Environmental sensitivity index mapping as a prevention strategy against oil spill pollution: A case study on the coastal area of South Sumatera Province in Indonesia

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Abstract. Coastal areas are vulnerable to oil spill pollution from tanker accidents or unappropriated operational procedures from the oil and gas industry. This study was aimed to develop a prevention strategy to minimize damage and to ensure vulnerable natural resources and local community fisheries economic activities in coastal areas are protected. The local community utilizes fisheries resources in coastal waters of South Sumatera Province as their main livelihood. The potential of fish and shrimp resources in this area is quite abundant due to the existence of good mangrove ecosystems and located in the high-organic environment of Musi River estuary. On the other hand, the area is highly potential to be threatened by oil spill accident from the nearby of Bangka Strait just right in front of the Musi Estuary. A model named Environmental Sensitivity Index (ESI) has been developed to classify the level of sensitivities along the shoreline and habitats of the study area to protect such area. Environmental sensitivity index takes into account the vulnerability, biological and socio-economical characteristics for each coastal environmental feature such as fisheries resources and mangrove ecosystem. These three fundamental ESI elements are transferred into three indexes, i.e. Vulnerability Index, Ecological Index and Social Index. Spatial analysis through the geographic information system of overlay technique is applied to determine each environmental feature to produce ESI Map. The results of the ESI analysis show that coastal waters which are habitat of brackish water fishes and shrimps harvested by passive fishing gear such as Kelong (a combination of Guiding Barrier and Fixed lift net) and Sero (Guiding Barrier) are categorized as the sensitive category, while other offshore waters are classed as moderate level. Shoreline type and mangrove ecosystems classified as very sensitive. As consequences, this area must be a top priority in protecting the area from any oil spill pollution. ESI analysis can be used as an appropriate tool in the determination of priority area need to be protected from any oil spill events.

Keywords: oil spill, fisheries resources, geographic information system, environmental sensitivity index.
1. Introduction

Environmental sensitivity should provide early warning for potential land-use conflicts, and identify the location and extent of likely adverse effects in order to inform planning and decision-making [1]. Sensitivity defined as the potential impact on a system from perturbations, including shocks and stress [2]. The issue of sensitivity can be generally related to the topic of sustainable development. As Nijkamp and Vreeker [3] have noted the sensitivity concept is one of the sustainability constraints together with, for example, the concept of minimum safety standards, quality standards, carrying capacity, eco-capacity, maximum sustainable yield, critical loads, environmental utilization space, etc. Such concepts may be useful for policy analysis and operational planning. Moreover, Van Pelt and Kuyvenhoven [4] mentioned that a sustainability constraint has at least four attributes: (1) it is expressed in one or more measurable parameters; (2) these parameters are linked to sustainability targets; (3) the parameters have proper geographical scale; and (4) these parameters have also relevant time dimension. It is also stated that ideally, these parameters should be mapped out as quantitative factors, but in reality, it is often confronted with qualitative, fuzzy and incomplete information [3]. In this context, therefore, a better understanding of the habitats and ecosystems and their sensitivity can be derived through the development of Environmental Sensitivity Index (ESI).

Sensitivity mapping of a coastal area is used to support the development of a response strategy for oil spill contingency plans. Sensitivity mapping of the various types of environments and resources potentially exposed to oil spills enables the identification of the most sensitive sites or resources, thus providing a basis for the definition of priorities for protection and clean-up, and information to plan the best-suited response strategy [5].

![Figure 1. Study area of coastal area of South Sumatera Province.](image)

In practical terms, environmental sensitivity can be associated to quality status of a given biophysical factor, the presence of a protected species or designation (e.g. biodiversity conservation areas would be naturally susceptible to change) and risks [1]. Therefore, the objectives of the study are
to develop an index named environmental sensitivity index which able to analyses the sensitivity level (ESI) of each environment entity (ecosystem, shoreline, and fisheries resources) in form of spatial data and to determine class of priority in term of environmental resources protection as prevention strategy against oil spill accident.

2. Methodology

2.1. Study area
The study was done in the coastal area of South Sumatera Province, facing to Bangka Strait (Figure 1). Access to reach this area is only through waterway along the Musi River and coastal water area. Shoreline type is dominated by the muddy beach and inhabited by mangrove vegetation. This shallow water area is affected by high-organic sediment of the Musi River. The local community utilizes the area as their fishing ground with major fishing gears such as Kelong (a combination of Guiding Barrier and Fixed lift net) and Sero (Guiding Barrier).

2.2. Analysis of Environmental Sensitivity Index
The development of ESI involves two important systems, namely: (1) coastal resources system (ecological system), and (2) coastal community system (social system). ESI is developed as a block of equation which incorporates two resources systems. The ESI system was initiated using the approach suggested by the National Oceanic and Atmospheric Administration [6]. It is comprised of three general types of information namely:
1) Shoreline classification; which are ranked according to a scale relating to sensitivity, natural persistence of oil, and ease of clean-up;
2) Biological resources including oil sensitive animals, and habitats which are utilized by oil-sensitive species such as submerged aquatic vegetation and coral reefs;
3) Human-uses resources; specific areas that have added sensitivity and value because of their use by humans, such as high-use amenity beaches, parks and marine sanctuaries, water intakes, and archaeological sites.

ESI value describes the relative environmental sensitivity of each area which is calculated and displayed as map layers. The area outlined in the sensitivity maps represents an integration of three main components of the ESI, namely Vulnerability Index (VI), Ecological Index (EI) and Social Index (SI). The integration of these values can be represented in a composite equation as follow:

$$CESI_i = \frac{1}{3} (VI + EI + SI)$$

Where: CESI, is the composite ESI of the area i based on pixel data of Geographical Information System (GIS) map.

Each component, i.e. vulnerability, ecological and social, have a value between 1 (minimum = the least sensitive) to 5 (maximum = the most sensitive). Since the Composite ESI (CESI) is a multiplication among these components, hence the CESI values range from 1 (the least sensitive) to 125 (the most sensitive). This formula is developed by CCMRS-IPB [7], which is referred to as ESI guidelines of NOAA [6]. Therefore, the CESI has a value between 1 to 5 and is categorized as follows:

| CESI value | Sensitivity level          |
|------------|---------------------------|
| 1          | Not Sensitive             |
| 1.1 - 2.0  | Less Sensitive            |
| 2.1 – 3.0  | Moderate                  |
| 3.1 – 4.0  | Sensitive                 |
| 4.1 – 5.0  | Very Sensitive            |

Table 1. Level of sensitivity based on composite environmental sensitivity values.
As represented in the equation, the sensitivity level of the study areas are determined based on the thematic layer according to the characteristics of the natural and human resources systems. This analysis will be presented as digital maps using GIS technology to undertake overlay modelling. Figure 2 shows the algorithm of this ESI approach.

![Algorithm Flowchart](image)

Figure 2. Schematic framework for developing environmental sensitivity index.

3. Results and discussion
ESI analysis includes the following thematic:

3.1. Shoreline type
The criteria for the shoreline type are determined based on the characteristic of shoreline type, and its ecological and economic values of shoreline utilization.

3.2. Mangrove
Based on Sloan [8], mangrove has the highest index (5) of vulnerability against the oil spill. Ecological resource analysis use parameters: density, Number of species, species diversity, tidal exposure, protected area and number of wildlife. Social value is calculated based on criteria of Potential tourism development area, Fishing ground and other mangrove utilization such as for construction/housing materials. Economic value is calculated based on resource economic approach.

3.3. Capture fisheries
The criteria for the vulnerability and ecological index for capture fisheries theme is determined by the type of fishing gear (active or passive gear) and category of fish catch (fish, Shells, or shrimp). The social value of capture fisheries is defined based on criteria fishing gear selectivity and the number of fishermen, while the economic value of capture fisheries is defined based on the frequency of catch (trip) and fishing cost.

3.4. Human settlement
The vulnerability Index of the settlement is defined based on the percentage of houses located in the shoreline. The ecological value of the settlement is defined based on the availability of fresh water supply for the inhabitants. The social value of the settlement is defined based on a social characteristic such as Human population density.
3.5. Agriculture field

The vulnerability Index of agricultural field and Ecological Index is determined as 3 (Based on Sloan [8]). Social index based on per cent of farmer and number of various cultivated.

Estuarine area of Bangka Strait has several small rivers as part of Musi River watershed. This fertile area in fisheries resources, especially shrimp, is supported by the availability of nutrient sourced from the catchment area of Musi River and surrounding mangrove areas. The sustainability of fisheries potential in this location is highly dependent on the existence of a healthy mangrove and estuary ecosystem. Disturbance or damage to the environment will affect the lifecycle processes of fish. Considering the location of the study is close to the activity of the vessel traffic both commercial vessels and oil tankers, this location has the potential for oil spills and threatens the preservation of natural resources such as mangroves and fish resources in coastal areas.

Sustainability of potential fisheries resources must be supported by management for ensuring conducive environment such as maintaining of water quality, preventive measures to avoid water pollution, functioning of food web systems, ensuring for the functioning of coastal ecosystems (mangroves, seagrass, and coral reef). FAO [9], release a more comprehensive approach to the implementation of the code of conduct for responsible fisheries in all its aspects namely Ecosystem Approach to Fisheries (EAF) that include from assessment to management and from capture to processing and trade.

An oil spill can cause disturbance to the food chain process on coastal water areas and interrelationship with fisheries. Wild fishes can swim away, avoiding oil spill. However, fishes can come back into an area following a successful oil spill recovery to some extent. Fisheries can also be interrupted if seasonal migration routes are changed as a consequence of an oil spill. Oil spills can consequence in loss of fishing opportunities with fishing fleet unable or unwilling to fish due to the risk of fouling. Coastal water areas may experience temporary financial loss to profitmaking fisheries for artisanal fishermen. While fish caught will cause a temporary shortage and decrease fish market stock. Losses due to the decline in fish stocks need a more comprehensive study several years after the pollution event. The result of ESI mapping is presented in Table 2 and Figure 3.

Table 2. Result analysis of Environmental Sensitivity Index.

| Unit of Analysis | Shoreline Type | Mangrove | Fisheries | Human Settlement | Agricultural Field |
|------------------|----------------|----------|-----------|------------------|-------------------|
|                  | ESI Class | ESI | ESI Class | ESI | ESI Class | ESI | ESI Class | ESI | ESI Class | ESI | ESI Class |
| West Kuala Upang | Very Sensitive | 5 | Very Sensitive | - | - | - | - | 2.82 | Moderate |
| Kuala Upang | Very Sensitive | 5 | Very Sensitive | - | - | 3.32 | Sensitive | 2.82 | Moderate |
| Salek Cape | Very Sensitive | 5 | Very Sensitive | - | - | 3.56 | Sensitive | 2.82 | Moderate |
| West Kuala Sugihan | Very Sensitive | 5 | Very Sensitive | - | - | - | - | 2.82 | Moderate |
| Kuala Sugihan | Very Sensitive | 5 | Very Sensitive | - | - | 3.91 | Sensitive | 2.82 | Moderate |
| Coastal Water | Very Sensitive | - | - | - | 3.28 | Sensitive | - | - | - |
| Offshore | Very Sensitive | - | - | - | 2.69 | Moderate | - | - | - |

1 https://www.itopf.org/
Figure 3. ESI Map Coastal Area of South Sumatera Province.

As a result of the sedimentation process, this has formed the shoreline types of muddy substrate that creates and ecologically productive environment. Shoreline type of the whole area is a muddy substrate and inhabited by mangrove so that their vulnerability index and ecological index a have maximum index that is 5. Also, the muddy and mangrove shoreline type has very potential for economical utilization as a fishing ground. Furthermore, the sensitivity level of all shoreline type is classified as “Very Sensitive”.

Mangrove ecosystems are observed at West Kuala Upang, Kuala Upang, Salek Cape, West Kuala Sugihan and Kuala Sugihan. This area is located on an identical landscape and influenced by continues sedimentation from the Musi River. The existence of mangrove ecosystems in the study area is threatened by land conversion activities to be planned as oil palm plantation areas. According to Landsat TM 5 imagery analysis, mangrove acreage in 2018 has decreased about 4.386 Ha compare to the mangrove area in 2015. Based on Sloan [8], mangrove determined has vulnerability index 5. Ecological mangrove ecosystem features relatively equal such as diversity, density, protected status, and tidal exposure, and utilized as fishing ground and source of firewood. The similar entity followed to socio-economic parameters resulted in identical Socio-Economic Index. Finally, the ESI of mangrove of all area has classified as “Very Sensitive”.

The coastal waters areas are full filled with fishing gear that it is indicating the potential abundant of fish resources. Nevertheless, there are indications of a decline of fisheries resources due to the decrease of the mangrove area. Local fishermen utilize the study area as their fishing ground with major fishing gears are Kelong, Tugo, Sero and Gillnet. Fish caught commodity among other are Shrimp (Penaeus sp.); Barramundi (Lates calcarifer); Croackers (Seudocierca sp.); Flat Fish (Solea sp.); Threadfin (Polynemus spp); Anchovy (Stolephorus sp.); Mullets (Mugil sp); and Spotted catfish (Arius thalassinus). According to Prianto et al. [10], indicated that fish cauht in March and June 2008 in Musi River estuarine was composed of 39 and 26 fish species respectively, and the total fish species
recorded was 54 species. The potency of fish resource of Musi River estuarine was estimated in the range of 24.5-105.47 kg/km$^2$. Furthermore, the composition of fish species is influenced by the season and area of fishing ground. At onshore area obtained 39 fish species in March (rainy season) and in June (dry season), it is increased to 44 fish species. While at offshore area obtained 25 fish species in March and it decreased to 16 species in June.

Offshore waters are dominated by the operation of mobile fishing gear such as gillnet and trammel net. The level of utilization of potential fisheries resource in the offshore area is not as intensive as in the coastal area. The dominant fishing gear in the area near the coastline is a passive fishing gear that has a Vulnerability Index value of 4, whereas, in the offshore, the dominant fishing gear is an active fishing gear with a Vulnerability Index of 3 [7]. Ecological value is related to combined fish caught. Demersal, pelagic and crustacean have a higher ecological value than fish catches with only pelagic and demersal fishes, while social values varied depending on the volume of production and the value of their production. Fish caught with more volume generate high income. ESI calculation results show that the level of sensitivity of fish resources in coastal areas has “Sensitive” level of sensitivity compared to locations in the offshore which are categorized as “Moderate”. Offshore areas with “Sensitive” levels are occupied with passive fishing gear such as Sero and Kelong whereas the area with “Moderate” sensitivity level is the fishing ground area by using active fishing gear such as trammel net and gillnet.

Mostly, all housing at study area is stilt houses that are houses raised on piles over the surface of the soil or a body of water. Stilt houses are built primarily as a protection against flooding. Accessibility to and from the human settlement area is by the sea or river, except in Salek Cape which has new connecting to the road network. The local community use firewood as a source of energy for their daily living. Main local community livelihood is dependent on coastal natural resources and fish resources and processes their fish caught through the traditional method to produced salted fish and shrimp paste. The end product of this fisheries processing is needed attention to achieve hygienic aspects. There is some local community move from Kuala Upang and Kuala Sugihan migrated to other locations such as to Bungin Village in Banyuasin river mouth, due to declining sources of income from fishery products.

Human settlement observed in this area is Kuala Upang, Salek Cape, and Kuala Sugihan. Most parameters of ESI for thematic of human settlement has quite similar data resulted in all human settlements area had similar sensitivity level that is “Sensitive”.

Palm oil field areas owned by firm or communities outside the area. Local people involved in the palm oil industry as farmworkers. Previous land-use area of the oil palm is initially as mangrove or peat area. Due to the similar characteristic of all thematic agricultural field, so that all unit of analysis have “Moderate” levels of sensitivity are based on vulnerability and social index which has medium categories.

Overall the area with the highest sensitivity level of the coastal land area is the mangrove ecosystem. As for locations in coastal waters, areas with “sensitive” level are located in waters that are filled with passive fishing gear. “Moderate” sensitivity level is found in offshore areas where the fishing ground is active fishing gear.

Response strategy for during an oil spill accident, the priority is focused on the area with the highest sensitivity, i.e. “Very Sensitive” level of sensitivity. However, according to the extent of the area with the highest level of sensitivity, and the limited oil handling facilities such as the oil boom need modelling study of oil spills in the ocean based on oceanographic characteristics and the influence of the season. Integration between ESI maps and the results of oil spill modelling will produce an accurate strategy for the environmental protection program.
4. Conclusions
Muddy substrate and mangrove are significant characters of this study area, and they are classified as “Very Sensitive”. Mangrove ecosystems are observed at West Kuala Upang, Kuala Upang and Salek Cape, West Kuala Sugihan and Kuala Sugihan with “Very Sensitive” class in the sensitivity level.

Local fishermen utilize the coastal as their fishing ground. The coastal water area fulfilled with passive fishing gear. The social-economic characteristic of capture fisheries such as main livelihood, small scale fisheries activities and traditional fish processing is resulting ESI level of “Moderate” and “Sensitive”.

Human settlement observed in Kuala Upang, Salek Cape, and Kuala Sugihan are classified as “Sensitive” due to the local community livelihood is dependent on coastal natural resources, especially fish resources. The area categorized as Very Sensitive is the highest priority in a contingency plan against the oil spill.

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References
[1] Gonzales A 2017 Mapping Environmental Sensitivity: A Systematic Online Approach to Support Environmental Assessment and Planning Environmental Impact Assessment Review 66 86–98
[2] Kasperson 2001 International Workshop on Vulnerability and Global Climate Changes: Workshop Summary (Stockholm, Sweden: Stockholm Environmental Institute)
[3] Nijkamp, P. and Ron Vreeker. 2000. Sustainability Assessment of Development Scenarios: Methodology and Application to Thailand Ecological Economics 33 7–27
[4] Van Pelt M J F, Kuyvenhoven 1992 Defining and Measuring Sustainability, Research Memorandum (Amsterdam: Free University)
[5] [IPIECA] International Petroleum Industry Environmental Conservation Association 2011 Sensitivity Mapping for Oil Spill Response (International Association of Oil & Gas Producers (OGP)) Report Number 477
[6] [NOAA] National Oceanic and Atmospheric Administration 1997 Environmental Sensitivity Index Guidelines, Version 3.0 (NOAA Technical Memorandum NOS ORCA 115. Seattle: Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration) 79 pp. + appendices
[7] [CCMRS-IPB] Center for Coastal and Marine Resources Studies, IPB University 1993 Developing Environmental Sensitivity Index Map in Coastal Area of Subang and Indramayu District, West Java Province (Bogor, Indonesia: CCMRS-IPB)
[8] Sloan N A 1993 Effects of Oil on Marine Resources, Literature Study from the World Relevant for Indonesia (Indonesia Ministry of Environment: EMDI Project)
[9] [FAO] Food and Agricultural Organization 2003 The Ecosystem Approach to Fisheries: Issues, Terminology, Principles, Institutional Foundations, Implementation and Outlook (Rome: FAO) Fisheries Technical Paper No. 443
[10] Prianto E and Suryati N K 2010 Composition of Types and Potential of Fish Resources in the Musi River Estuary (Komposisi Jenis Dan Potensi Sumber Daya Ikan Di Muara Sungai Musi) Jurnal Penelitian Perikanan Indonesia 16 (1)

Further Reading
[1] Alves T M, Kokinaou E, Zodiatis G, Lardner R, Panagiotakis C and Radhakrishnan H 2015 Modelling of oil spill in confined maritime basins: The case for early response in The Eastern Mediterranean Sea Journal of Environmental Management 206 350–399
[2] Castanedo S, Juanes J A, Medina R, Puente A, Fernandez F, Olabarrieta M and Pombo C 2009 Oil spill vulnerability assessment integrating physical, biological and socio-economical aspects: Application to the Cantabrian coast (Bay of Biscay, Spain) Journal of Environmental Management 91 149–159

[3] Fabiyi O 2008 Mapping Environmental sensitivity index of the Niger delta to oil spill; the policy, procedures and politics of oil spill response in Nigeria (Nigeria: Paper on Department of Geography, University of Ibadan Seminar) p 1–20

[4] Grigalunas T A and Congar R 1995 Environmental Economics for Integrated Coastal Area Management: Valuation Methods and Policy Instruments (UNEP: UNEP Regional Seas Reports and Studies) No. 164

[5] Helle 2015 A probabilistic approach for a coast-benefit analysis of oil spill management under uncertainty: A bayesian network model for the Gulf of Finland Journal of Environmental Management 158 122–132

[6] Lan D, Bin L, Chenguang B, Minghui M, Yan X and Chungyan Y 2015 Marine oil spill risk mapping for accidental pollution and its application in a Coastal City Marine Pollution Bulletin 96 220–225

[7] Li P, Chen B, Li Z, Zhen X, Wu H, Jing L, Lee K 2014 A Monte Carlo Simulation based two-stage adaptive resonance theory mapping approach for Offshore Oil Spill Vulnerability Index Classification Marine Pollution Bulletin 86 434–442

[8] Jupites S, Phinn S, Duke N and Poots D 2006 Changing mangrove distribution in the Pioneer Estuary (Queensland, Australia): Evaluation a technique for monitoring mangrove health Proceeding of 10th International Coral Reef Symposium 1727–1731

[9] Kathiresan K 2005 Methods of Studying Mangroves. Centre of Advanced Study in Marine Biology (India: Annamalai University) 105–125

[10] Kathiresan K 2007 Important of Mangrove Ecosystem (India: Centre of Advanced Study in Marine Biology, Annamalai University) p 136–168

[11] Klein A H F, Petermann R M, Araujo R S, Silva A F, Oliveira T C R, Menezes J T and Sperb R M 2003 Environmental Sensitivity Index (ESI) Maps for The Shorelines of the State of Santa Catarina, Southeastern Brazil

[12] Nybakken J W 1982 Marine Biology: An Ecological Approach Translated by: Koesoebiono, Bengen D G, Eidman M, Hutomo M and Sukardjo S (Jakarta: PT Gramedia Pustaka Utama) p 168–184

[13] Langangen Ø, Olsen E, Stige L C, Ohlberger J, Yaragina N A, Vikebø F B, Bogstad B, Stenseth N C and Hjermann D Ø 2017 The effects of oil spills on marine fish: Implications of spatial variation in natural mortality Marine Pollution Bulletin 119 102–109

[14] Odum E P 1971 Fundamental of Ecology Edisi ke-3 Translated: Samingan T and Srigando B (Yogyakarta: Gajah Mada University Press) p xv+697

[15] Prianto E, Suryati N K and Kamal M M 2012 Diversity and feeding habits of fish in estuary waters of Musi River BAWAL: Center for Marine Research, Research and Human Resources (BRSDM), Ministry of Maritime Affairs and Fisheries 4(1) 35–43

[16] Sapari N 1998 Marine Pollution and Coastal Resources Sensitivity Index (Department of Environmental Sciences Universiti Pertanian Malaysia 43400 UPM Serdang) p 1–8

[17] Suzuki E and Tagawa H 1983 Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, South Japan Jap. J. Ecol. 33 231–234

[18] Zingel S, Hayes M O, Michel J and White M 1998 Integrated Planning form the Mountain to the sea: Environmental Sensitivity Mapping in Caribbean p 113–117