

# Environmental assessment of Pari Island towards oil spill using Geographic Information System (GIS): a preliminary study

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**Abstract.** Major national and international ship traffic routes pass through the western part of Java Sea. Due to this reason, this area is vulnerable to oil spills from ships and offshore exploration. One of the most vulnerable areas to oil pollutant is the MPA (Marine Protected Area) of the Seribu Islands, particularly the region around Pari Island. The current study was part of IndoNACE (Indonesian seas Numerical Assessment of the Coastal Environment) project and aimed to assess the coastal vulnerability towards oil spill using a Geographic Information System (GIS). In this frame, a spatial analysis was conducted by overlaying coastline map, bathymetry map, and ecosystem distribution map. The overlay method was referred to the Environmental Sensitivity Index Guidelines created by NOAA (National Oceanic and Atmospheric Administration). The preliminary results showed that 38%, 24%, and 38% of Pari Island coastline were high, moderate, and low vulnerable towards oil spill pollution, respectively. The low and moderate vulnerable areas were located at the outer reef crest and inner lagoon. Meanwhile, the high vulnerable area was located at the vegetated shoreline which dominated by mangrove. Due to its biological value and its role in the environment, the vegetated area should receive priority protection against oil pollution.

## 1. Introduction

The western part of Java Sea is one of the several busiest ocean in the world. Several major international shipping routes pass through this region connecting the Pacific Ocean to the Indian Ocean [1]. Based on the research by Lu (2003), the areas of intense oil pollution correlate very well with the major shipping routes. Due to this reason, this area is considered to be vulnerable to oil spills from ships and offshore exploration. One of the most vulnerable areas to oil pollutant is the MPA (Marine Protected Area) of the Seribu Islands, and particularly the region around Pari Island. The previous study regarding the oil pollution in Indonesia by Bodennec and Joanny (1984) stated that Seribu Islands is two hundred times more polluted than Riau Islands, Makassar Strait, and South of Java [2]. Oil spills in Seribu Islands had been recorded since 2003, 2004, 2006, 2007, and 2008 [3]. In a year, there could be at least two oil spills which occurred on the transition monsoon between December-January and April-May [4, 5, 6]. During



the IndoNACE observation in 6<sup>th</sup> November 2015, the oil slick was discovered at the southern shore of Pari Island which consists hydrocarbon concentration of 1.7 mg/l [6].

The fate and behaviour of spilled oils depend on the weathering process which reduces the concentration hydrocarbon in water and alters the chemical composition of spilled oils [7]. Naturally, the oil in the sea could also disperse by biodegradation process. Major environmental factors affecting oil biodegradation include weathering processes, temperature, availability and concentration of nutrients, availability and concentration of oxygen, and pH [8]. Meanwhile, the oil spill spreading is mostly affected by ocean physical processes such as currents, waves, and tides.

Contingency planning for potential oil spills is becoming a necessity for most of the coastal waterways [9]. One of the earlier attempts to estimate coastal oil spill vulnerability can be found in Gundlach and Hayes (1978) where a classification of coastal environments based on their physical and geological characteristics is presented [9, 10]. Many approaches were used and described to determine the shoreline sensitivity toward oil spills, including GIS (Geographic Information System) application and remote sensing techniques [11].

Seribu Islands, here in particular Pari Island is facing several environmental stresses such as oil pollution. Therefore, it is important to determine the shoreline vulnerability. The main question of the present research was to assess the level of coastal vulnerability of Pari Island toward oil spills. An integral part of this study was to determine which coastal area would be most seriously damaged by an oil spill so that they may receive priority protection [9]. Furthermore, the map of oil spill vulnerability is an important tool to develop the best-suited oil spill responses strategies [12].

## 2. Methodology

This research was utilized Geographical Information System (GIS) to determine the vulnerability index. The GIS allows analysis through the relationship linking the data together [13]. Then it becomes easy to build up any combination of some variables of different cartographic nature and spatial density [13]. There were two main maps which used in this research i.e. Base Map and Ecosystem Map. Base Map obtained from the satellite image of Lansat 8 (downloaded from Google Earth) which has the resolution by 15x15 m<sup>2</sup>. This map was digitized using GIS to obtain the map of shorelines classification. Meanwhile, ecosystem map was obtained from Indonesian Institute of Sciences.

The scoring classes of vulnerability parameters are shown in table 1. There were four parameters which are taken into account to determine the vulnerability index, i.e. shoreline, ecosystem, depth area, and human activity (table 1). The choosing of vulnerability parameters was referred to NOAA's Environmental Sensitivity Index (ESI) with some modifications [14]. Each of parameters was divided into three classes and the score represent the level of vulnerability. The higher class score indicated the higher vulnerability towards oil spill and vice versa. Based on table 1, the shoreline was classified into three type i.e. vegetated sand, sandy beach, and human-made structure. Moreover, there were three main tropical ecosystems i.e. mangrove, seagrass, and coral [15]. Since the focus of the research was the coastal area, therefore the depth classification was limited to 5 meters. The last parameter is the human activities which classified into high, moderate, and low.

**Table 1.** Scoring classes of vulnerability parameters

No	Shorelines Classification	Ecosystem	Depth area	Human Activities	Class Score
1	Vegetated sand	Mangrove	Beach (0-1 m)	High (port)	3
2	Sandy beach	Seagrass	Shallow (1-5 m)	Moderate (tourism, beach, residence)	2
3	Human-made structure	Coral	Deep (> 5 m)	Low (uninhabited islands)	1

In addition to the parameters, the mapping of vulnerability area was also referred to NOAA's Environmental Sensitivity Index (ESI). The ESI is a spatial information system which is composed of three main components: a shoreline type, oil-sensitive biological resources, and human-use resources of commercial, recreational, or subsistence value [10, 14, 16]. Vulnerability index was calculated using the weighted overlay method. Every parameter on map layer was given a sensitivity score towards oil spill based on ESI Guidelines Version 3.0 with some modifications [16]. Vulnerability index was calculated using the equation (1) [16]:

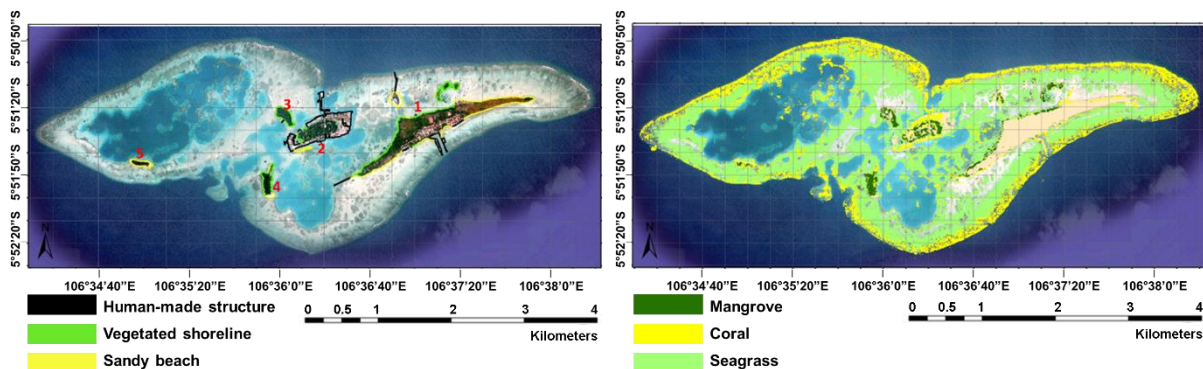
$$X = \sum_i^n W_i \times X_i \quad (1)$$

Where  $X$  denotes the vulnerability index,  $X_i$  is the class score of parameter- $i$ ,  $W_i$  is the weighted score of parameter- $i$ , which are 0.3 for shoreline, 0.4 for habitat, 0.2 for bathymetry, and 0.1 for human activities. Symbol  $n$  shows the number of parameter which used to determine the vulnerability index.

### 3. Results

There were three main types of shoreline in Pari Island (figure 2) i.e. human-made structure (grey), sandy beach (brown), and vegetated shoreline (green). Human-made structure mostly made of concrete. There was also the sandy beach which mostly covered the eastern side of Pari Island. The sediment analysis in several beach around Pari Island showed that sand percentage varies from 80-96%, followed by silt from 2-14%, gravel from 1-6%, and clay which lower than 2.9% [17].

The sediment type of beach determines the rate of oil penetration [18]. The coarser grained sediment has a higher potential of oil penetration rather than compact and solid sediment [18]. At the coarse-grained sand beach, for example, the oil may sink and/or be buried rapidly making the clean-up process more difficult [9]. On the contrary, at the fine-grained sand beaches, oil does not penetrate into the sediment [9]. At the fine-grained sandy beach, oil was accumulated and formed an oil-slick-ribbon along the intertidal zone.



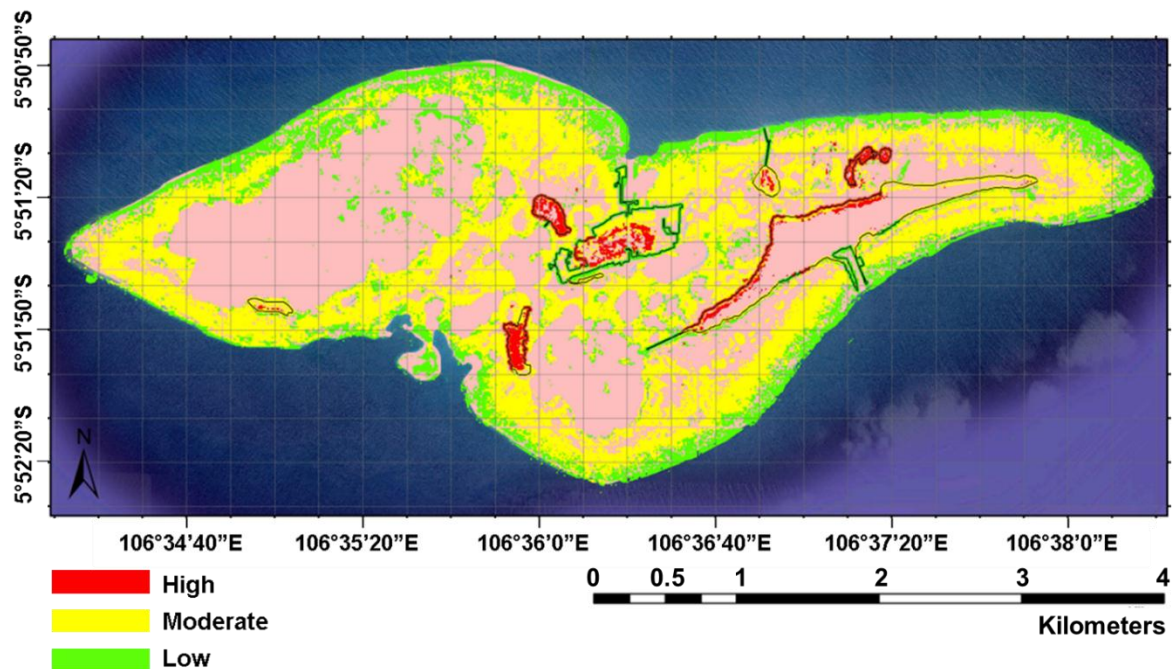
**Figure 1.** Shoreline (left) and ecosystem (right) classification map. Number 1=*Pari* Island, 2=*Tengah* Island, 3=*Kongsi* Island, 4=*Burung* Island, and 5=*Tikus* Island.

In addition to human-made and fine-grained sandy beach, the shoreline was also classified into the vegetated shoreline. The vegetated beach in *Pari* Island had a total length of 5.5 km which dominated by mangrove. The mangrove vegetation that lies on the shore was the most vulnerable to oil spill because of its biological value [19, 20]. Mangrove forest is an important ecosystem since its role for the carrying capacity of the environment such as a spawning or breeding and enlarging various types of nursery ground for aquatic biota (fish and shrimp) and terrestrial [12]. Based on the map of the ecosystem, mangrove which lies on the shorelines was dominantly located in the northern of *Pari* Island (figure 1).

The group of *Pari* Island was surrounded by extensive fringing reefs characterized by a sand flat, reef flat or lagoon, reef edge, and reef slope which drops to a depth of 20 m [21]. This coral reef was one of the main tropical ecosystem in *Pari* Island (figure 1) [15]. Oil spills in the ocean can disturb the coral reefs through oil slick on the sea surface and sink oil [3]. Oil slick on the sea surface will disrupt the

living organisms on the surface, increasing the sea surface temperature, blocking the sunlight intensity and ocean-atmosphere gas exchange [3, 5].

In addition to the ecosystem, human activity also took into account to determine the vulnerability index. Human activities differ into three main type that is the high activity (port), medium (tourism, beach, residence area), and low (uninhabited islands). The highest of human activities located in the port. The port was one of the sources of the oil spill due to the high of ship activities.



**Figure 2.** Map of vulnerability towards oil spill index in Pari Island.

The weighted overlay method of shorelines, ecosystem, and depth classification map produced the vulnerability index map (figure 2). These maps show the level of vulnerability toward oil spill in the group of Pari Islands. The index was classified into three classes i.e. high, moderate, and low. The low and moderate index were mostly located in the outer reef crest because they were facing the open sea. This area was exposed to the higher of water dynamics rather than the inner lagoon. The mixing process by the wave generated the faster flushing process. As stated by Utyanto *et al.*, 2003 that the coast which exposed to the strong wave and tides would recover faster from the oil spill, as the coast can be naturally cleaned by both wave and tides flux energy [18].

Besides the outer reef crest, the moderate index also located in seagrass area and sandy beach surround *Tikus* Island, also in northeast, southwest, and southeast area of *Pari* Island. Meanwhile, the high index located in north and west area of *Pari* Island. Dominantly the high index was located in vegetated shoreline (mangrove and seagrass). The high index cover at least 38% from 14.5 km of *Pari* Island shoreline. The high index was mainly caused by the existence of vegetation, here in particular mangrove which had the highest score among the other ecosystem. The oil spill impact on mangrove was determined by tidal condition. When flood tide, the oil could submerge to the shore and sticking to mangrove roots. In the event of the slight oil spill, the clean-up would occur naturally. However, in the event of the heavy oil spill, oil may be cleaned-up by oil dispersants.

Furthermore, the high index was also resulted from the low exposure of most types of beaches in *Pari* Island to natural clean-up process. The inner lagoon had relatively calm water than the outer reef slope because of its isolated morphology. It caused the longer of flushing process in the event of the oil spill. Based on this result, it can be considered that the vegetation area of the inner lagoon should receive priority protection against the oil pollution. This area was including *Burung* Island and northern coast

of Pari Island. For future research, it is important to include the wave and tides as part of the vulnerability index parameters.

#### 4. Conclusions

The vulnerability index showed that 38%, 24%, and 38% of Pari Island shoreline were considered to be high, moderate, and low vulnerable towards oil spill pollution, respectively. The low and moderate vulnerable area was located at the outer reef crest and inner lagoon. Meanwhile, the high vulnerable area located at the vegetated shoreline which dominated by mangrove. In the event of the oil spill, the vegetated area would take a longer time to clean-up especially by the natural processes. The further research is needed to consider the potential location of oil sources as well as the ocean dynamics such as tides and waves as the factor of the vulnerability index.

#### Acknowledgements

We express our thanks to IndoNACE (Indonesian seas Numerical Assessment of the Coastal Environment) for data observation and funding this research.

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