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Research Article

Spatial Modeling for Silvofishery and Greenbelt to Reduce the Risk of Sea Level Rise in Indramayu Coastal Area, West Java-Indonesia

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Abstract: Global warming increases the sea-level of Java Sea by averagely 5 mm yr^{-1}. The sea level rise (SLR) induces environmental and social problems in coastal area of Indramayu. This research aimed to model coastal hazard and its impact on land use, as well as to construct a silvofishery and green belt modeling. The research method consisted of four steps, namely (i) tidal flood modeling in SLR scenarios by iteration and neighborhood operation based on DEM, (ii) land use mapping based on satellite imagery, (iii) the inundation-affected landuse mapping by superimposed analysis, and (iv) the spatial modeling for silvofishery and green belt. The silvofishery and green belt modeling is the solution prepared for planning mangrove belt and fishpond by conducting a shoreline buffer analysis based on the Minister of Environment Decree No. 201/2004. Fishpond is the most largely-impacted land use by SLR. There are more than 2 000 ha of fishpond inundated in the 25-cm SLR scenario, and more than 12 000 ha in the 100-cm scenario. Inundation causes not only damages to physical infrastructures but also economic losses. The suitable silvofishery type for Indramayu coastal area is Komplangan. The area between 0 m to1 000 m from shoreline should be covered by mangrove with a ratio 70 % to 90 %. Intensive aquaculture activity could be safely done in the area located more than 3 000 m from the shoreline with mangrove plants occupying 20 % to 50 %. This result provides input for the inundation management in coastal aquaculture area affected by sea level rise.

Keywords: *Komplangan*, Mangrove, Suitable silvofishery, Tidal flood modeling.

1. INTRODUCTION

Increasing world population, especially after the Industrial Revolution, affects the natural ecosystem. Fuel utilization in human life and landuse changes increases the greenhouse gasses (GHG) concentration in the atmosphere. GHG are gasses in the atmosphere that trap radiant energy, consist of many gasses, but the important are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and halocarbons (CFCs, HFCs, etc.) [1]. They are the primary factor causing climate change in the world. High levels of carbon dioxide (CO_2), methane (CH_4) and chlorofluorocarbon (CFC) produced by human activities result in the depletion of the ozone layer. Consequently, the temperature of the Earth's surface increases rapidly [2]. The global warming phenomena increase the number of melting ice and snow and, therefore, trigger the global sea level rise. In the last 50 yr, 27 % of the ice in the North Pole has melted [3, 4]. In other words, increasing seawater temperature induces water mass swelling [5]. The ice melting and the water mass swelling contribute to the average sea level rise [6] that inundates the coastal area. Tidal flood causes many losses for the people in the coastal area, such as damaged infrastructure, agriculture and fishery failures, and sanitation and health problems [7].

Indonesia is one of the largest archipelagoes in the world [8] with more than 17 508 islands and 99 093 km long shoreline [9]. Such a broad coastal area increases the susceptibility to the coastal

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disaster caused by global warming [5, 7, 10]. The average global sea level rise is 3.5 mm yr^{-1} [11] and the sea level of Java Sea rises averagely by 5 mm yr^{-1}, as shown in Fig. 1. The sea level rise could cause an increasing tidal amplitude [12] as illustrated in Fig. 2. Mean higher high water line (MHHWL) and mean lower low water line (MLLWL) represent the intersection of the land with the water surface at the elevation of the average of higher high and lower low water height each tidal day observed over a period of several years.

Based on Fig. 1, the mean sea level of the Java Sea in the next 100 yr will be 50 cm higher. In an extreme condition, high tide will even be 2 m higher than the present sea level. Consequently, the low-lying coastal area will be permanently inundated because of the sea level rise. One of the SLR-affected coastal areas along the Java Sea is Indramayu, which is periodically inundated by tidal flooding [14]. Indramayu Regency covers an area of 204 011 ha and is divided into 31 subdistricts and 210 villages. The 11 subdistricts belong to the coastal area or about 35 % of the whole region [15]. The coastal area has a flat, smooth, and low topography with alluvium material. Based on the physical condition, Indramayu coastal area has a high susceptibility to sea level rise-induced floods [16].

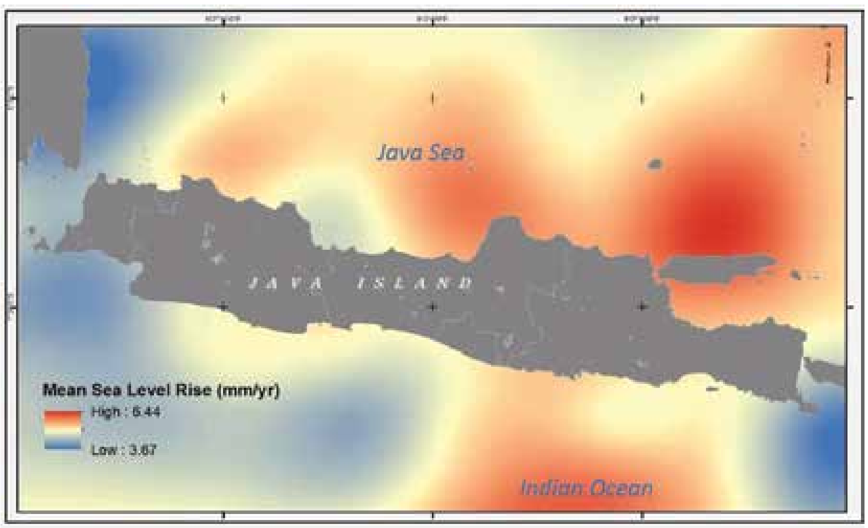

Fig. 1. The trend rate of regional sea level rise from October 1992 to April 2013 by Aviso [11]

This coastal area is utilized by aquaculture activities. Moreover, the most extensive landuse is fishpond, followed by agricultural land and settlement (Fig. 3). During rainy seasons, farmers use the fishpond for fish farming. While in dry seasons, some of the ponds are functioned as salt evaporation ponds, especially in the dry sandy substrate. Economic dependence on fish and salt persuades coastal communities to change areas covered with mangrove into ponds.

Based on the temporal analysis of LANDSAT satellite images and topographic maps (Fig. 4), the shoreline of Indramayu was eroded by 574 m to 950 m during period of 1959 to 2010. Indramayu coastal area is composed of soft materials like clay, silt, and fine sand. These materials are very easily relocated by wave and current, resulting in coastal erosion. Sea level rise permanently inundates and even submerges the coastal area and, subsequently, the shoreline retreats.

Klein and Nicholls [17] explain the two approaches in coastal management, i.e., mitigation and adaptation. Mitigation approach is employed to decrease any hazardous possibilities by implementing preventive efforts. As a natural phenomenon, sea level rise is almost inevitable. Therefore, in this case, the adaptation approach is more appropriate to apply. There are three strategies for global warming adaptation in coastal management, namely coastal area protection, planning, and accommodation [18]. The protection of the coastal area potentially decreases any disaster

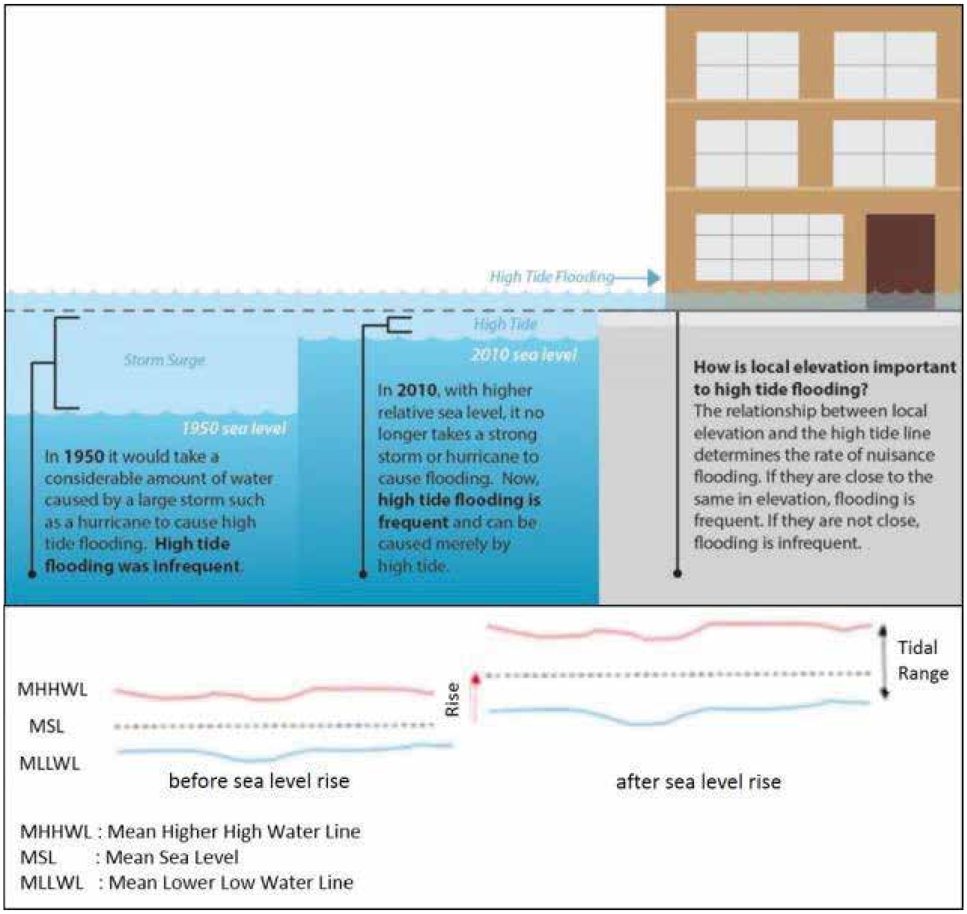

Fig. 2. Illustration of mean sea level rise followed by high tide and, in some cases, extremely high tide and cause flooding (adapted from [13])

Fig. 3. Land use map of Indramayu Coastal Area (source: Topographic Map of Indramayu 2014 Scale 1:25 000)

probabilities. While coastal area planning prevents the affected regions from becoming wider, coastal area accommodation reduces the impacts of sea level rise by accommodating coastal processes. In practice, these adaptation efforts are managed by coastal engineering and ecological techniques based on the characteristics of the coastal area. Some part of Indramayu coastal area is protected

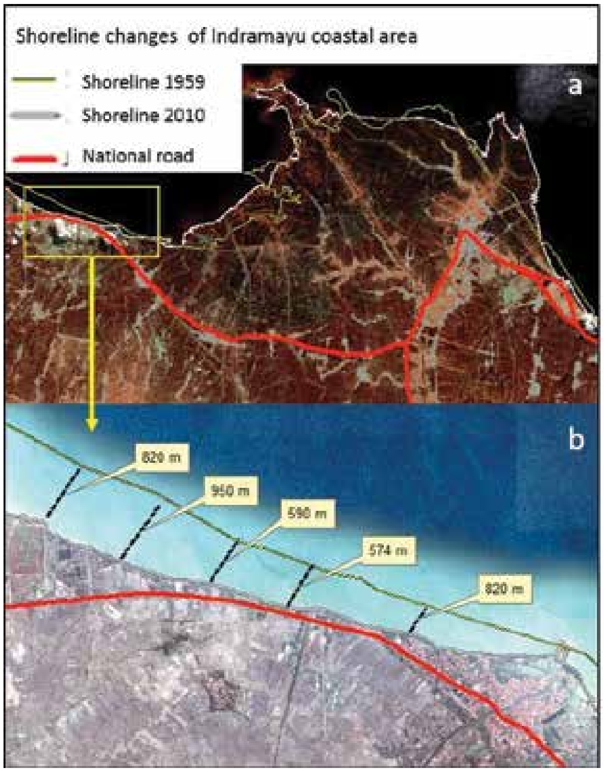

Fig. 4. Shoreline changes of Indramayu coastal area (1959 to 2010) (a), shown that the coastal retreat is up to 950 m in yelow box area (b)

by dikes along the river and the shores as an engineering technique protection. Whereas, it's the ecological technique protection using mangrove belt still needs optimization. There is mangrove conservation area in a village of Indramayu coastal area, namely Karangsong. Community have planted mangrove since 2006 for silvofishery as well as tourism destination area. However, it is only a small part of Indramayu coastal area. In the other parts, mangroves grow naturally with low density so they do not have economic as well as ecological function.

The sea-level rise, permanently inundate low-lying area and cause many losses in Indramayu coastal area. The natural phenomenon can not be prevented, but we can still adapt to natural processes to reduce the impact of sea level rise. It is important to predict inundated area next 50 yr or 100 yr that coastal can be managed by considering the model. Ecological technique by mangrove nursary is one of sustainable strategy to reduce the losses. The paper has two aims, they are to do coastal hazard modeling and its impact on landuse, and to construct a silvofishery and green belt modeling in Indramayu coastal area.

2. MATERIALS AND METHODS

2.1. Digital Elevation Model (DEM) Development

In the Spatial model of sea level rise, a disaster modeling based on digital elevation model (DEM) data was employed elevation. The digital elevation model was generated using contour line, elevation point, and hydrological networks from a topographic map scaled 1:25 000 of Indramayu coastal area as well as elevation point from direct measurement of field survey. The main terrain data, i.e., surface slope, were interpolated into a raster elevation grid in which a pixel value represented information of elevation. Every pixel value was spatially correlated with the surrounding pixels. The nearest data have the most influence than the furthest [19, 20]. The digital elevation model was validated by field surveys to determine artificial features, such as sea dikes, river dikes, and road elevation in order to correct for real conditions of the surface. The resulted DEM provides a resolution of 15 m.

2.2. Tidal Flood Modeling

The basic concept of tidal flood modeling is that water gravitationally inundates low-lying land, i.e., an area whose elevation is lower than that of the water level. The modeling was performed in ILWIS open source software in order to calculate the inundated area using iteration and neighborhood pixel operation techniques from the validated DEM as the input [21]. The operation used six scenarios, they are 25 cm, 50 cm, 75 cm, 100 cm, 125 cm and 150 cm to predict inundated area in the future. Based on the average mean sea level rise rate (5 mm yr^{-1}), it is assumed that mean sea level will be 25 cm higher in the next 50 yr, 50 cm higher in the next 100 yr, and 150 cm in the next 300 yr. This step produced a hydro-connected inundation model.

2.3. Affected Land Use Mapping

Land use, as the product of human interaction and natural environment, is one of the vulnerable objects to tidal flood. It is directly affected by inundation. In this research, the landuse of Indramayu coastal area was visually interpreted based on GeoEye satellite image in 2014 by Digital Globe. The satellite image provides a resolution of 0.5 m that enable detailed

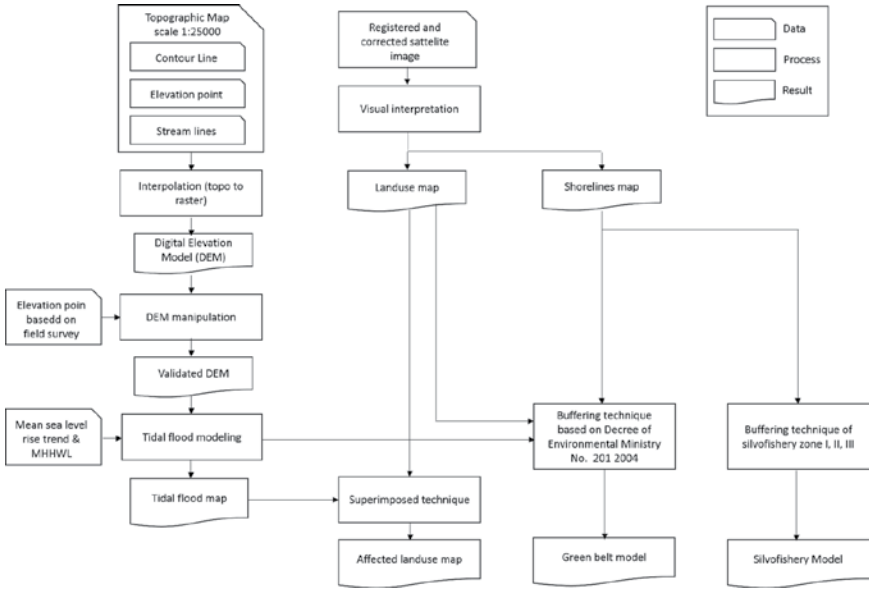

Fig. 5. The flowchart of the methodology of tidal flood and silvo fishery modeling

interpretation of land use. The impact of tidal floods on the existing landuse was analyzed using a superimposed technique by overlaying landuse map and tidal flood map. The overlay toolset is used for combining, modifying, or updating spatial features [22], resulting inundated landuse.

2.4. Green Belt and Silvofishery Modeling for Sea Level Rise Mitigation

Mangrove restoration is a green belt model designed to reduce any sea level rise impacts. In this research, it was created using the buffering technique according to the Ministerial Decree of Environmental Ministry No. 201/2004. As a green belt, mangrove has to be planted as far as 100 m from the shoreline and 50 m from the river bank. Silvo fishery is a combination of fishpond and mangrove vegetation developed based on the percentage of the mangrove area and the fishpond area. The closer the area to the shoreline, the higher the percentage of the mangrove belt. Distance to shoreline also determines the suitable silvofishery type.

The four interrelated steps in the analysis (i.e., from subchapter 2.1 to 2.4) were conducted in order. A detailed flowchart of the methodology is presented in Fig. 5.

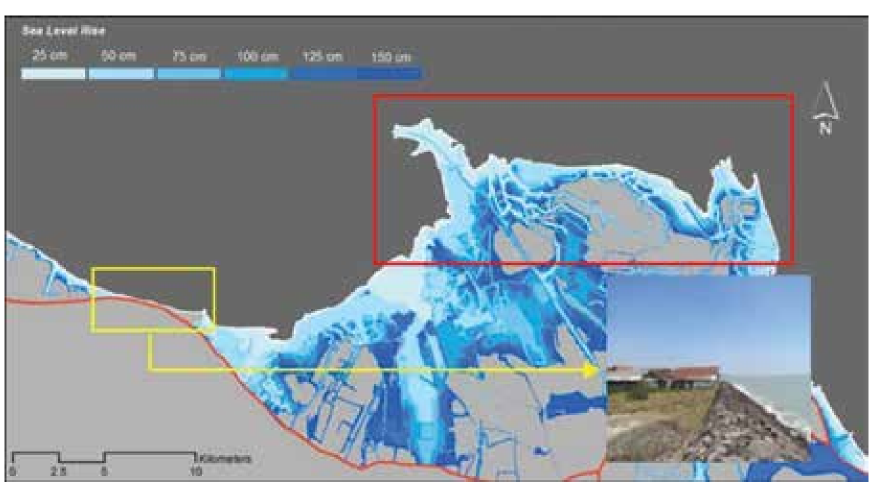

Fig. 6. Coastal inundation map of Indramayu using tidal flood modeling based on sea level rise scenarios (25, 50, 75, 100, 125, and 150) cm

Table 1. The land use area affected by sea level rise in Indramayu coastal area

Land use	Area of sea level rise-affected land use (ha) in various scenarios					
	25 cm	**50 cm**	**75 cm**	**100 cm**	**125 cm**	**150 cm**
Industrial area	72.60	142.16	177.31	241.21	282.85	292.85
Agricultural land	252.50	1 402.80	1 891.60	2 986.90	4 836.64	6 778.78
Fishpond	2 064.07	7 224.95	9 166.68	12 071.07	14 077.83	16 593.75
Mangrove	276.49	397.04	401.31	401.64	406.25	424.33
Settlement	41.05	572.61	722.37	991.18	1 324.48	1 732.91
River	92.73	414.36	496.08	523.87	554.50	628.39
Total	2 799.43	10 153.92	12 855.34	17 215.87	21 482.54	26 451.01

3. RESULTS AND DISCUSSION

3.1. Tidal Flood Modeling and Affected Land use Inventory

Indramayu coastal area is a rural region that is majorly developed for fishpond. The most developed area is Karangsong Village functioning used as fish market and local port. The coastal area is highly susceptible to tidal flood because of its physical condition. The tidal flood model was developed with some scenarios as explained in the subchapter 2.2. The resulted models showed a large affected area (Fig. 6).

The tidal flood modeling was performed by the presence of the dikes built by the government along the river and the shore (inserted photograph in Fig. 6). The government constructed a 2-m high dike along Eretan Kulon and Eretan Wetan Villages (yelow box in Fig. 6) to decrease the impact of sea level rise as well as coastal erosion. The dike protect land and infrastructures, such as national roads, coastal settlement, and fishpond from inundation. The main road connecting Indramayu to cities in North Java is located less than 100 m from the shoreline. The settlements are also built in this area.

Cimanuk Delta, a landform in the western part of the coastal area (red box in Fig. 6), is more widely affected than other coastal landforms with straight morphology (yelow box in Fig. 6). The extensive impact is due to the minimum hard structure built in the delta. In contrast to the Eretan Kulon and Eretan Wetan area, the dike in the delta area is only 0.5 m along the river near coastal settlement and there is not even dike in other part of the delta. The areas of the landuse affected by tidal flood in various scenarios are shown in Table 1.

Based on the area, the most largely affected landuse is fishpond, followed by mangrove and agricultural land. Approximately 2 064 ha of fishpond were flooded in the 25-cm scenario.

Fig. 7. The settlement along the river bank with no dike has higher susceptibility to tidal flood

This number increased to 16 593 ha in the 150-cm scenario. Fishpond is the largest landuse in Indramayu coastal area. It is the primary economic activity performed by the community in the area. Farmers breed and raise milkfish and shrimp twice a year in October-April when enough fresh water is available. Tidal flood can inundate fishpond and sweep away the fish and shrimp. Soil dike as fishpond border is gradually eroded by the flood.

The existing mangrove in Indramayu is naturally grown in the foreshore, notably in the delta landform (red box in Fig. 6 and green area in Fig. 10), with a width of 0-m to 175-m. In the 25-cm and 150-cm scenarios, the flooded mangrove areas were 276 ha and 424 ha, respectively. Coastal flood can inundate mangrove ecosystem and damage small and young mangrove, but it does not influence old mangrove with a strong structure. On the contrary, mangrove structure can trap and bind the soil, sediment, and litter fall transported by the flood.

The flooded agricultural lands in the 25-cm and 150-cm scenarios were 252 ha and 6 778 ha, respectively. The potential agricultural commodities in the area are mainly rice and seasonal crops, which are harvested twice a year. The agriculture and aquaculture are the main economic activities of the coastal community in Indramayu. The affected agricultural land and fishpond physically damage the land and infrastructure and cause financial losses.

Indramayu coastal area has a linear pattern of settlements along the streets. These houses are built on the natural landform of the river, which is higher than the surrounding area. They are located more than 4 000-m from the shoreline, except for the ones in Kandanghaur Village at a distance of 20-m to 4 000-m from the shoreline. The affected settlement is not as extensive as the fishpond and agricultural land. Forty-one ha of the settlement was flooded in the 25-cm scenario. This number increased to 1 732 ha in the 150-cm scenario. Although the affected area is relatively small, the economic and social losses in this landuse are as high as the agriculture and aquaculture land because the settlement has high investment value.

3.2. Green Belt and Silvofishery for Coastal Area Protection

Mangrove has essential biogeochemical (e.g., production, nutrient cycling), ecological (e.g., habitat for the organism, natural protection of coastal erosion), and anthropogenic functions (e.g., maintenance of fisheries, management of sediments) [23]. Mangrove is planted in tropical and subtropical coastal areas with fine substrate [24], like Indramayu coastal area and other coastal areas in northern part of Java. Indramayu coastal

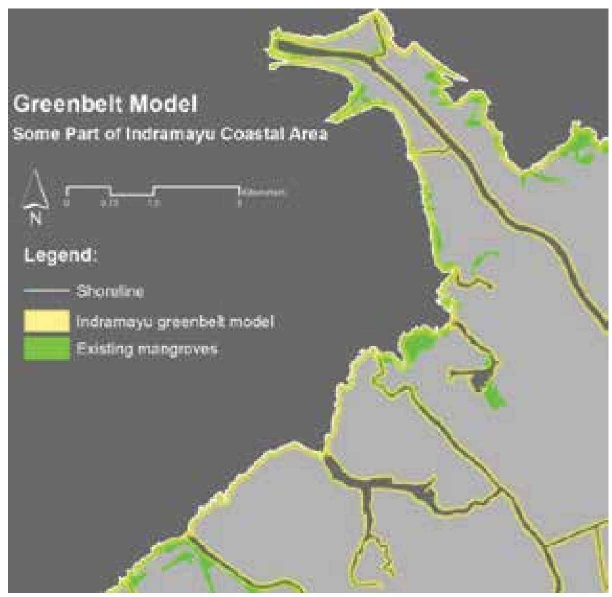

Fig. 9. GIS model of green belt recommendation in Indramayu coastal area to decrease the impacts of sea level rise

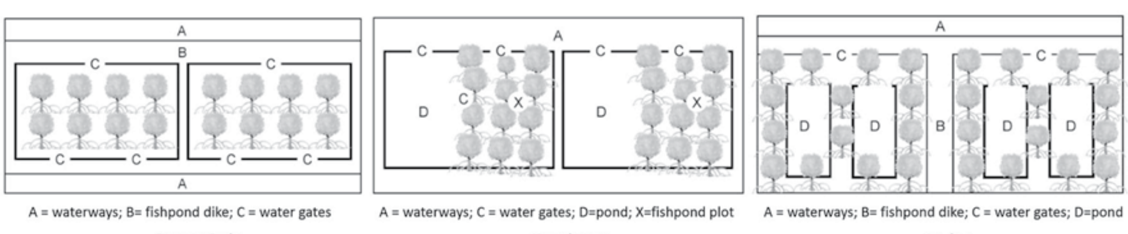

Fig. 8. Illustration model of silvofishery ponds (Source: [27])

Fig. 10. The silvofishery implemented in Indramayu coastal area that is in need of optimization

area is primarily used for fish farming and salt production by the community as their source of income. Silvofishery combines forest and fishpond by planting mangrove in the fishpond area based on a suitable ratio. There are three types of silvofishery applied in Indonesia namely *Empang parit, Komplangan,* and *Jalur (Kao-kao)* (Fig. 8). Most coastal communities have adopted *Empang parit* and *Komplangan* [25].

Sambu et al. [26] reviewed and analyzed various types of silvofishery in Sinjai Region for their ecological aspect. They found that *Komplangan* is the most appropriate one for not only ecological but also economic aspects. This type separates the areas of mangrove and fishpond in one location with at least two water gates that facilitate water flow and drainage. Aside from collecting sediment and breaking sea wave and current, mangrove formation also plays a role as water biofilter. Mangunharjo and Tugurejo, two villages in Semarang coastal area, have been implementing silvofishery with *Kaokao* type. In *Kaokao* silvofishery, mangroves are planted on 1 m to 2 m wide line of mounds, which are constructed in the ponds side by side with a distance of 5 m to 10 m. The area between the mounds is 1-m to 1.5-m deep and is used for fish cultivation.

The silvofishery was modeled using the buffer feature provided by geographic information system (GIS) technology. Buffer is one of spatial analysis tools to select area within specified distance [22]. In this case, it produces areas of selection at a distance of 100-m from the shoreline and 50-m from the river bank. Fig. 9 shows a map of green belt model overlaid with the existing mangrove. Based on this map, the areas in need of mangrove cultivation were identified.

Indramayu coastal area is covered by low density of mangrove (Fig. 10). Therefore, better cultivation is recommended as to increase the density and the distribution of mangrove plants. Greenbelt and silvofishery can improve mangrove ecosystem in the area and protect coastal area from coastal hazards. Greenbelt zone has a distance of 100-m from the shoreline and 50-m from the river bank. This zone has to be entirely cultivated with mangrove. The decree may face a difficult implementation in Eretan Kulon and Eretan Wetan villages since the communities already built settlement in the area between 20-m and 3 000-m from the shoreline and riverbank a long time ago. A social approach such as the improvement of community's awareness and knowledge related to coastal hazard and its management should be actualized. Instead of greenbelt, coastal area protection still relies on hard structure engineering constructed by the government, namely a 2-m high seawall along the shoreline.

The fishponds located closer to the shoreline should be covered by a larger area of mangrove

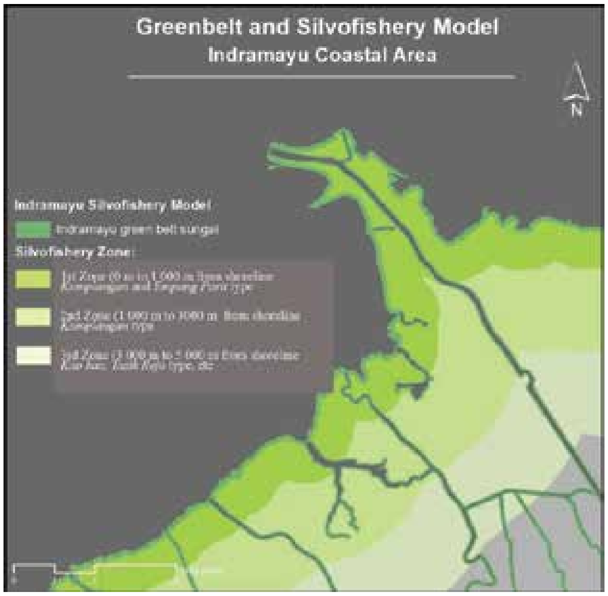

Fig. 10. Zonation of green belt and silvofishery area based on model in Indramayu coastal area

because they may be exposed to higher wave and stronger current and tide energy. For coastal area protection, the suitable type of silvofishery in the foreshore is *Komplangan* and *Empang parit* that are constructed in the area between 0-m and 1 000-m from the shoreline.

The relative area for mangrove in *Komplangan* is usually 70 % to 90 %. In this silvofishery type, mangroves are planted on the shallow area (mangrove plot) called "*pelataran*" intermittently with fishpond. Fish or shrimps are bred and raised in the remaining 10 % to 30 %, which is deeper than the mangrove plot. *Empang parit* has mangrove plants in the middle of fishpond area. Fish and shrimps are farmed in a deeper pond surrounding the mangrove. *Komplangan* is also appropriate for the area between 1 000-m and 3 000-m from the shoreline. About 50 % to 70 % of the area is covered by mangroves. Area located between 3 000-m and 5 000-m from the shoreline may be safely used for intensive aquaculture activity. About 50 % to 80 % of the area can be developed for fish or shrimp farming with mangrove plants occupying at least 20 % to 50 % of the area using the *kaokao* type. Mangrove is planted along the one to two-meter wide fishpond dikes. *Kaokao* type has larger area for fish cultivation and receives high enough sunlight.

Fig. 11 shows the green belt and silvofishery model in Indramayu coastal area. However, *Komplangan* is the most appropriate type for this coastal area. Most people in Indramayu obtain their main incomes from fish farming. Silvofishery can be sustainably applied by determining the economic value gained by the people.

4. CONCLUSIONS

Fishpond as the main source of income of Indramayu coastal community is threatened by sea level rise. Based on the GIS modeling, it is the most widely inundated landuse, namely more than 2 000 ha in the 25-cm sea level rise scenario and more than 12 000 ha in the 100-cm scenario. The inundation damages the landuse physically and disrupts the economic and social aspects in the study area. The green belt zone (100 m from the shoreline and 50 m from the river bank) should be fully planted with mangrove. The suitable Silvofishery type in Indramayu coastal area is Komplangan. The area located between 0 m to 1 000 m from shoreline should be planted with mangrove with a ratio of 70 % to 90 %. Intensive aquaculture activity could be safely done in the area located more than 3 000-m from the shoreline with mangrove plants occupying 20 % to 50 %. The results of the research are expected to be valuable as one of the inundation management models in coastal aquaculture area affected by sea level rise.

5. ACKNOWLEDGMENTS

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