Environmental sensitivity index assessment algorithm in coastal areas: A method

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Abstract. Accuracy of data is needed for assessment of environmental sensitivity index (ESI) in coastal areas. This paper aims to create an algorithm and database system for calculating ESI values with three main elements, vulnerability index (VI), ecological index (EI) and socio-economic index (SI). The themes that are calculated include the type of beach, coral reef, mangrove, seagrass ecosystem, and location of community economic activities such as tourism, port, agricultural land, fishpond, salt ponds, mariculture, and capture fisheries. Algorithms are compiled for ESI calculations so that they are structured and accurate through the compilation of databases from VI, EI, and SI determinants, preparation of input tables, and presentation of results of ESI calculations. The database is built using Microsoft Excel software.

1. Introduction

Coastal areas are areas that have a very large influence on the lives of the surrounding communities. An impact occurs; pollution will put pressure both ecologically and economically on existing ecosystems. Generally, some coastal and marine ecosystems which include coastal areas consist of mangrove ecosystems, seagrass beds, and coral reefs. Apart from these three general ecosystems, coastlines, settlements, and places of community activities such as settlements, tourism, fish ponds, salt ponds, marine culture, and fishing areas are also areas that have a sensitivity level to any of pollution [1-3].

Environmental sensitivity or consideration of vulnerability is very important in the management of natural resources, especially in the analysis of interactions between people and ecosystems [1, 3, 4]. The Environmental Sensitivity Index (ESI) is a systematic approach to compiling information about coastal sensitivity, biological resources, and resources utilized by humans [3-5]. Michel and Dahlin [6] and Sloan [3] mention ESI is a classification of a coastal and marine-based on the level of sensitivity to damage towards any oil pollution and other sources of damage. Benefits derived from the calculation of the ESI are information about coastal and marine areas that require protection, maintenance and rehabilitation [2, 7]. This information is presented in the form of an ESI map [3, 4, 7]. In addition, environmental sensitivity analysis is important, because it can provide early warning.
for potential land-use conflicts, and identify the location and level of adverse impacts that may occur to inform planning and decision making [3, 7, 8].

The method or approach used in determining the ESI is divided into three basic types of elements, namely the vulnerability index (VI), ecological index (EI), and socio-economic index (SI). The ESI is interpreted into a formula that includes all three elements [3, 7, 9, 10], also used the method of determining ESI from the modified [3, 4]. The themes calculated by the ESI include beach types, coral reef ecosystems, mangrove ecosystems, seagrass ecosystems, and places of community activities such as settlements, tourism, fishponds, salt ponds, marine aquaculture, and fishing areas.

Sloan [3] and CCMRS-IPB [5] also stated that the algorithm for calculating the value of the ESI of the coastal area is built with three main elements, namely the VI, EI, and SI. Algorithms are sequences of logical steps to solve problems that are arranged systematically and logically, so that the ESI calculation becomes structured and accurate through the compilation of databases of the determinants of VI, EI, and SI, a compilation of input tables, and presentation of the results of ESI calculations. The algorithms are presented by a flowchart, which represents a sequence diagram of the operations performed to obtain the desired outcome.

The purpose of this study is to make a simple application for the ESI calculation with the compiled algorithm. The tool used for the model is Ms. Office Excel, which is a sophisticated spreadsheet application program (electronic worksheets) that is quite popular. Determination of ESI values can be made simpler by using this software, such as in compiling database tables for VI, EI, and SI for each theme, making input tables, and tables of ESI calculation results. One of the main functions used in this study from Ms. Office Excel is the Data Validation and LOOKUP functions, where the LOOKUP function is used to find and retrieve data from a reference table based on a certain value. While Data Validation, is a function that can build a list of input data, so the process of inputting data from the determinants of VI, EI, and SI will be faster because there is no need to retype data, because the input data is made into a kind of data list, and certainly eliminate errors in typing input data. The benefits of this application include, the user can calculate the ESI of each theme quickly and accurately.

2. Calculation methods

2.1. Environmental Sensitivity Index (ESI)

The approach used in this study includes field surveys and data analysis. This approach has two important systems. According to CCMRS-IPB [5], it is stated that two important systems in the field survey approach for coastal areas are the ecological system (coastal and marine), and social system (human-coastal communities).

The approach used in determining the ESI is divided into three basic types of elements, namely the VI, EI, and SI. The ESI is interpreted into a formula that includes all three elements [3, 5].

\[ ESI = VI \times EI \times SI \]

Where:
- ESI : Environmental Sensitivity Index
- VI : Vulnerability index
- EI : Ecological index
- SI : Socio-economic index

Observations made in the study of ESI, divided into several locations that are assumed to be areas potentially affected by any of oil spill incident. The determination of the level of sensitivity is then determined based on the value of the ESI obtained by each ecosystem (Table 1).
Table 1. Environmental sensitivity score and level.

| ESI SCORE | Sensitivity Level | Sensitivity Colour |
|-----------|-------------------|--------------------|
| 1         | Not Sensitive     |                    |
| 2 – 8     | Less Sensitive    |                    |
| 9 – 27    | Moderate          |                    |
| 28 – 64   | Sensitive         |                    |
| 65 – 125  | Very Sensitive    |                    |

Source: modified by CCMRS-IPB [5].

2.2. Vulnerability Index (VI)

Vulnerability index is an illustration of how severe the ecosystem is affected by the impact. VI observations in this study are by identifying the ecosystem conditions or parameters that can be used as sensitive area levels if they are affected by any impact of oil spill events at a location, such as mangrove ecosystems, coral reefs, seagrasses, economic activities such as tourism, ponds, etc. Determination of the score of the VI is based on a qualitative assessment with five levels of sensitivity [3, 5]. Determination of the level of sensitivity made for the VI to each observation of the ecosystem and human utilization area is done collecting data of the environmental conditions in the study area. Determination of the sensitivity level to each ecosystem is identified by assuming if the ecosystem has an influence from the environment in the form of pollution (oil exposure). This condition will make nature is disrupted and can eliminate the function or use of the ecosystem. Based on this, the determination of the level of sensitivity to mangrove ecosystems, coral reefs, fishing areas, beach types, tourism areas, and others is carried out based on subjective assessment (expert justification), based on the criteria established by Sloan [3] and NOAA [4] as well as the modification of CCMRS-IPB [5].

2.3. Ecological Index (EI)

The EI of each ecosystem and the activities contained in the observation can be calculated using the geometric mean aggregation technique as follows [3]:

$$EI_j = \sqrt[1]{(E_{j1} \times E_{j2} \times E_{j3})}$$

Note: $EI_j = $ Ecological index value j; $E_{ji} = $ Score ecological value criterion i at location j.

Calculation and determination of the score of each ecosystem are determined based on the method obtained based on the existing references. The scores of each ecological value of each ecosystem in detail can be calculated, determined as follows.

EI in mangrove ecosystems is determined by calculating the aggregation of the number of species, the density of mangroves, protection status, wildlife habitat, and types of mangrove species. EI value of mangrove ecosystems will be higher if it consists of more than three species, has a density of more than 1,000 ind/ha, if it is a conservation area, if it is alienated with more than three wildlife habitats, and inhabited by genus that is sensitive to any oil spill pollution [8]. The EI table for mangroves is simplified by the CCMRS-IPB modification method (Table 2) [5].

2.4. Socio-Economic Index

The social value of the mangrove ecosystem is defined as the function of the mangrove ecosystem in meeting the needs of the surrounding community. The social benefits of ecosystems for coastal areas
according to Grigalunas and Congar [11] were adopted and modified by CCMRS-IPB [5] can be identified based on any potential economic activity that can be developed in the area (Table 3).

**Table 2.** Ecology index and scoring (mangrove ecosystem).

| ECOLOGICAL CRITERIA | INDEX 1 | INDEX 2 | INDEX 3 | INDEX 4 | INDEX 5 | SITE SCORES |
|----------------------|---------|---------|---------|---------|---------|-------------|
| SITE                | Score Index | Score Index * 0.15 |
| MANGROVE - Mangrove dominant species | Bruguiera sp., Nypa sp., Xylocarpus sp., Scyphiphora sp. | Luminitzeras sp., Rhizophora sp., Ceriops sp., Sonneratia sp., Excoeceria sp., Avicennia sp. | Score Index | =Score Index * 0.15 |
| - Mangrove Diversity (Shannon Index) | 1 | - | 1 – 3.322 | > 3.322 | Score Index | =Score Index * 0.15 |
| - Mangrove Density (ind/ha) | < 600 | 600-900 | 900-1200 | 1200-1500 | > 1500 | Score Index =Score Index * 0.13 |
| - Protected Status | Not protected | - | Locally conserved | Nationally conserved | Score Index =Score Index * 0.1 |
| - Wildlife Protected | Not exist | 1-2 | 3 | > 3 | Score Index =Score Index * 0.27 |
| - Tidal Exposure | Low exposure | - | Medium exposure | High exposure | Score Index =Score Index * 0.20 |
| TOTAL RATING | TOTAL | | | | Geometric Mean |

Source: CCMRS-IPB [5] and Jupites et al. [10].

**Table 3.** Mangrove ecosystem and socio-economic index and scoring.

| ECOLOGICAL CRITERIA | INDEX 1 | INDEX 2 | INDEX 3 | INDEX 4 | INDEX 5 | SITE SCORES |
|----------------------|---------|---------|---------|---------|---------|-------------|
| SITE                | SITE 1 | Score |
| MANGROVE - Potential for tourism development area | Not potential | Less potential | Moderate | Potential | Very potential |
| - Fishing ground | None | Rare | Moderate | Intensive | Very intensive |
| - Other utilization | None | Less utilized | Moderate | Utilized | Highly utilized |
| TOTAL RATING | | | | | Geo Mean (Score) |

Source: Modified by CCMRS-IPB [5].

### 3. ESI calculation algorithm

Algorithms are sequences of logical steps to solve problems that are systematically and logically arranged. Logical thinking is the key to a developed algorithm. The algorithm for constructing ESI calculation can be described by a flowchart (Figure 1).
Figure 1. ESI calculation system development algorithm.

From the flowchart presented in Figure 1, it is seen that the process of building the ESI calculation system includes the following stages:

1) Determination of the theme of the data to be calculated in the ESI, including the theme of the type of beach, coral reefs, mangrove ecosystems, seagrass beds, marine culture, fish/shrimp ponds, salt ponds, tourism, settlements, and capture fisheries.

2) Preparation of the ESI determinant criteria table was adopted from the criteria compiled by CCMRS-IPB [5], into a database. As an example, the compilation database of EI of mangrove determinant criteria can be seen in Figure 2. Database tables compiled consists of a VI database table, a table of determinants of the EI and a table of determinants of the SI of each theme. The preparation of this database table is done in Ms. Office Excel. The database table can be seen in Appendix 1.

Figure 2. Example of compiling an Ecological Index (EI) database of mangroves from the criteria table compiled according to CCMRS-IPB [5].

3) Data input tables VI, EI, SI, ESI, CRITERIA OF SENSITIVITY, etc. is prepared, where each thematic in one-unit table, the input data table contains fields.

4) Preparation of VI, EI, SI template of each theme based on a database table that has been compiled using LOOKUP functions in Ms. Office Excel software. LOOKUP is a function of Ms. Office Excel is used to find and retrieve data from a reference table based on a certain value. By using this function, the data input process (VI, EI, SI) will be faster because there is no need to retype data and eliminate errors in typing input data and the index values of each theme automatically
appear. Besides that, with this function, errors in data input are not possible because each database has been locked by its input needs (Figure 3).

5) Data Validation Process is a function that can build a list of input data, so the process of inputting data from the determinants of VI, EI, and SI will be faster because there is no need to retype the data. This also as a way to minimize errors while typing the input data. Process of validation is seen in Figure 3.

![Figure 3](image1.png)

**Figure 3.** Examples of lookup function schemes and data validation (list data) determinants of EI mangrove dominant species in the mangrove data input table.

6) Calculations of VI, EI, and SI values are done based on geometrical averages. These geometric mean formulas are found in Ms. Office Excel (GEOMEAN).

7) Values of VI, EI, and SI are processed to calculate the final ESI value by using the formula of ESI = VI * EI * SI.

8) Displaying the results of ESI values using sensitivity criteria and the following symbol colours: Not Sensitive (green), Less Sensitive (yellow), Moderate (blue), Sensitive (pink), and Very Sensitive (red) (IF-Then and Conditional Forming Functions). All process explained are presented in Figure 4.
4. Testing the system

The following steps are conducted to test the system, whether it is running well or not:
1) Select the theme that the ESI will count (case study: the theme of mangrove ecosystem);
2) Open the theme worksheet;
3) Input the name of the observation location;
4) Input VI;
5) Input the EI, consist of (a) the dominant mangrove species; (b) the mangrove diversity (Shannon Index); (c) the mangrove density (ind/ha); (d) the mangrove protected status; (e) the protected wildlife; (f) tidal exposure;
6) Input the SI consists of the potential of (a) tourism development area; (b) the fishing ground; (c) other utilization; and
7) Output generated by the system: (a) VI; (b) EI; (c) SI; (d) ESI; (e) Sensitivity Criteria; (f) Colour sensitivity criteria.

The case study system presented in this paper is ESI calculations for the theme of mangrove ecosystems only. The steps to calculate mangrove ESI in this system are as follows:

4.1. Display the mangrove data input table

Figure 5 shows the columns for all determinants of VI, EI, and SI values as well as the ESI calculation columns, ESI criteria and colour symbol fields for sensitivity. Data input is based on observations in the field. Observation location is the main key in input data because the data in the input table is arranged based on the observation location.

Figure 5. Display the mangrove data input table.
4.2. Determine the value of mangrove Vulnerability Index (VI)
Display list of Mangrove VI determinant data in the VI Mangrove Vulnerability field by clicking on the data list button, then the value VI appears automatically in the ‘VI field’ (Figure 6).

![Figure 6. Display automatic display of VI values in the mangrove data input table.](image)

4.3. Determine the Ecological Index (EI) mangrove value
There are six determinants for calculating the EI value of mangroves in a location, namely dominant species of mangrove, mangrove diversity, mangrove density, protected status, protected wildlife, and tidal exposure, each of which has their respective index values according to its parameters. For the total EI mangrove value, it is calculated as the total value of each existing determinant index.

4.3.1. Mangrove dominant species. Display the list of EI determinants ‘Mangrove dominant species’ in the ‘Mangrove dominant species’ field like shown in Figure 7.

![Figure 7. Process of selecting dominant species of mangroves.](image)

4.3.2. Mangrove diversity (Shannon Index). Select the determinant of EI’s ‘Mangrove Diversity (Shannon Index)’ whose value matches the observation data by clicking on the appropriate option (Figure 8).

![Figure 8. The process of selecting ‘Mangrove Diversity’](image)
4.3.3. Mangrove density (ind/ha). Select the determinant of EI’s ‘Mangrove Density (ind/ha)’ whose value matches the observation data by clicking on the appropriate option (Figure 9).

![Figure 9](image)

**Figure 9.** The process of selecting ‘Mangrove Density’.

4.3.4. Mangrove protected status. Select the determinant of EI’s ‘Mangrove Protected Status’ whose value is according to observational data (Figure 10).

![Figure 10](image)

**Figure 10.** The process of selecting EI’s ‘Mangrove Protected Status’ determinant.

4.3.5. Protected wildlife. Select the determinant factor for EI ‘Wildlife Protected’ whose value is according to observational data (Figure 11).

![Figure 11](image)

**Figure 11.** The process of selecting the EI determinant factor ‘Wildlife Protected’.

4.3.6. Tidal exposure. Select the determinant of EI ‘Tidal Exposure’ whose value is by observational data (Figure 12).

![Figure 12](image)

**Figure 12.** The process of selecting the determinants of EI mangroves ‘Tidal Exposure’.
4.4. Determine mangrove Social Value Index (SI)
There are three determining factors for calculating the value of SI mangroves in a location, namely the potential for the tourism development areas, fishing ground, and other utilization, each of which has its respective index values according to the respective parameters. For the total mangrove SI value, it is calculated as the total of the values of each existing determinant index.

4.4.1. Potential for the tourism development area. Select the determinant of the mangrove SI ‘for Potential for tourism development area’ whose value is by observational data (Figure 13).

| Potential for tourism development area | SI_T_D |
|--------------------------------------|--------|
| 1. Potential for tourism development area - Not Potential | N/A    |
| 2. Potential for tourism development area - Less Potential | N/A    |
| 3. Potential for tourism development area - Moderate | N/A    |
| 4. Potential for tourism development area - Potential | N/A    |
| 5. Potential for tourism development area - Very Potential | N/A    |

Figure 13. The process of selecting mangrove SI determinants ‘Potential for the tourism development area’.

4.4.2. Fishing ground. Select the determinant of the SI mangrove fishing ground chosen in the ‘Fishing ground’ field in the mangrove data input (Figure 14).

| Fishing ground | SI_F_G |
|----------------|--------|
| 1. Fishing ground - None | N/A    |
| 2. Fishing ground - Rare | N/A    |
| 3. Fishing ground - Moderate | N/A    |
| 4. Fishing ground - Intensive | N/A    |
| 5. Fishing ground - Very intensive | N/A    |

Figure 14. The process of selecting the determining factors for SI mangrove ‘Fishing ground’.

4.4.3. Other utilization. Display the list of mangrove SI determinants of ‘Other utilization’ data in the ‘Other utilization’ field by clicking on the data list button (Figure 15).

| Other utilization | SI_O_U |
|-------------------|--------|
| 1. Other utilization - None | N/A    |
| 2. Other utilization - Less utilized | N/A    |
| 3. Other utilization - Moderate | N/A    |
| 4. Other utilization - Utilized | N/A    |
| 5. Other utilization - Highly Utilized | N/A    |

Figure 15. The process of selecting the mangrove SI determinant factor ‘Other utilization’.

4.5. Calculation of ESI values, sensitivity criteria and colour of mangrove sensitivity
The calculation of mangrove ESI values, sensitivity criteria and colour symbol sensitivity are calculated automatically using the functions found in Ms. Office Excel (Figure 16).
Figure 1.6. Display ESI values, sensitivity criteria and sensitivity colour symbols in the Mangrove input table.

For data input in other locations, the same steps are carried out as the steps above, until all observational data is entered in the data input table. Examples of the results of mangrove data input can be seen in Figure 1.7.

Figure 1.7. Example display of ESI values, sensitivity criteria, and sensitivity colour symbol on the mangrove input table.

5. Conclusions
The ESI value for coastal areas can be calculated with three main elements, including the VI, EI, and SI. They can be built with an algorithm or with logical steps systematically and logically arranged, so that the ESI calculation becomes structured and accurate through the compilation of databases from the determinants of VI, EI, and SI, preparation of input tables, and presentation of ESI calculation results.

The tool used in building the calculation system is Ms. Office Excel, special functions used such as LOOKUP, GEOMEAN, Data Validation, and Conditional Formation, which have their respective functions in the construction of this system. From the results of the trial implementation, there are several advantages of the system being built:

1) A simple system that is easy to use (User-friendly)
   The system built can be easily operated by the user; no specialized training is needed to operate this system; it only takes a little introduction to the procedure for operating the system.

2) The ESI calculation process can be obtained quickly and accurately
   This is because the entire calculation process in this system is calculated using functions that exist in Ms. Office Excel, such as the multiplication, addition, and determination of sensitivity criteria using formulas applied in the system.

3) Users do not type manually in data input and minimize data input errors
   Users do input data without manual typing at all, because all the inputted data is built in the database, at this point the user in inputting data makes a selection of data, then executes it, in this way data input errors can be minimized.

4) Does not require qualified computer specifications

5) The final result is a database that is ready to be combined with the system in GIS because the data format has been arranged in a database, and then the data can be combined with the system in GIS, by pinning this data table with the spatial data.

6) With this simple algorithm and software, ESI calculation can be performed more systematic and simpler and can be used as input for decision-makers in deciding priority area related to the protection of coastal area towards any oil spill events.
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## Appendix 1.

Database compilation of the determinants of VI, EI, SI

### 1) Mangrove Ecosystem

1.a. Mangrove Vulnerability Index (VI) Table

| VULNERABILITY CRITERIA                  | VULNERABILITY INDEX |
|----------------------------------------|---------------------|
| Mangrove Ecosystem                      | 5                   |

1.b. Mangrove Ecology Index (EI) Table

| ECOLOGICAL CRITERIA                      | ECOLOGICAL INDEX |
|------------------------------------------|------------------|
| Mangrove dominant species - *Bruguiera* sp., *Nypa* sp. | 1               |
| Mangrove dominant species - *Lumnitzera* sp., *Xylocarpus* sp., *Scyphiphora* sp. | 2               |
| Mangrove dominant species - *Rhizopora* sp., *Ceriops* sp. | 3               |
| Mangrove dominant species - *Sonneratia* sp., *Excoeceria* sp. | 4               |
| Mangrove dominant species - *Avicennia* sp. | 5               |
| Mangrove Diversity (Shannon Index) 1     | 1               |
| Mangrove Diversity (Shannon Index) 1 – 3.322 | 3               |
| Mangrove Diversity (Shannon Index) > 3.322 | 5               |
| Mangrove Density (ind/ha) < 600          | 1               |
| Mangrove Density (ind/ha) 600 – 900      | 2               |
| Mangrove Density (ind/ha) 900 – 1200     | 3               |
| Mangrove Density (ind/ha) 1200 – 1500    | 4               |
| Mangrove Density (ind/ha) > 1500         | 5               |
| Protected Status - Not protected         | 1               |
| Protected Status - Locally conserved     | 3               |
| Protected Status - Nationally conserved  | 5               |
| Wildlife Protected – Not exist           | 1               |
| Wildlife Protected – 2                   | 2               |
| Wildlife Protected – 3                   | 3               |
| Wildlife Protected > 3                   | 5               |
| Tidal Exposure - Low exposure            | 1               |
| Tidal Exposure - Medium exposure         | 3               |
| Tidal Exposure - High exposure           | 5               |

1.c. Mangrove Socio-Economic Index (IS) table

| SOCIO ECONOMIC CRITERIA                   | SOCIO INDEX |
|------------------------------------------|-------------|
| Potential for tourism development area - Not potential | 1           |
| Potential for tourism development area - Less potential | 2           |
| Potential for tourism development area - Moderate | 3           |
| Potential for tourism development area - Potential | 4           |
| Potential for tourism development area - Very potential | 5           |
| Fishing ground - None                     | 1           |
| Fishing ground - Rare                     | 2           |
| Fishing ground - Moderate                 | 3           |
| SOCIO ECONOMIC CRITERIA                  | SOCIO INDEX |
|-----------------------------------------|-------------|
| Fishing ground - Intensive              | 4           |
| Fishing ground - Very intensive         | 5           |
| Other utilization - None                | 1           |
| Other utilization - Less utilized       | 2           |
| Other utilization - Moderate            | 3           |
| Other utilization - Utilized            | 4           |
| Other utilization - Highly Utilized     | 5           |