IMPACT OF SEA LEVEL RISE TO COASTAL ECOLOGY: A CASE STUDY ON THE NORTHERN PART OF JAVA ISLAND, INDONESIA

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ABSTARCT: The coastline of Indonesia, which borders almost 17,500 islands and the sea and extends for more than 80,000 km, is vulnerable to sea level rise. This paper aims to investigate the impact of sea level rise on coastal ecology in Indonesia focusing on coastal area of Jakarta, Pekalongan, Semarang and Demak in the northern part of Java Island. Geo-spatial data, i.e. satellite images and maps were used to monitor the environmental changes and primary data were obtained through field survey and observation on the specified area. In Jakarta, sea level rise has been predicted to bring great damages to infrastructure in coastal area. Multiple impacts of sea level rise towards mangrove, agriculture, and aquaculture ecosystem occurs in Pekalongan. Semarang coastal area also suffers from the widening spread of health problems as the coastal inundation increases. At the same time, Demak experiences major losses on mangrove and aquaculture ecosystem due to sea level rise.

KEY WORDS: climate change impact, coastal ecology, sea level rise, Indonesia

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Introduction

Rapidly increasing human population, especially after the industrial era, has major impact on natural environment. The utilization of fossil fuel energy to almost all parts of human activities, including electricity, transportation, and industry, results in the increase of greenhouse gases in the Earth's atmosphere. This condition leads to the worldwide issue of anthropogenic climate change (IPCC 2000, 2007). At present various potential climate change impacts have been identified in almost all parts of the world. The type of impact and its magnitude tend to be different from one place to another. As one of its impacts, increasing extreme event such as flood and drought has been observed (Naylor et al. 2007, Ward et al. 2010). Coastal area, which is considered as the most vulnerable area affected by climate change, suffers a major impact (Marfai, King 2007). The threat arises in the form of sea level rise, which is increasing due to ice melting in the polar region, and sea water expansion due to higher temperature (IPCC 2007).

Indonesia, as one of the largest archipelagoes in the world, has more than 17.500 islands and 80.000 kilometers of shoreline. Climate change is predicted to bring severe impact towards its coastal area and small islands (Marfai 2011a). Various environmental problems have been af-

fecting them, which are mainly caused by coastal flooding, coastal erosion, land subsidence, and environmental sanitation problem (Marfai et al. 2008a, Marfai 2011b, Mardiatno et al. 2012, and Purnama et al. 2012), and are potentially increasing as climate change induces. Unmanaged land use change in coastal area, especially in the urban, makes higher climate change vulnerability foreseeable and thus the risk and impact of sea level rise increase (Marfai, King 2008).

Sea level rise-induced hazard combined with higher vulnerability in coastal area may lead to more risk followed by more damages and losses. Therefore, disaster risk reduction concerns more on development of mitigation and adaptation strategies (Ward et al. 2010), which best applied when identification of element at risk is due consideration. Both natural and artificial coastal ecosystems are deemed precise elements at risk; in consequence of which, identification of affected coastal ecosystem becomes necessary.

Objective

This paper aims to identify various impacts of climate and environmental change-induced sea level rise on the coastal ecology of Indonesia with the focus on the northern part of Java Island, upon which four cities as the study area, i.e. Jakarta, Pekalongan, Semarang, and Demak. Due to rapid urban development, it has been suffering from complex environmental problems. Therefore, the assessment of mainly sea level rise-induced impact has been conducted on both natural and artificial ecosystems; some of which have been determined and mostly cover mangrove, agriculture, fish pond/aquaculture, and urban settlement ecosystems.

Methods

Spatial analysis using remote sensing data and maps was conducted on the study area, while field measurement and observation were also implemented during fieldwork. This research utilized landsat images for visual analysis, especially for environmental analysis on the coastal area of Demak and Pekalongan. Meanwhile Ikonos images has been used to analysis the environmental change on the coastal area of Semarang. The image anaysis has been done by visual interpretation. Geospatial data in the form of map has been developed on this research by vector based map using GIS technology. Secondary data from previous reports and literatures including government policies significantly gave input to data analysis. The reports from city planning board and public work give significant input, especially on the dynamic change on the coastal area during last 10 years. In addition, interview with stakeholders and governmental agencies, such as with the village leaders, key persons, public work agency, planning agency and coastal manager was conducted to obtain data related to existing risk reduction program on the coastal area.

Study Area

Java, as the most populated island in Indonesia, has an area of only about 6% of total land extent of Indonesia. Despite its relatively small area, more than 60% of its total population lives there (NBSC 2010). Consequently, built-up area develops rapidly almost in the whole island which supports the idea of changing natural ecosystem into artificial one. Location of the study area is presented in Figure 1.

According to Bemmelen (1949), Java, which has been developing as volcanic island, consists of thousand volcanoes in the middle and folding plane and flat-lowland area in the north; while karstic-limestone plateau predominates in the south. Lowland topography and gentle sea wave initiate and attract people to inhabit and thus coastal cities such as Jakarta, Semarang, and Surabaya are urbanized.

As summarized by Bird and Ongkosongo (1980), Sunarto (2004), and Marfai et al. (2008b), northern coast of Java, especially Central Java, is dominated by erosion and sedimentation process. Since they are the most dynamic process occurring in coastal area, dynamic shoreline change is expectantly found in the study area in which Tegal, Semarang, and Demak experience the most dynamic change (Marfai et al. 2008b, Sartohadi et al. 2009, Maulina 2010).

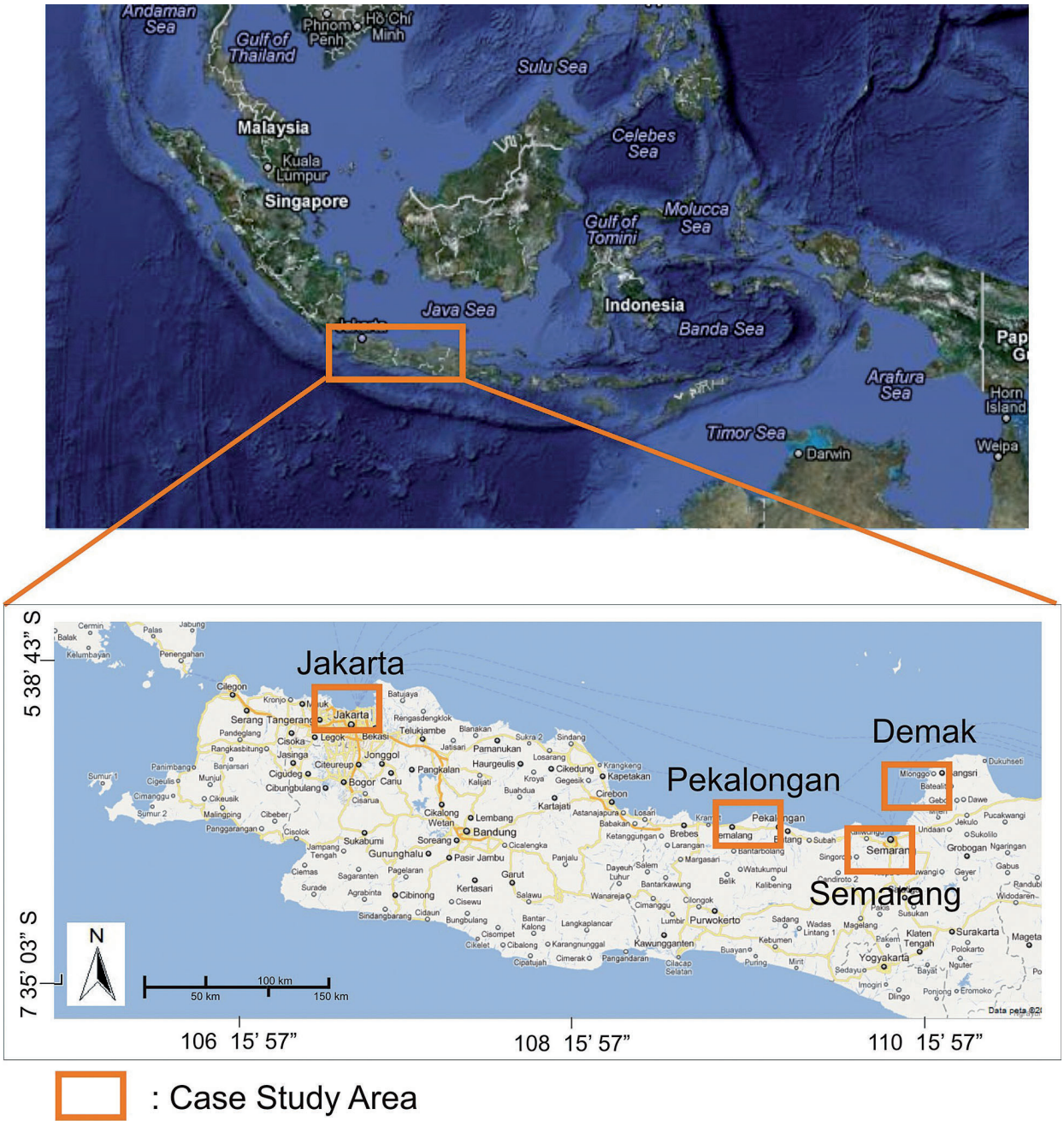

Fig. 1. Location of the study area

Various types of ecosystem, from natural (e.g. mangrove) to artificial urban area, exist in the study area on account of dynamic coastal area and human-induced land use changes. Mangrove, agriculture, and aquaculture ecosystems are the most abundant in Pekalongan and Demak. Quite different condition is found in Jakarta and Semarang in which built-up areas predominate.

Impact of Sea Level Rise to the Coastal Area

Various processes and ecosystems in the north of Java control the difference in potential impact of sea level rise as it is induced by climate and environmental change. The identified sea level rise impacts include:

- increasing coastal erosion,
- increasing coastal flooding,

- damages on mangrove ecosystem,
- damages on fishpond/aquaculture,
- damages on agriculture,
- damages on urban settlement and infrastructure,
- increasing environmental sanitation problem,
- increasing vector-borne disease and health problem.

Comparison analysis on several parts of North Java, upon which Jakarta, Pekalongan, Semarang, and Demak, showed that each coastal area in the study area has specific problem related to sea level rise (Table 1).

Based on Table 1, it can be inferred that each type of ecosystem existing in coastal area brings their contribution to different impact of sea level rise. There are significant difference between the cities, i.e. Jakarta and Semarang are physically characterized by urban features, while Pekalongan and Demak are by rural features (e.g. agriculture and aquaculture).

Jakarta, as the most populated city in Indonesia, is predicted to suffer from major losses due to severe impact of sea level rise. Ward et al. (2012) also confirmed that the northern part of Jakarta and surrounding small islands have been experiencing intensified flood inundation as tidal process increases from time to time. Sea level rise influences artificial ecosystems in Jakarta in many ways, i.e. increasing coastal flooding, damages on the settlement and infrastructure, increasing environmental sanitation problem, and also increasing vector-borne disease and health problems. Several inundation scenarios of coastal flooding induced by sea level rise showed that urban settlement and business area are the largest area affected (Fig. 2 and Table 2). It is worsened by low soil drainage in the urban settlement in Jakarta and thus water recedes driftly. Therefore, sanitation problem emerges and affects vector-borne disease and health problems to increase.

In Pekalongan, tidal flood-affected area, which includes mangrove, agriculture, and aquaculture ecosystems, has spread more widely on account of sea level rise. Therefore severe impact of sea lavel rise-induced tidal flood can be observed in this city. Marfai (2011b) affirmed that shoreline change occurring since the last 5 years on its coastal area leads to extending tidal inundation. Nowadays, an increase on economic losses and crop failure, as the result of coastal inundation, in aquaculture sector is unavoidable. Several local adaptation strategies have been applied, mainly by building elevated small dikes to border agriculture and aquaculture area.

Sea level rise also intensifies coastal erosion in Pekalongan. Consequently, the damages on mangrove ecosystem, agriculture, and aquaculture ecosystem are getting more severe. In 2003–2009, its average rate was around 10.5 m with only slight difference in each location. Figure 3 shows the rate of coastal erosion in some locations in Pekalongan in detail.

Semarang has similar condition to Jakarta on the emergence of increasing coastal flooding, damages on urban settlement and infrastruc-

Table 1. Predicted Impact of Sea Level Rise to Ecosystems in Study Area

Major impacts of sea level rise towards ecosystem	Location			
	Jakarta	Pekalongan	Semarang	Demak
Increasing coastal erosion		√	√	√
Increasing coastal flooding	√		√	
Damages on mangrove ecosystem		√		√
Damages on fishpond/aquaculture		√		√
Damages on agriculture		√		
Damages on urban settlement and infrastructure	√		√	
Increasing environmental sanitation problem	√		√	
Increasing vector-borne disease and health problem	√		√	

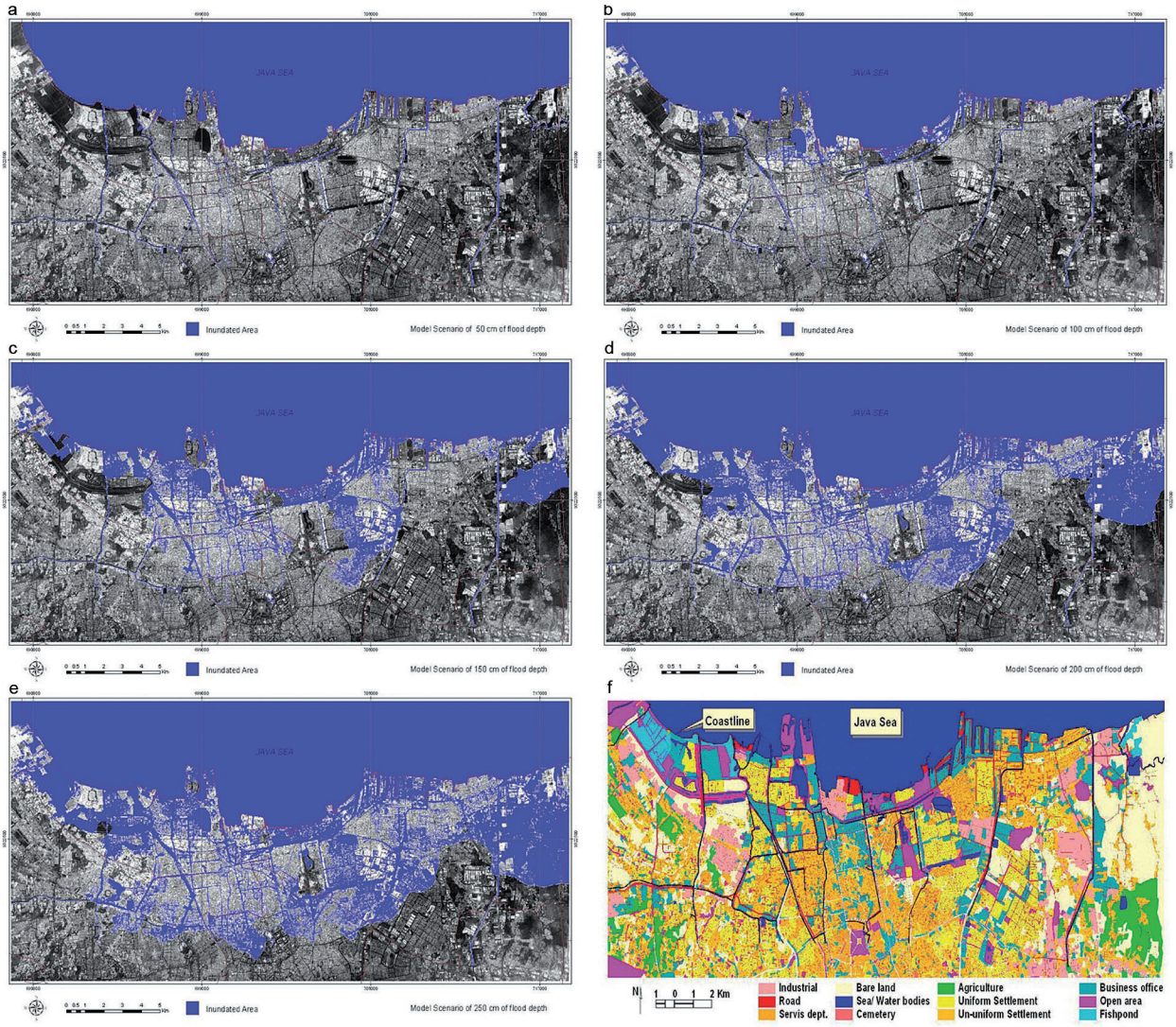

Fig. 2. Inundated area in several water level scenarios (after Ward et al. 2010)
a) 50 cm, b) 100 cm, c) 150 cm, d) 200 cm, e) 250 cm; and f) land use of the study area

Table 2. Land Use Affected by Coastal Flooding Scenario in the North of Jakarta (ha)

No.	Type of land use	Scenario of inundation flood model				
		0.50 m	1.00 m	1.50 m	2.00 m	2.50 m
1	Industrial	44.38	120.22	149.44	230.67	643.77
2	Road	246.58	458.82	626.14	774.30	1462.58
3	Service dept.	24.81	113.19	155.65	208.91	674.19
4	Bare land	15.10	268.06	477.32	813.42	2293.70
5	Cemetery	0.00	0.00	0.00	0.13	1.39
6	Agriculture	0.00	0.00	0.00	26.20	260.87
7	Uniform settlement	128.39	459.67	602.40	727.48	1775.67
8	Un-uniform settlement	68.38	242.82	384.99	557.46	1515.59
9	Business office	349.68	673.66	850.59	1059.81	1829.27
10	Open area	126.41	292.65	380.03	463.17	1070.32
11	Fishpond	310.50	341.31	406.09	458.14	483.78

Source: some data were adopted from Marfai and Sekaranom 2012

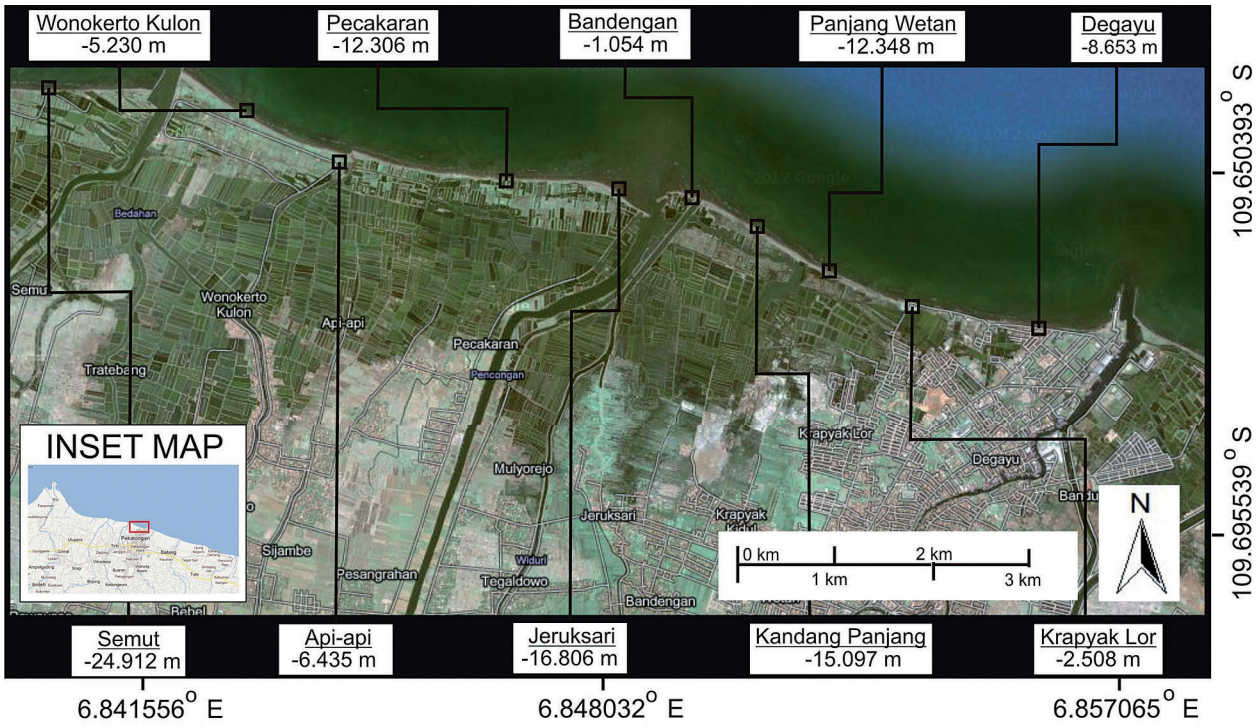

Fig. 3. The rate of coastal erosion in Pekalongan in 2003–2009

ture, environmental sanitation problems, and vector-borne disease and health problems. It results in more severe damage considering the occurrence of land subsidence in Semarang. As mentioned by Marfai and King (2007) subsidence in Semarang has been increasing rapidly due to groundwater withdrawal on the coastal area for more than 10 years. Nowadays, vector-borne disease and health problems in Semarang tend to be increasing, as summarized in Table 3.

Besides vector-borne disease and health problems, sea level rise also has major impact on the damages of aquaculture area in several areas in Semarang. Coastal erosion changes shoreline fast in Semarang. Terboyo Kulon experienced 101.7 m of change from temporal analysis on 2003 and 2005 satellite images and 625.7 m on 2005 and 2009 (Irwani et al. 2010) (Fig. 4).

Demak, located at the east of Semarang, has quite different problem compared to Semarang. While most of the area of Semarang is dominated by urban ecosystem, it is dominated by aquaculture ecosystem in which the most of local community works. Aquaculture experiences the most severe damage of all from coastal erosion. Furthermore, mangrove ecosystem has also been affected. Nowadays, severe coastal erosion has been occurring in Demak and has reached up to almost 5 kilometers to the mainland, i.e. in Tambaksari-Sayung area where coastal erosion affects almost all of it (Fig. 5).

Sea level rise is calculated to reach 5 mm y^{-1} resulting in devastating impact on coastal area in

Table 3. Diseases Suffered by Local Community in Semarang due to Sea Level Rise

Illness	Malaria	Dengue fever	Labtoferosis	Others	Total
Kuningan	10	8	0	8	26
Bandarharjo	4	5	0	2	11
Dadapsari	12	10	0	16	38
Tanjung Mas	22	19	1	17	59
Total	48	42	1	43	134
Frequency (%)	36	31	1	32	100

Source: Soedarsono (2011)

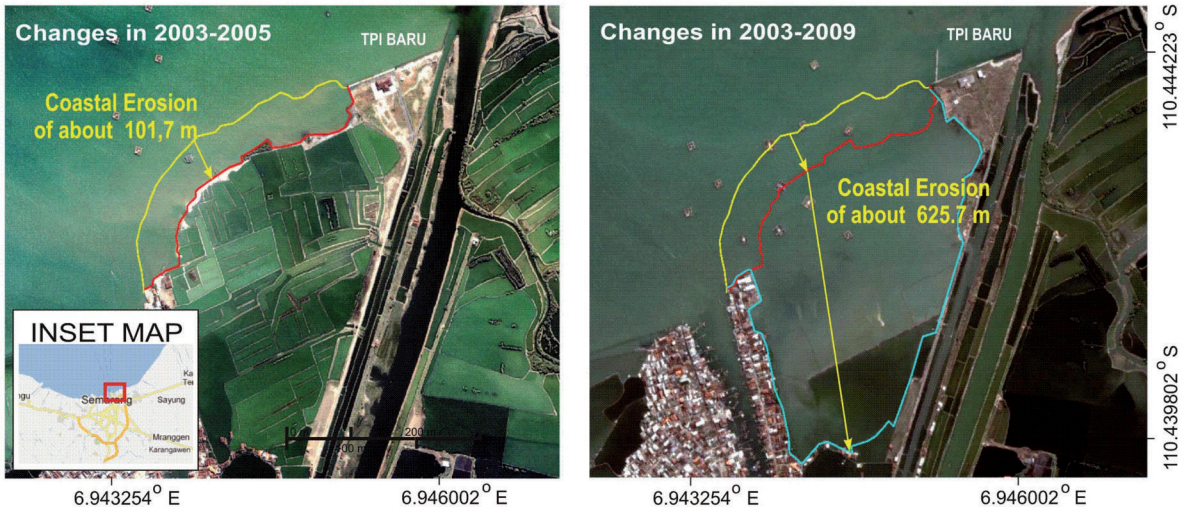

Fig. 4. Coastline change due to coastal erosion in Terboyo Kulon, North Semarang (after Irwani et al. 2010)

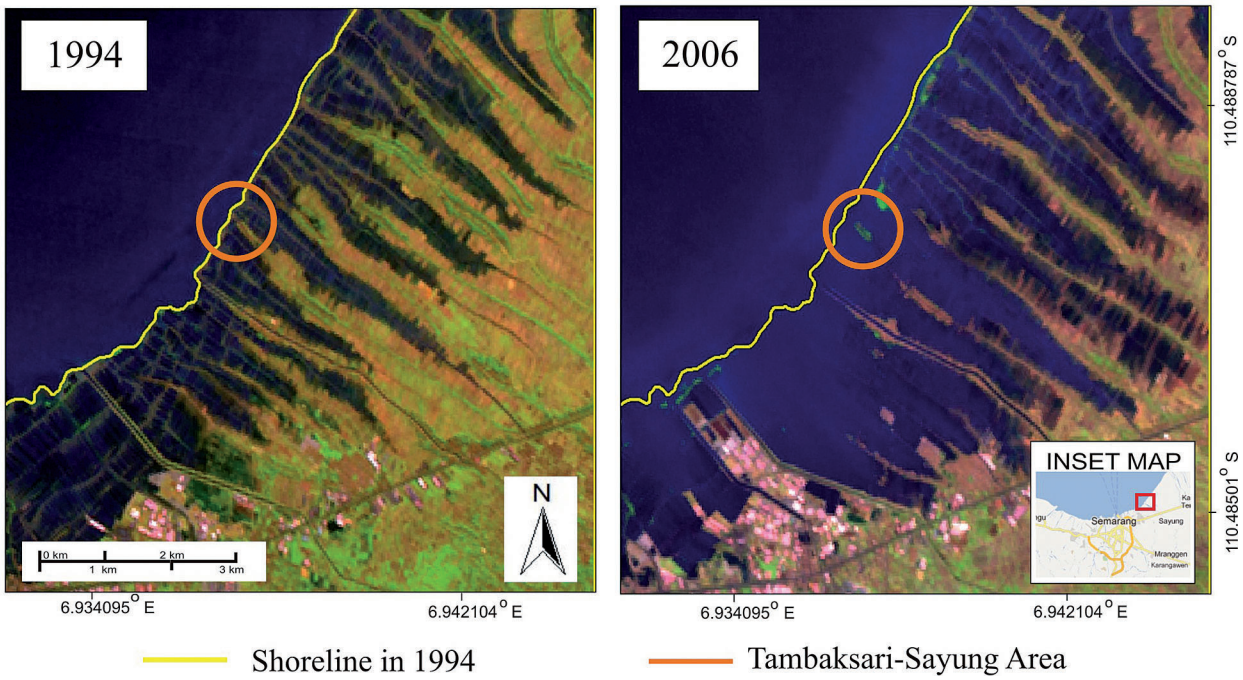

Fig. 5. Coastal erosion at Tambaksari-Sayung area, Demak

Demak. Despite this fact, local communtity has successfully developing adaptation strategies. They are:

- planting mangrove alongside of shoreline,
- elevating ground level,
- building staged house,
- utilizing deep well for freshwater supply,
- maintaining social interaction with mainland community,
- collecting fish from mangrove as food supply,
- changing occupation into tourism sector.

Conclusions

Various impacts of climate change-induced sea level rise have been identified in the north part of Java. The potential impacts include: (a) increasing coastal erosion (b) increasing coastal flooding (c) damages on mangrove ecosystem (d) damages on fishpond/aquaculture (e) damages on agriculture (f) damages on urban settlement and infrastructure (g) increasing environmental sanitation problem and (h) increasing vector-borne disease and health problem.

Various land uses predominating Jakarta, Pekalongan, Semarang, and Demak resulted in difference on ecosystem developed in the coastal area. Ecosystems affected by sea level rise in the study area are mangrove, agriculture, fishpond/ aquaculture, and urban ecosystem. Each coastal ecosystem, as an element at risk affected by sea level rise, will be experiencing different possible impact due to sea level rise. Thus, future mitigation and adaptation strategies need to consider the type of ecosystem affected by sea level rise. Different ecosystem possibly require different mitigation and adaptation action, for example building dikes and polder system in preventing damages in artificial ecosystem, or applying mangrove conservation in preventing coastal erosion-induced damages in aquaculture ecosystem.

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