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A methodology to assess environmental vulnerability in a coastal city: Application to Jakarta, Indonesia

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ABSTRACT

The assessment of environmental vulnerability is a sound basis for environmental management measures because it provides an objective standard for the priorities for implementation. Although several methods have been used by international agencies to assess and compare national environmental vulnerabilities, relatively few methodologies have been proposed to assess vulnerability on the local scale. In this study, we developed a methodology to assess the environmental vulnerability of a coastal city, with the goal of overcoming the limitations of a previous method that compared countries' vulnerabilities on a global scale. We applied this methodology to Jakarta, Indonesia, to identify its utility in providing a basis for the development of environmental policy measures. We assessed the relative environmental vulnerabilities of Jakarta's five districts, using a conceptual diagram composed of exposure, sensitivity, and adaptive capacity. For environmental exposure, we considered inundation due to heavy rainstorm, flood from sea level rise, and environmental pollution. For sensitivity, sectors of human and natural systems were considered using a land cover map from GIS data. To examine adaptive capacity, we addressed environmental awareness, policy foundation, economic status, and infrastructure. The assessment results showed that the East and North districts are more vulnerable than other districts. We suggested environmental policy measures for each district using radial graphs that show the dominant indicators within the composite index. Our proposed methodology has a significant relevance in the sense that it extracts key indicators of environmental vulnerability by considering local conditions, and provides a useful tool to compare results within a vulnerability assessment and to inform appropriate environmental policy measures.

1. Introduction

Management of environmental vulnerability is prerequisite to global sustainable development. For this reason, many international agencies have conducted assessments that compare national environmental vulnerabilities on a global scale, and used the results of these assessments as standards for setting their institutional priorities. For example, the South Pacific Applied Geoscience Commission (SOPAC) and the United Nations Environment Programme (UNEP) have developed the Environmental Vulnerability Index (EVI), which compiles 50 different indicators regarding weather and climate, geology, geography, ecosystem resources, and human populations and composites them into a single index (Kaly et al., 2004). This kind of composite index is a relatively simple way to combine various aspects of vulnerabilities for consideration. The concept of environmental vulnerability typically incorporates both biophysical and socioeconomic factors (Kaly et al., 2004; Adger, 2006). Data on biophysical aspects mainly relate to risk of hazards, climate, geology, and geography, whereas socioeconomic aspects include the system's inherent resistance to damage and acquired adaptive capacity (Kaly et al., 2004; Adger, 2006).

Assessment of environmental vulnerabilities on a global scale is important because the results of such assessment provide criteria that can be used to distribute international funds, for example. In addition, vulnerability assessment on the local scale is also very useful because the results can serve as the basis for local environmental measures. However, the same methodologies used to assess vulnerability on the global scale cannot be directly applied to the local scale because they tend to mask heterogeneous impacts and risks imposed

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on the local scale by averaging them out (Adger et al., 2004; Vincent, 2007). Birkmann (2007) also pointed out that the key indicators of vulnerability could vary with spatial scale. For these reasons, we need a different methodology to assess local environmental vulnerability, but despite this need, local environmental vulnerabilities have been widely evaluated simply based on historical records of natural disasters or pollution. Hong and Hwang (2006) used damage costs from flooding as a proxy for comparing local vulnerabilities in 16 districts of South Korea, retrieving damage costs from the statistical data in national disaster records in the period 1970–2004. Firman et al. (2011) summarized potential climate change vulnerabilities in five districts of Jakarta, also by using recorded data from natural disasters, including floods; sea level rise; tornado activity; landslides; and water, air, and noise pollution. Although the results of these assessments could be utilized in identifying higher-priority districts, they could not have provided concrete information for setting local environmental policy measures.

In this sense, there is a need to develop a new methodology to assess local environmental vulnerability, including considerations beyond just risk of hazards or damage from disaster. To be useful in informing the development of environmental measures, such a new method should consider specific local conditions. In this study, we introduced a new framework for the assessment of environmental vulnerability on a local scale by integrating a geographical information system (GIS), local statistics, and a survey. The ultimate objective of this work is to find a new methodology to assess local vulnerabilities that includes consideration of site-specific characteristics. Another goal is to develop a new tool based on the Jakarta assessment to aid local policy makers in assessing local conditions and developing appropriate environmental measures based on the results.

2. Development of methodology

2.1. Characterization of the study area

Indonesia, a country of 17,000 islands that has the second longest coastline in the world, is endowed with abundant natural resources and biodiversity. Recently, the country has shown the potential to become a powerhouse in Asia by taking a leading role in the international arena. However, the country is faced with many environmental problems in its coastal zones due to numerous stresses that were brought about by rapid and unplanned or poorly planned industrial and economic development. Jakarta, the capital city of Indonesia, is located on the northern coast of Java Island; the city is reported to be susceptible to environmental shocks such as floods, rising sea level, and other natural disasters as well as to anthropogenic pollution (Hadi et al., 2009).

Yusuf and Francisco (2009) reported that, among coastal cities in Southeast Asia, Jakarta was one of the most vulnerable to climate change. According to Hadi et al. (2009), areas on the northern side of the Java coastal system are suffering from different oceanic hazards such as sedimentation and erosion caused by wind and waves, and storm surges from the Indian Ocean threaten coastal areas on Java's southern side. In addition, environmental conditions in Jakarta have been seriously deteriorating, mainly because of water pollution from the sewage of more than 20 million residents and industrial waste from over 2000 factories. Among the 1400 tons of solid waste generated in Jakarta, 1100 tons are discharged directly into Jakarta Bay. As a result, the generation of marine litter in the Thousand Islands (also called the Seribu Islands) has increased twofold during the last decade. Bradshaw et al. (2010) reported that Indonesia ranked fourth among 200 countries in environmental pollution discharge.

With these reasons, Jakarta Bay was chosen as our study site. The spatial unit for this study is the five municipal districts which are East, West, South, North and Central Jakarta. Although a large city like Jakarta has highly variable nature of vulnerability from one corner to the other, we decided to use the five districts as our spatial unit because they are the minimum basis for setting up and implementing environmental measures. In this way, results of vulnerability assessment would be efficiently incorporated into setting up local environmental measures.

2.2. Conceptual framework

We defined environmental vulnerability as a function of environmental exposure, sensitivity, and adaptive capacity (Fig. 1). This framework was adopted from the concept of climate change vulnerability suggested by the Intergovernmental Panel on Climate Change (IPCC, 1995). In this study, we considered environmental exposure as the negative impacts of inundation from heavy rain, flood from sea level rise, and system damage from environmental pollution. Sensitivity is defined as the degree to which a system is affected either adversely or beneficially (IPCC, 2001). In our framework, sensitivity refers to the attributes of a system, whether human or natural, that render it more or less susceptible to environmental exposure. The combined effects of environmental exposure and the system's sensitivity will determine the potential impacts. Adaptive capacity is defined as the ability to cope with the adverse effects of environmental degradation. We considered four aspects of adaptive capacity: economic status, infrastructure, level of awareness of environmental problems, and administrative foundation for policy implementation. The concepts of environmental exposure, sensitivity and adaptive capacity are described in more detail in the following sections.

2.3. Environmental exposure

Firman et al. (2011) reported that inundation occurred every year in almost all Jakarta districts. Inundation can be caused either by the natural states of rainfall, high tide, or sea level rise, or combinations thereof. Following Firman et al. (2011), we subdivided the cause of inundation into heavy rainfall and sea level rise. For inland water flood risk from heavy rain, we used inundation records from a report of the Indonesian Central Board of Statistics (BPS, 2009). The BPS (2009) provided the statistics on the number of localities where flooding occurred from 2005 to 2008 in each district. Although the statistics were limited to four years of record, this data can serve as a good proxy for comparing the degree of environmental exposure due to inland water inundation. We also considered sea level rise as another important factor for flood and simulations were carried out to project the area of inundation using ArcGIS 9.2. A contour map was extracted from a digital elevation map (DEM) with a 1-m interval. After overlaying a land cover map (source: BAKOSURTANAL), the flooded area was calculated for sea level rises of 1, 2, 3, 4, and 5 m. The levels of sea rise are based on IPCC (2007) and Vaughan and Sponge (2002) who projected 0.18 m~0.59 m and 5 m of sea level rise by the end of 21st century, respectively.

The total flooded area in each district in the simulated 3 m scenario was used as a proxy for environmental exposure to flood by sea level rise. Two causes for flood were combined by taking the larger vale between the two (using the “maximum” function in excel) because they are closely correlated. For example, the area of frequent inland water flood is also prone to be flooded by sea level rise.