this policy as insight, this study aims to identify ESAs in Batticaloa District using Geospatial technology.

In this process to fill the gap of geospatial data and information related to ESAs were generated for Batticaloa district by using different environmental data sources. The Batticaloa District of Sri Lanka has unique ecological diversity, including forests, wetlands, and coastal, marine, freshwater, and agricultural ecosystems. This study will provide geospatial information about ESAs in the Batticaloa district. The availability of geospatial data on ESAs enables public, and private sectors and communities to pay special attention to ESA areas and avoid degradation, and fragmentation in such areas. Further, this research will provide useful information for land use planning and management. A few studies are found in Sri Lanka about ESA mapping however, there is no research in the Batticaloa district on ESAs which emphasizes the need for more research.

The ESAs have unique environmental characteristics that require specific consideration to preserve wildlife corridors, open space, habitat, storm, water management, filtration, flood prevention, and erosion control. Furthermore, protecting surface and groundwater quality. ESAs are essential for the long-term preservation of natural resources. In the previous study, ESAs were classified based on the functions of ESAs, such as disaster risk, and life support systems, heritage value, (Leman et al., 2016). In another study on ESAs were considered as individual environmental features, such as forest coverage, shoreland, peatland, high slope, river riparian, lake riparian, mangrove, key biodiversity area, cultural values, and disaster risk area (Hammond et al., 2019). Various methods and criteria have been utilized by different authors for the assessment of ESAs with a combination of GIS techniques, such as the layer cake model, multi-criteria decision support system, fuzzy matter element model, MEDALUS model (The Mediterranean Desertification and Land Use), evaluation of eco-environmental sensitivity using GIS, LU/LC method and factor overlay model.

The GIS-based eco-environmental sensitivity evaluation is available in the literature. (Wang et al, 2017; Niu et al., 2020). The comprehensive index method considers the significance of ESAs in the context of the larger issues of ecological functioning. The GIS-based integrated ESA evaluation for land-used panning was carried out in Malaysia (Leman et al., 2015). A case study was conducted in Shandong Province, Eastern China by Li, Guo, and Guan. In this study, the ecological protection redline was identified based on the key ecological function, such as net primary production, and the ecosystem services using Arc-GIS (Li, et al., 2018). A GIS-based environmental sensitivity was evaluated using an urban expressway project in Shenzhen, China. In this study, the author adapted spatial overlay analysis to evaluate environmental sensitivity (Wei et al., 2018). This study assessed the spatial variation of eco-environmental sensitivity using remote sensing and GIS platforms. This was performed to evaluate the eco-sensitivity and relative spatial variability in critical soil conservation areas (Niu et al., 2020).

The sensitive urban-environmental areas are identified using a multi-criteria evaluation method with weight combination. The author's objective in this research is to analyze urban Eco-ESAs based on variable weighting methods to identify urban Eco-ESAs. The Eco-Environmental Sensitivity Assessment Index typically consists of assessment indicators related to ecosystem services, such as net primary production (NPP), biodiversity conservation, windbreaks and sand fixation, water, and soil conservation (Wang et al., 2017). This research also includes assessment indicators related to some ecosystem services, such as the biodiversity index and water resources. A geospatial application in desertification monitoring in Rajasthan was carried out using the NOAA-AVHRR Normalize Difference Vegetation Index (NDVI). In this study, NDVI Anomaly Index, integral NDVI (iNDVI), and time trends were used as a proxy for Net Primary Production (NPP) (Rajendram et al., 2021).

2. Study Area

The district of Batticaloa, located in the Eastern part of Sri Lanka, extends between 7°42'36" N latitude, and 81°41'32" E. longitude (Figure 1).

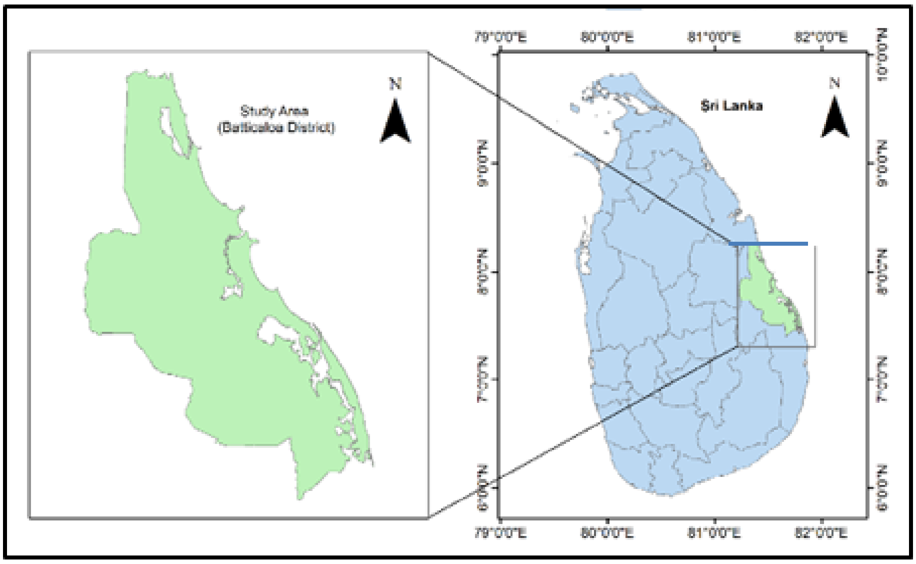

Figure 1: Location of the study area

The area of the district is 2584 Km^2 (1,102 Sq. miles). For administration, the district was divided into 14 Divisional Secretariat Divisions and 346 Grama Niladhari Divisions. The total population of the district is 590,000 (Planning Division, 2021). The climate of Batticaloa is tropical monsoonal. The annual average rainfall of Batticaloa is 1706 mm. In the period between 1871-2020, the highest rainfall was received (3581 mm) in 2011, and the lowest rainfall was recorded (840 mm) in 1968 as a result of massive floods and drought experienced in the district (Rajendram, 2022). The temperature range is between 32.1 °C and 25.87 °C.

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3. MATERIAL AND METHODS

Primary and secondary data were used in this study. Especially, the geospatial data have been obtained from various data portals from web sources. To study the slope, elevation data was obtained from SRTM (30m resolution) USGS-Earth Explorer. This high-resolution elevation data is obtainable from the Shuttle Radar Topographic Mission. To study the LU/LC and NDVI, LANDSAT-8 satellite images (30-meter resolution) were obtained from USGS-Earth Explorer to study the area (2023). In addition to that Esri Land Cover information (10-m resolution) also were used. To study the erosivity digital soil data including soil texture was obtained from the Global Soil Information System (FAO-Soil Portal) To study the climatic condition annual rainfall data was obtained from POWER Data Access viewer and the Department of Meteorology, Colombo (1991-2023). To study the river proximity, the river shape file was obtained from Stanford Digital Repository, and an Open-street map. The environmental elements and variables are given in Table,1.

Table 1: The ESAs Assessment Variables

ESA functions	ESA elements	Assessment Variables
Disaster risk	Topographic condition	Elevation
	Soil erosion	Soil erosion potential zones
	Flood	flood susceptibility zones
Life support system	Food resources	Paddy field (%)
		Other food crops (%)
	Water sources	Distance to surface water sources (m)
		Surface water bodies (%)
Heritage values	Biological diversity	Forest cover (%)
		Distribution of wetlands (%)
		Biodiversity index

3.1 Environmental Sensitivity Analysis Procedure

The flow diagram for the ESA assessment procedure is shown in Figure 2. A group researcher assessed the environmental sensitivity based on the disaster risk, life support system, and heritage value (Leman et al., 2015). The present study also followed all three ESA functional variables. Preparation of geodatabase, the vector and raster layers were integrated using Arc GIS software (Arc GIS 10.41). The composite biodiversity index is derived from the Biodiversity and Linear Infrastructure map and data portal (2023). All these assessment factors were defined as raster and vector data layers in the geospatial environment.

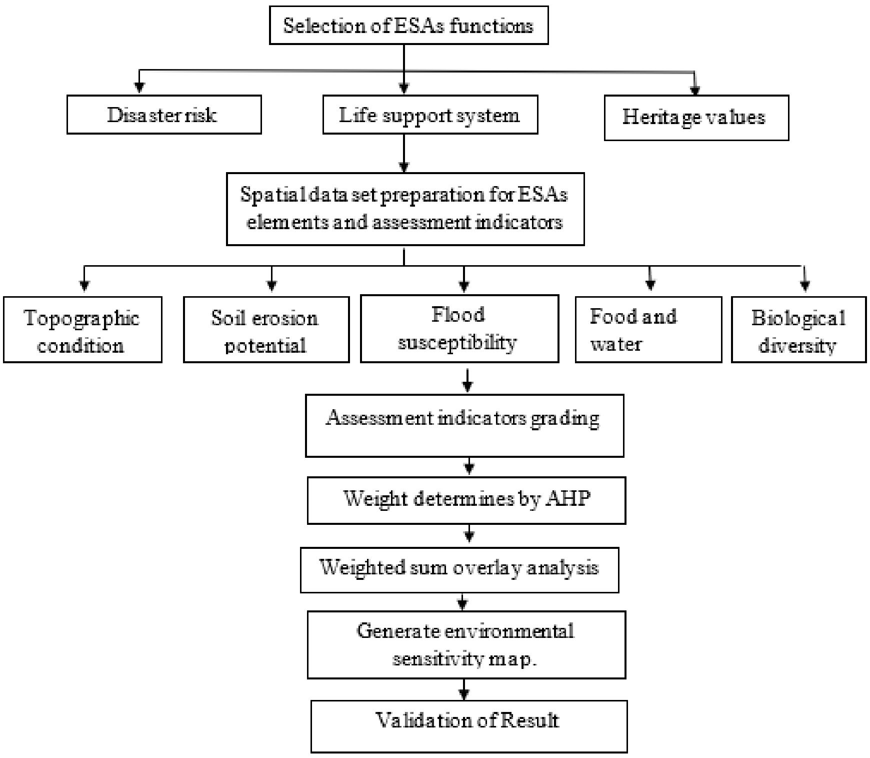

Figure 2: The flow diagram for Environmental Sensitivity Assessment

The environmental sensitivity evaluation was carried out using a Geospatial platform. Geospatial Technology is a useful, cost-effective, and convenient tool for evaluating environmental sensitivity by efficiently measuring, analyzing, and visualizing spatial data collected from the real world (Li et al., 2018). The Geospatial Technology-based eco-environmental sensitivity evaluation is widely applied by many scholars and is available in various literature (Tavana, et al., 2023; Sindhuja et al., 2022; Niu et al., 2020; Li, et al., 2018; Nazren Lemana, et al., 2015; Bahreini, et al., 2013; Pan et al., 2012; Chen et al., 2010; Mukhlisin, et al., 2010; Liu et al., 2008; Basso et al., 2000). The assessment variables were defined as raster data sets with 30m×30m resolution for analyzing ESA using the GIS-based multi-criteria method and the Analytic Hierarchy Process (AHP) techniques. To study the environmental sensitivity each ESA function was individually assessed based on the variables given in Table, 1. Under this method, raster layers with pre-established scoring standards and weights were used for the weighted sum overlay technique to produce an environmental sensitivity map for each ESA function. Using the weighted sum overlay technique, the environmental sensitivity was assessed considering the disaster risk, life support system, and heritage value. The flood susceptibility zone, Land use/Land cover, soil erosion hazard zone, elevation, paddy field, surface water resources, cropland land, forest cover, and the biodiversity index are considered as the assessment variables. Generated spatial maps for the above-selected variables are given in Figure 3a-h.

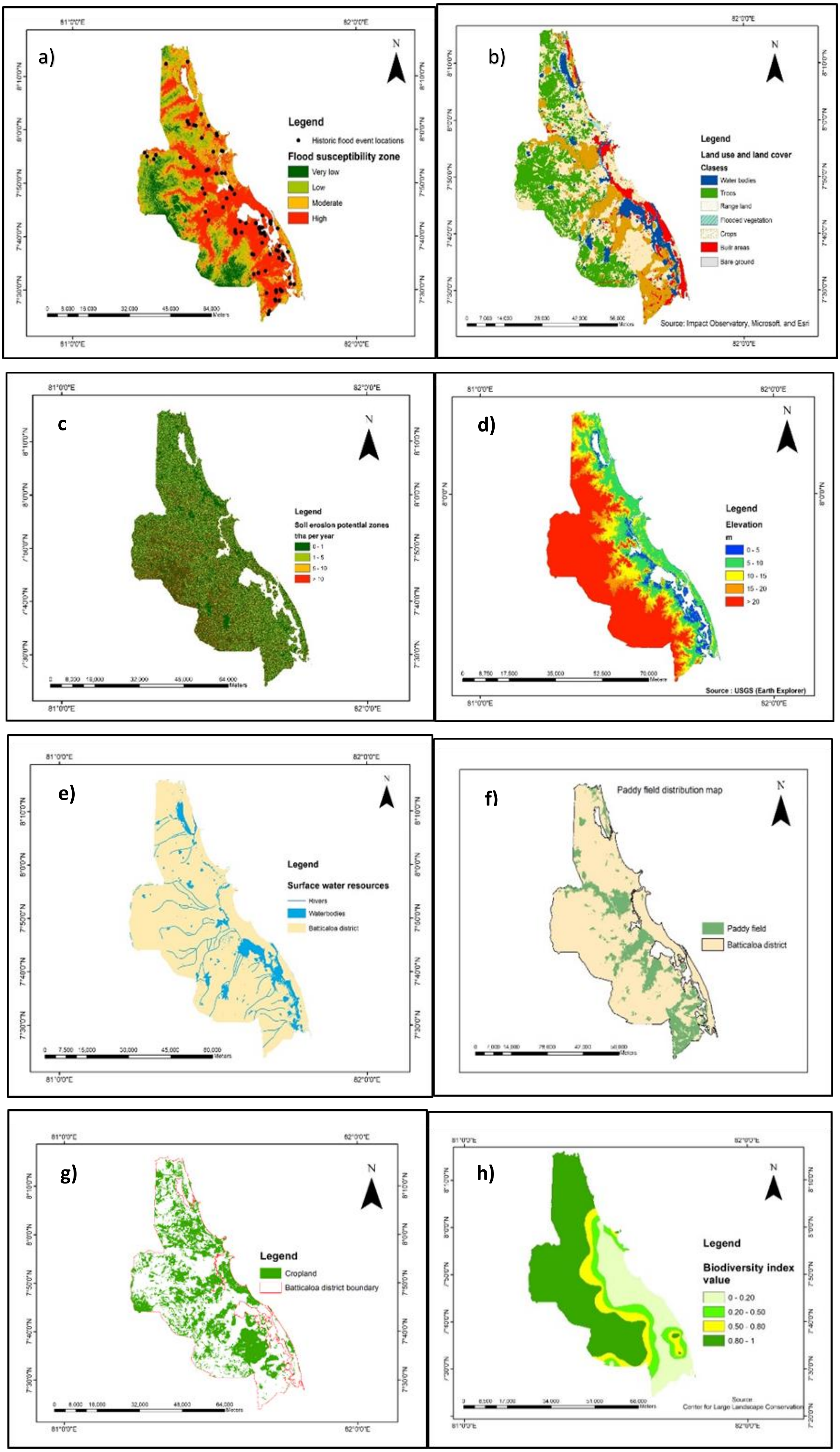

Figure 3: (a) Flood Susceptibility, (b) Land use/Land Cover, (c) Soil Loss, (d) Elevation, (e) Surface Water, (f) Paddy Field, (g) Crop Land, (h) Composite Biodiversity Index

3.2 Classification and grading of environmental sensitivity assessment

First, the grid data in the raster layer corresponding to each indicator were classified into four classes such as non-sensitivity, low sensitivity, moderate sensitivity, and high sensitivity. The sensitivity ranges are specified in Table, 2. This classification and grading method is adapted according to some study (Leman, 2015; Li, et al., 2018; Niu et al., 2020). The index is used to assess environmental sensitivity based on the environmental characteristics, since current environmental issues and concerns.

3.2.1 Determination of the Weight of Assessment Variables

The AHP pairwise comparison method was used to calculate the weights for each assessment variable (Leman et al., 2015; Li, 2018). The weights were calculated by using the principal eigenvector of the decision matrix resulting from a pairwise comparison of the variables' influence on the assessment of environmental sensitivity. The weight calculated for each assessment indicator is shown in Table, 2. A weighted sum overlay analysis has been performed for ESA evaluation for each grid cell based on the weights of each assessment variable for each ESA function. A spatial overlay analysis was then applied, and raster overlay was calculated through a superposition analysis based on the weights of each ESA element to obtain the integrated sensitivity values, according to the multiple-factor evaluation model (Eq.1)

$$M= \sum_{i=1}^{n} Ai\ X\ Wi \quad (1)$$

Where M is the overall environmental sensitivity value of each unit, Ai is the buffer zone score for each ESA element (i.e., A=1,3,5,7), Wi is the assigned weight for each ESA element, and n is the number of the ESA element.

Table 2: Grading system of Indicators for evaluating environmental sensitivity

ESA Function	Weights for ESA Function	Assessment Variables	Classes	Class Ranges	Class rating	Weights (Priority)
Disaster risk	0.33	Elevation (m)	0 - 100	NS	1	0.21
			100 - 200	LS	2	
			200 - 382	MS	3	
		Soil erosion potential zones	< 10	NS	1	0.24
			10 - 25	LS	2	
			26- 50	MS	3	
			>50	HS	4	
		Flood susceptibility zones	Very low	NS	1	0.55
			Low	LS	2	
			Moderate	MS	3	
			High	HS	4	
Heritage values	0.33	Forest cover (%)	< 10	NS	1	0.55
			10 - 25	LS	2	
			26 – 43.49	MS	3	
			-	-	-	
		Distribution of wetlands (%)	< 10	NS	1	0.24
			10 - 25	LS	2	
			26 - 50	MS	3	
			>50	HS	4	
		Biodiversity index	0 - 0.20	NS	1	0.21
			0.20 - 0.50	LS	2	
			0.50 - 0.80	MS	3	
			0.80 - 1	HS	4	
Life support system	0.33	Paddy field (%)	< 10	NS	1	0.5
			10 -25	LS	2	
			25- 25.5	MS	3	
			-	-	-	
		Other food crops in (%)	0 - 10	NS	1	0.5
			10 – 16.44	LS	2	
			-	-	-	
			-	-	-	
		Distance to water bodies and waterways in meter	>150	NS	1	0.5
			100 -150	LS	2	
			50 -100	MS	3	
			< 50	HS	4	
		Surface water bodies %	< 10	NS	1	0.5
			10 - 25	LS	2	
			26- 50	MS	3	
			>50	HS	4	
HS: High Sensitivity MS: Moderate Sensitivity LS: Low Sensitivity NS: No Sensitivity						

Source: Nazren Leman, 2015.

The natural breaks (Jenks) approach was used to classify the final environmental sensitivity map. The integrated environmental sensitivity map was produced by weighted sum overlay analysis. To generate the integrated environmental sensitivity map, the disaster risk, life support system, and heritage value were combined to produce the integrated output map. Raster layers were combined to produce the finalized integrated environmental sensitivity map as specified in Figure 4.

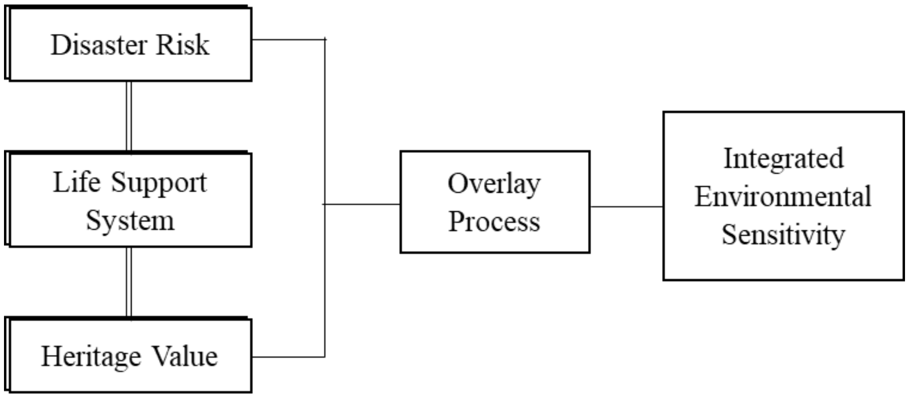

Figure 4: Integrated Environmental Sensitivity Raster Layer Procedure

The proximity has been performed to the water bodies, areas along the rivers, and high erosion potentiality areas for deriving the disaster-related environmental sensitivity. According to the functions of ESAs, soil erosion, flood-prone zone, topographic condition, wetland, forest, paddy land, agricultural land, and bio-site assessment variables were used.

3.2.2 Accuracy Assessment of Classification

In a classification scheme, the accuracy assessment is a crucial aspect. It makes an accurate or ground truth comparison with the classified image. The Kappa coefficient (KC) of agreement was applied to check the accuracy of the generated integrated ESA map. To find the accuracy, the integrated ESA map was classified into two classes using the natural breaks approach (Hamboldt et al., 2019; Feizizadeh et al., 2022). The ground truth points were collected from the field surveys using stratified random sampling techniques based on the identified criteria. About 48 ground truth points were used to find the accuracy of the classification. These 48 ground truth points represent both sensitive areas and non-sensitive areas. The Error matrix was used to calculate the Kappa coefficient (KC). The matrix's assessment indicators, Producer Accuracy (PA), User Accuracy (UA), and Kappa coefficient (KC), make up its total accuracy (Lu and Weng, 2007).

4. Results and Discussion

4.1 Spatial Distribution of Environmental Sensitivity Areas based on the ESAs functions

The ESAs maps were generated from the environmental sensitivity evaluation based on ESAs functions of disaster risk, life support system, and heritage value. The spatial distribution of the ESA map for the study area is illustrated in Figures 5a, b, c and Figure 6. According to disaster risk function high and moderative sensitivity areas were noticed as 14.6% (360.82 km^2) and 29.18% (720.35 km^2) of the total area respectively which indicate the significant areas under disaster prone as well as environmental sensitivity. In the disaster risk map, highly, sensitive areas are predominantly found near the water bodies and rivers proximity (Figure 5a). The low sensitivity areas include 27.46% (677.97 km^2) and non-sensitivity areas 28.75% (709.86 km^2) respectively (Table 3).

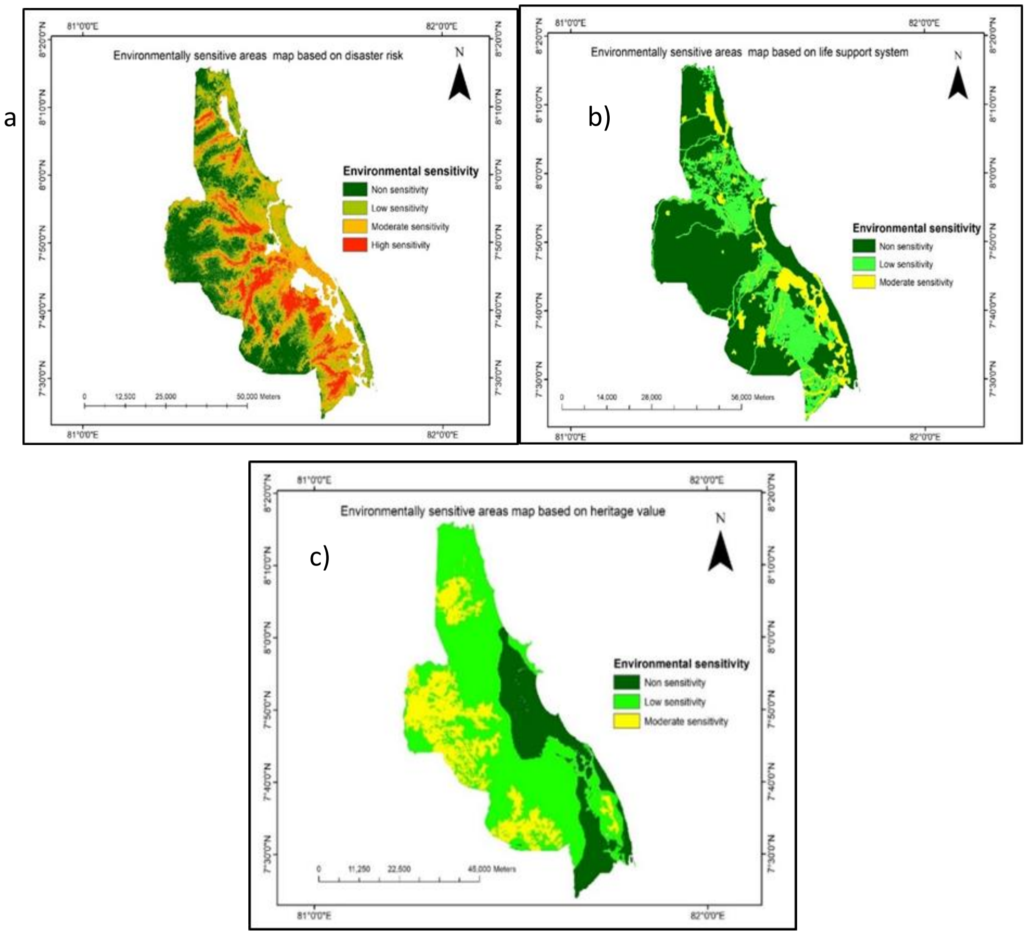

Figure 5: (a) ESAs based on Disaster Risk (b) ESAs based on Life Support System (c) ESAs based on Heritage Value

Table 3: Results of Environmental Sensitivity Evaluation in Batticaloa district based on ESA functions

ESA function	Classification	Areas (km²)	Percentage of total area (%)
Disaster risk	No sensitivity	709.86	28.75
	Low sensitivity	677.97	27.46
	Moderate sensitivity	720.35	29.18
	High sensitivity	360.82	14.61
Life support system	No sensitivity	1630.05	63.18
	Low sensitivity	702.08	27.21
	Moderate sensitivity	247.97	9.61
	High sensitivity	0.00	0.00
Heritage Value	Non-sensitivity	549.67	21.30
	Low sensitivity	1475.80	57.20
	Moderate sensitivity	554.75	21.50
	High sensitivity	0.00	0.00

The findings also point to disaster risk-free zones, which are mostly found in forested areas. The life support system is another function of ESA. Under this category could not find any high sensitivity areas in the study region. Non and low-sensitivity areas were found as 63.18% (1630.05 km^2) and 27.21% (702.08 km^2) respectively. Moderate sensitive areas include only (247.97 km^2) 9.61% (Fig, 5b and Table 4). The surface water bodies and riverine areas represent the areas of moderate sensitivity. Cropland is reflected in low environmental sensitivity. The environmental sensitivity map for heritage value is represented in Fig 5c. The results reveal that the high-sensitivity areas could not be found. Based on the heritage value of ESAs function the findings indicate that most of the areas, which constitute approximately 1475.80 km^2 with less sensitive as specified in Table-3, and Fig.5c. This less sensitive area falls within the rangeland and agricultural fields. Forest areas represent moderate sensitivity, covering 21.5 % (554.75 km^2) of the total area.

4.2 Integrated Environmentally Sensitive Areas (IESA)

The findings indicate that the spatial distribution of ESAs for each ESA function individually and combined. The percentage of the proportion of IESAs and their spatial distribution is shown in Figs.6 & 7 respectively. The greater part of highly sensitive areas encompassed in the or closer to surface water bodies, river basins, and wetlands, which constitute around 441.11 Km^2 (17.87 %) of the total area of the district as specified in Table 6. The moderately sensitive areas constituted about 648.02 Km^2 (26.24 %) of the total land area which adjoin with the highly sensitive zone (Figure 7 and Table 4).

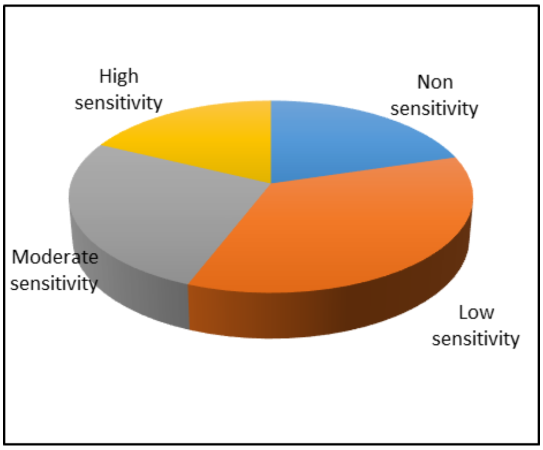

Figure 6: Environmental Sensitivity Areas (Sq. Km)

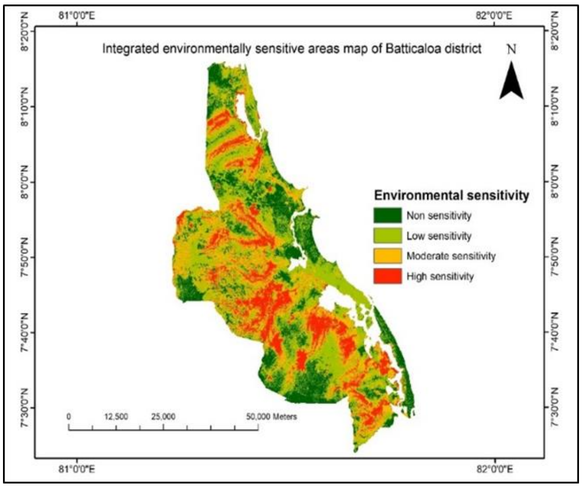

Figure 7: Integrated Environmental Sensitivity Areas

The IESA results reveal that about 44.11% of study areas are either highly or moderately environmentally sensitive areas. About 20.34% of the study area only show non-sensitivity, remaining areas are sensitive which includes about 79.66% (1966.77 Km^2). The identification and evaluation of ESAs are critical to the decision-making process in future land use planning and sustainable land management in environmentally sensitive areas.

Table 4: Integrated Environmental Sensitivity Areas

Category	Areas (km^2)	Percentage of Total Area (%)
No sensitivity	502.23	20.34
Low sensitivity	877.64	35.55
Moderate sensitivity	648.02	26.24
High sensitivity	441.11	17.87

5. Conclusions

This research aimed to study the ESAs in the Batticaloa district by using a Geospatial Technology-based multi-criteria model and the AHP technique. The present study focused on the ESAs by evaluating environmental sensitivity variables of disaster risk, life support system, and heritage value. The IESAs results reveal that about 20.34% of the study area only shows non-sensitivity, the remaining 79.66% of the total areas are environmentally sensitive either high or moderate or low. In general, environmental protection follows two pathways which are maintaining ESAs to minimize the impact of neighboring development and making policies such as riparian areas to preserve the environmental quality. In this process, the results of ESA evaluation are very useful for establishing spatial planning for the conservation and management of natural resources. ESA map is widely used for the decision-making process in land use planning and sustainable land management.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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