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MODELING OF SHORELINE CHANGES IN WEST KALIMANTAN USING REMOTE SENSING AND HISTORICAL MAPS

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Abstract

Mapping of potential site for nuclear reactors in Indonesia's coastal areas is a part of the national program. The coast of West Kalimantan is selected as a potential location for nuclear site, it needs understanding of shoreline changes. The main requirement for determining nuclear site location must be built in minimum abrasion and accretion. This study aimed to analyse the shoreline changes based on remote sensing and historical maps data. We used historical maps for 1945, whereas Landsat imagery for 1990, 2005, and 2020. These imageries are analysed to determine total suspended soilid (TSS) as the main driver. Shoreline changes analysed using 'Digital Shoreline Analysis System' (DSAS), including linear regression rate (LRR), net shoreline movement (NSM), End Point Rate (EPR), and predicted model in 2030 and 2040. Shoreline in West Kalimantan is separated into 7 (seven) segments. The result study shows that period 1945-1990 has a highest acretion which reach 209.84km^2. It different to 1990-2005 period, the shoreline was decreased reach 56.56km^2. In 2040, the shoreline will reduce up to 4 percent. The segment 3 (Bengkayang) is most stable area with a change rate of 0.0036m per year and relatively balanced in gain/loss perspective. TSS had correlation with the shoreline changes in 1990 and 2020. This research is expected as reference in coastal protection efforts for the first National Nuclear Energy's contrcuction in Indonesia.

***Keywords**: Abrasion; Accretion; Shoreline changes; West Kalimantan*

Introduction

The development of nuclear power plant on West Kalimantan aims to meet national electricity needs, spur industrial growth, and improve community welfare, it requires spatial modeling to ensure location suitability and minimize damage to coastal areas [1, 2]. West Kalimantan is a priority for the development of the electricity industry. This region's role as transportation route and vital to Indonesia, which includes fishing, coastal tourism, and marine conservation. Environmental monitoring and provision of data related to West Kalimantan as a

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prospective nuclear power plant site location need to be well prepared according to its geographical dynamic.

Coastal environment in West Kalimantan is strongly influenced by South China Sea and tropical monsoon, especially on biogeophysical conditions. Changes to coastal environment occur due to human activities [3]. Focus for development of nuclear power plants in this region is shoreline changes due to abrasion and accretion. These changes happen to rapid development that is not accompanied by environmental protection and rehabilitation. Changes have also occurred in estuary of some main rivers in West Kalimantan. Without a good understanding of this situation, nuclear power plants can threaten coastal ecosystems [4]. Sediment is an early indicator in evaluating coastal environmental conditions. Material originating from rivers is one of the causes of sedimentation and causes shoreline changes. Sediment transport is influenced by tides, waves, river discharge, salinity, bathymetry, sediment origin, coastal structures, and shoreline changes [5]. This phenomenon often causes problems on anthropogenic structures, for example, deposition in ports, reservoirs, and ponds.

Observation of shoreline changes is very important to support site selection for this first nuclear power plant in Indonesia. Actually, this observation can be done through field observations, but these activities are considered inefficient. Shoreline changes are commonly observed through remote sensing techniques, satellite imagery data that has been available since the early 1970s [6]. The use of satellite imageries, especially multispectral, are capable of extracting other information on coastal research, namely total suspended sediment (TSS) as the main factors of shoreline change [7, 8]. Knowing the spatial distribution of TSS, geodynamic process for shoreline changes can be better analyzed.

Even it has high efficiency for observing shoreline changes, remote sensing imageries still have limitations because these data only present information in the last 50 years [9]. We need another source of information and it comes from historical maps that have been made by credible institutions. In Indonesia, historical maps generally originate from Dutch East Indies since beginning of the 20th century which have been continuously updated until end of World War II by US Army-Map Services (AMS) [10]. Shoreline changes data needs to be entered for analysis of potential nuclear power plant site that requires stability from abrasion and accretion in long period, so combining remote sensing imageries, especially from Landsat series, and historical maps are the right option. This study aimed to analyze the shoreline based on remote sensing and historical maps data, also is equipped with TSS analysis as the main driver.

Expermental Part

Study area

This research is located along the coastal area of West Kalimantan, Indonesia. The region has hot temperatures (27.25ºC), high humidity (84 percent), and high annual rainfall (more than 3000 mm). Administratively, the coastal area of West Kalimantan consists of two cities and six regencies, ie. Sambas Regency, Bengkayang Regency, Singkawang City, Pontianak City, Mempawah Regency, Kubu Raya Regency, Kayong Utara Regency, Ketapang Regency (Fig. 1). It is bordered by Sarawak (Malaysia), Java Sea, Central Kalimantan, East Kalimantan, North Natuna Sea (South China Sea), and Karimata Strait [11].

To meet demand for electricity in Kalimantan, Indonesian Government has pursued power plant development in West Kalimantan through coal-fired power plants in Bengkayang, Pontianak, Ketapang, and Kayong Utara [12]. The coastal area of West Kalimantan included in national nuclear energy (NNE) development planning, because this region is safe from disasters (earthquakes, tsunamis, forest and land fires), near industrial areas, and shallow peatlands. The assessment of biogeophysical aspects of nuclear power plant site has been carried out since 2014. These data are continuously updated to support the analysis process, determining the most feasible and safe location, including the threat of shoreline changes.

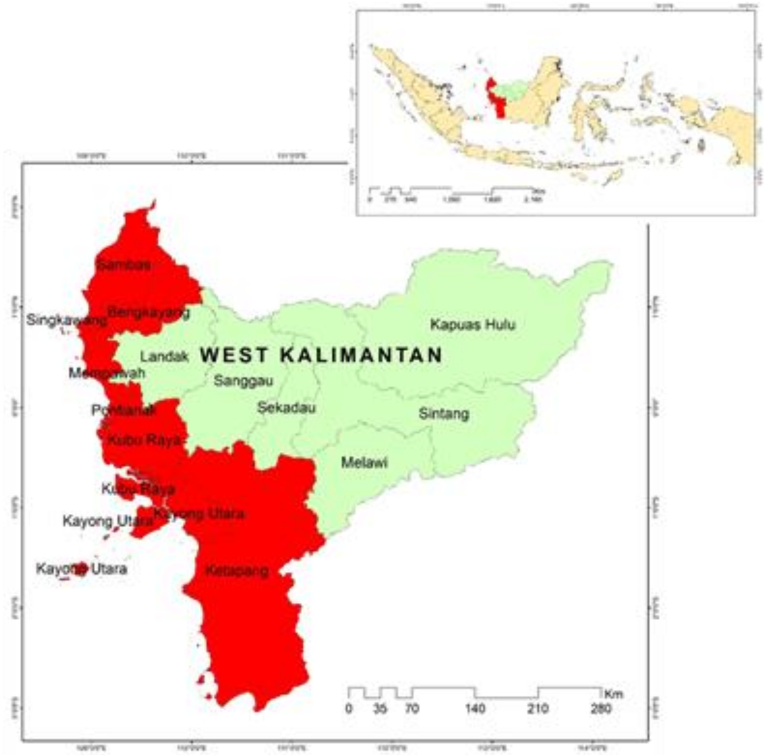

Fig. 1. Research study map

Data acquitition and analysis

Analysis unit in this study using administrative region on the level of city or regency. There are 8 administrative which are directly adjacent to sea. For ease of analysis, we separate these regions into 7 (seven) segments, where Sambas (segment 1), Singkawang (segment 2), Bengkayang (segment 3), Mempawah and Pontianak (segment 4), Kubu Raya (segment 5), Kayong Utara (segment 6), and Ketapang (segment 7). Remote sensing data and historical maps are used to analyze the dynamics of shoreline changes. In detail, we got data from Dutch East Indies Maps (1945), Landsat-7 TM (1990 and 2005), and Landsat-8 OLI (2020). Satellite imageries need to be corrected to produce valid information [13, 14].

These images require a composite band in RGB format, 432 for Landsat-7 TM and 543 for Landsat-8 OLI) [15]. Shoreline data is obtained by visual digitizing. In addition, we need baseline data for shoreline change analysis with Digital Shoreline Analysis System (DSAS). This plug-in facilitates more detailed analysis of shoreline changes such as gain and loss, LRR (Linear Regression Rate), NSM (Net Shoreline Movement), EPR (End Point Rate), and forecast up to 10 and 20 years [2]. LRR is a linear regression of all points of intersection of shoreline and its segments, whereas EPR is a result of shoreline changes rate by dividing the distance between longest shoreline with last year's shoreline. Different from LRR and EPR, NSM measures the distance between longest and most recent shoreline changes [16].

Remote sensing techniques are also used in TSS monitoring because each object has different reflections. The corrected image is then processed using Parwati and Purwanto algorithm [17]. This algorithm uses a band that is sensitive to changes in sediment concentration in shallow tropical waters and has been shown to produce good accuracy when juxtaposed with direct measurement [2, 8]. Parwati and Purwanto algorithm can refer to the following equation. Interaction between shoreline changes and TSS is known by correlation test using Spearman-Rank formula [18]:

$$TSS = 0.6211 \times (7.9038 \times exp\ (23.942 \times RB))^{0.9645}$$

where: TSS is total suspended sediment (mg/L), exp is exponensial value, and RB is red band.

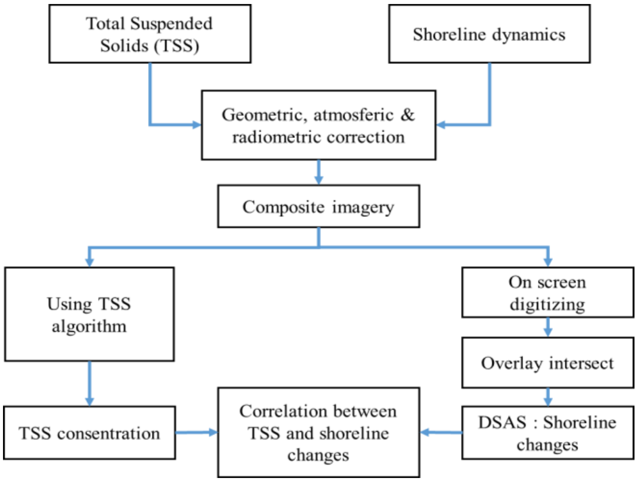

Fig. 2. Research framework

Results and discussion

Dynamic of shoreline changes

Based on morphometry, length of the shoreline has decreased, but it is relatively stable. In 1945, the length was 1117.89km and it will reduce by 1073.35km (4 percent) in 2040. Currently, segment 7 is the longest shoreline in West Kalimantan, opposite segment 2 as the shortest (Table 1). Almost all periods have gain, which means that accretion is greater than abrasion. In 1945-1990 had highest gain up to 209.84km^2. Only in 1990-2005 and 2020-2030 show reverse conditions (Table 2). In 1990-2005, land was more loss than accretion, reaching 56.56 km^2. Shoreline stability refers to LRR, EPR, and NSM. From these results, we can find out the shoreline in each segment. Segment 3 is a stable area when compared to others with a change rate of 0.0036m/year, EPR 1.83m, additional distance of 138.15m, and the smallest gain/loss of 0.20km^2 (Table 3 and Table 4). In the future (2030-2040), these conditions are relatively same as now. This happens success of conservation and rehabilitation efforts in coastal areas in Bengkayang through breakwaters and mangrove vegetation since end of 1993 [19]. Breakwaters and mangrove vegetation function as guards from abrasion [20].

Table 1. Shoreline dynamics 1945-2040

Shoreline	Length (km)							
	Seg. 1	**Seg. 2**	**Seg. 3**	**Seg. 4**	**Seg. 5**	**Seg. 6**	**Seg. 7**	**Total**
1945	187.50	23.94	40.49	77.06	273.90	195.10	319.90	1117.89
1990	183.20	23.33	39.04	75.91	281.80	194.10	316.00	1113.38
2005	186.70	23.43	39.63	76.16	284.30	191.90	316.50	1118.62
2020	186.40	22.35	40.08	77.47	278.10	190.70	319.90	1115.00
2030	181.10	22.17	38.03	75.25	267.40	183.40	297.00	1064.35
2040	183.40	22.07	38.19	75.69	270.60	184.60	298.50	1073.05

Table 2. Shoreline's gain and loss by length

Shoreline	Gain and loss (km)							
	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Mean
1945-1990	-4.30	-0.61	-1.45	-1.15	7.90	-1.00	-3.90	-0.64
1990-2005	3.50	0.10	0.59	0.25	2.50	-2.20	0.50	0.75
2005-2020	-0.30	-1.08	0.45	1.31	-6.20	-1.20	3.40	-0.52
2020-2030	-5.30	-0.18	-2.05	-2.22	-10.70	-7.30	-22.90	-7.24
2030-2040	2.30	-0.10	0.16	0.44	3.20	1.20	1.50	1.24

Table 3. Shoreline's gain by area

Shoreline	Gain (sq. km)							
	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Total
1945-1990	51.51	4.22	1.87	26.67	120.80	44.96	97.24	347.27
1990-2005	6.66	0.30	0.18	1.55	18.66	18.79	31.56	77.69
2005-2020	53.02	6.69	14.60	25.36	50.52	19.91	28.02	198.12
2020-2030	7.35	0.10	0.09	3.08	28.10	13.75	26.47	78.94
2030-2040	9.07	0.81	0.66	4.11	16.94	7.55	10.55	49.69

Table 4. Shoreline's loss by area

Shoreline	Loss (sq. km)							
	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Total
1945-1990	43.80	1.83	1.68	5.31	30.67	19.80	34.34	137.43
1990-2005	18.68	3.09	9.52	16.36	35.08	18.58	32.94	134.25
2005-2020	3.13	0.55	0.18	0.57	9.82	8.16	34.59	57.00
2020-2030	25.54	1.55	6.72	7.65	21.90	9.17	21.77	94.30
2030-2040	4.17	0.28	0.46	0.93	3.65	2.16	3.38	15.05

Table 5. Shoreline's Gain and Loss by area

Shoreline	Gain and loss (sq. km)							
	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Total
1945-1990	7.71	2.39	0.19	21.36	90.13	25.16	62.90	209.84
1990-2005	-12.02	-2.80	-9.34	-14.81	-16.42	0.21	-1.38	-56.56
2005-2020	49.89	6.14	14.42	24.79	40.70	11.75	-6.57	141.12
2020-2030	-18.19	-1.45	-6.63	-4.57	6.20	4.58	4.70	-15.36
2030-2040	4.90	0.53	0.20	3.17	13.29	5.38	7.17	34.64

Segment 5 has the most dynamic shoreline changes with an LRR value of 6.52m/year, EPR 7.07m, NSM 533.23 meters, and the gain/loss prediction results reaches 13.29km^2 (Table 6). If sorted according to shoreline stability, the order will be Bengkayang, North Kayong, Ketapang, Sambas, Singkawang, Mempawah & Pontianak, and Kubu Raya. Coastal stability is an important requirement in the construction of nuclear power plants because the more prone to gain triggering the intervention of various parties which give rise to conflict of interest. Likewise, with abrasion, nuclear power plants need a location that has minimal erosion to keep the construction of the building strong and the distance of hot water discharge from sea waters [21]. Efforts to observe the stability of the shoreline help reduce losses and minimize expenditures. For detail, please see Figure 1 to Figure 10.

Table 6. LRR, EPR, NSM in West Kalimantan

Location	LRR (m/year)	EPR (m)	NSM (m)
Segment 1	2.32	3.49	263.40
Segment 2	3.20	4.32	326.19
Segment 3	0.0036	1.83	138.15
Segment 4	4.54	5.69	429.40
Segment 5	6.52	7.07	533.23
Segment 6	2.29	2.44	184.17
Segment 7	2.95	2.76	207.65

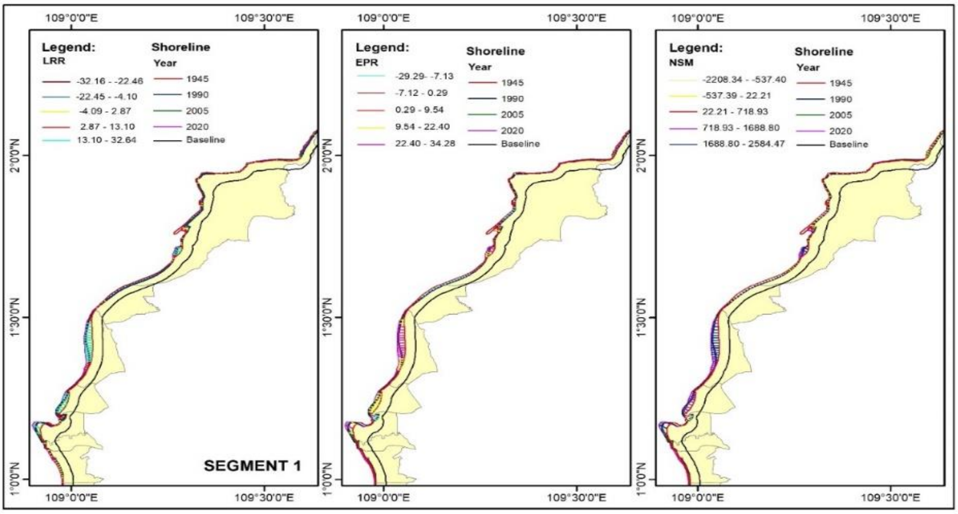

Fig. 3. Shoreline changes in segment 1

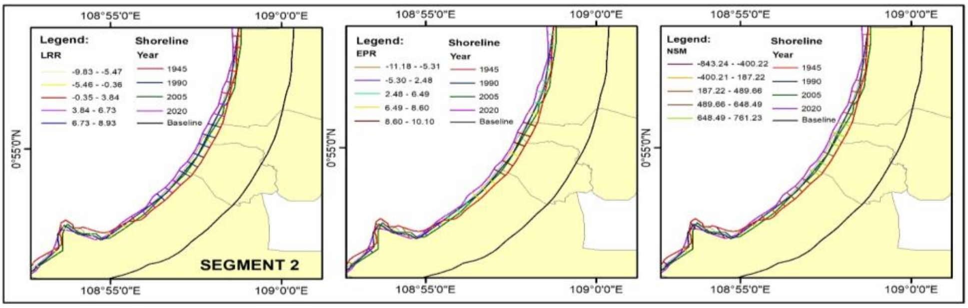

Fig. 4. Shoreline changes in segment 2

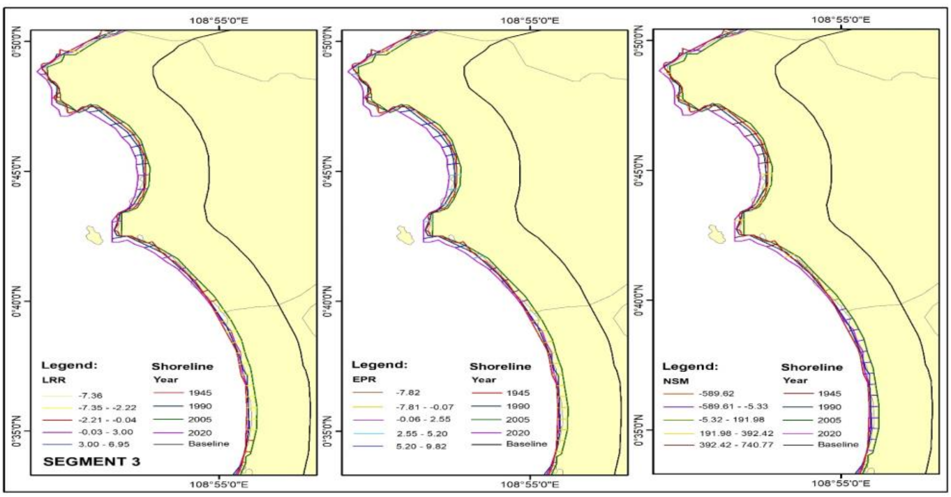

Fig. 5. Shoreline changes in segment 3

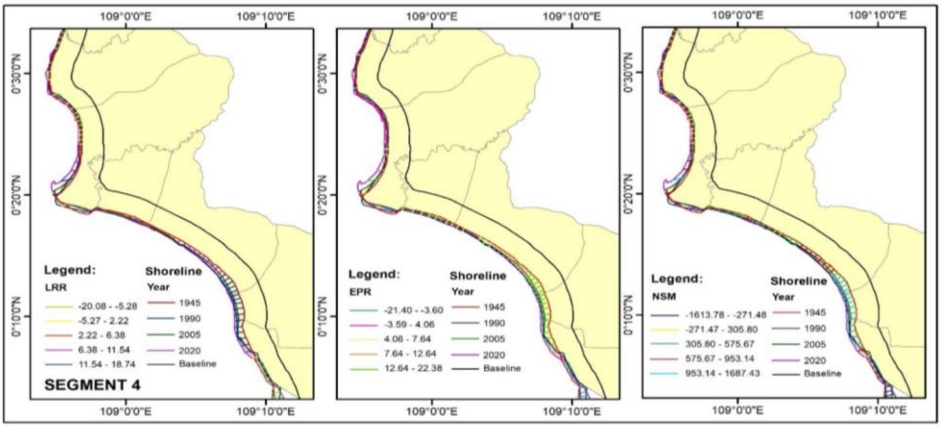

Fig. 6. Shoreline changes in segment 4

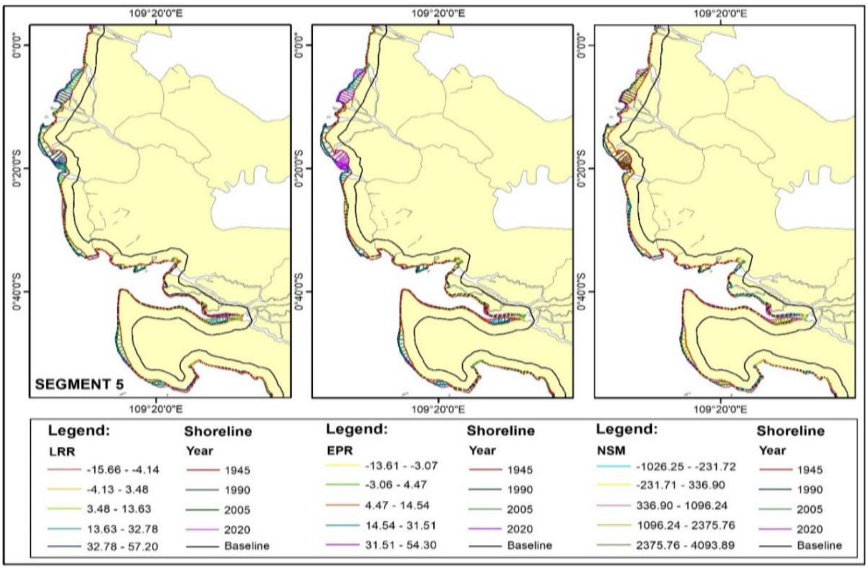

Fig. 7. Shoreline changes in segment 5

Related to the existence of coal-fired power plants in West Kalimantan, especially in strategic locations such as Bengkayang, it is necessary to take ecological considerations. Based on previous studies, coal-fired power plant cases caused changes in environmental quality such as increased TSS, decreased chlorophyll-a, and increased air pollutants [22-24]. Meanwhile, a nuclear power plant requires a large water source to cool the reactor. This power plant is more environmentally friendly even though they are faced with sustainability of aquatic biota which may be impacted by the increase in temperature. The two types of power plants have different consequences, nuclear has advantages over coal in terms of energy efficiency. Currently, the challenge of nuclear power plant in Indonesia is people rejection.

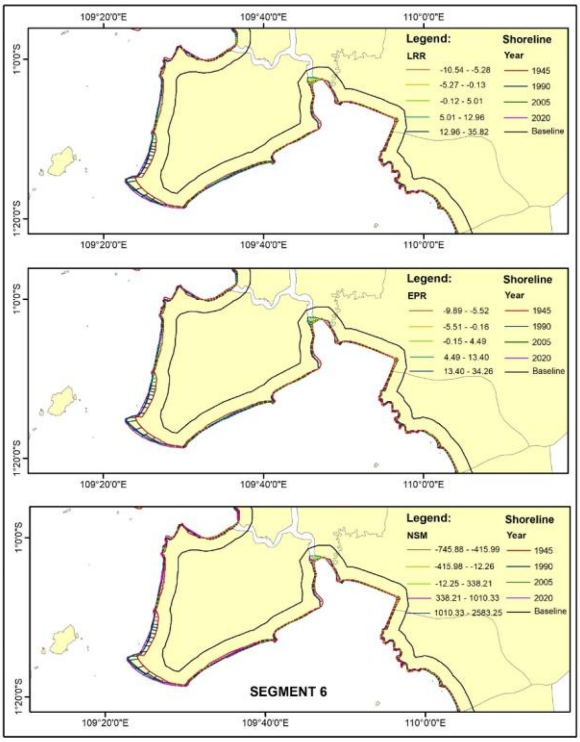

Fig. 8. Shoreline changes in segment 6

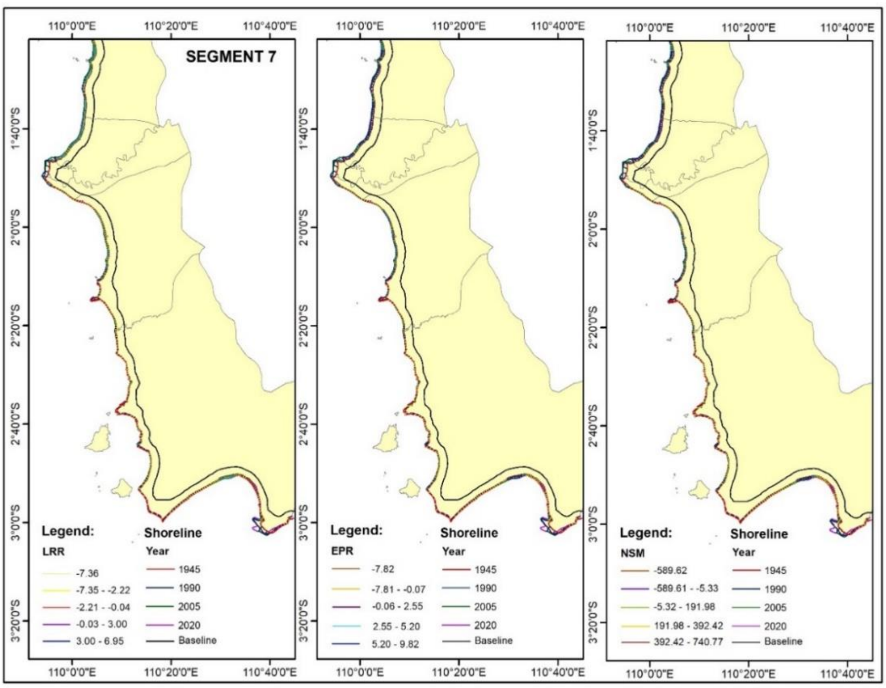

Fig. 9. Shoreline changes in segment 7

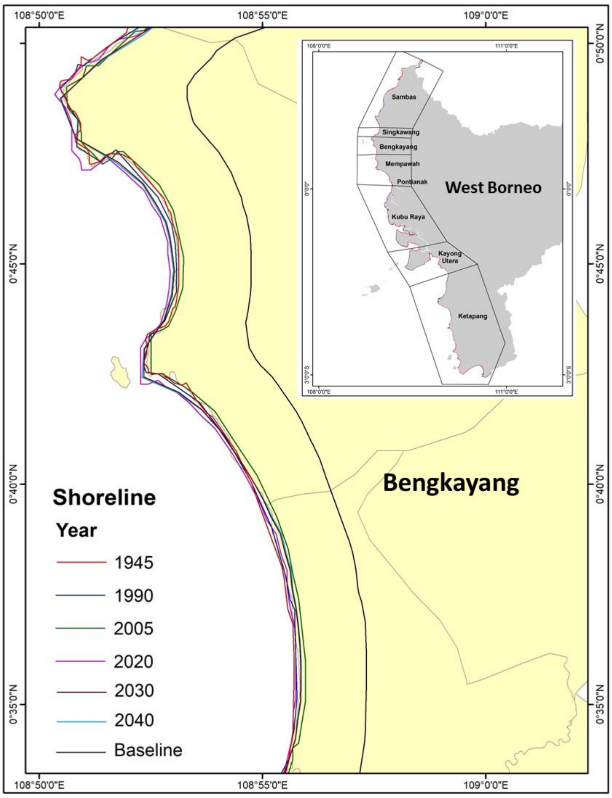

Fig. 10. Shoreline forecasting in 2030 and 2040

TSS Concentration

TSS concentrations near shoreline and estuary, generally show higher values and influenced by sediment supply from land carried by rivers [25] and are caused by the influence of the monsoon [26]. In West Kalimantan, there are large rivers that empty into the sea including, such as Kapuas, Melawi, Sambas, Sekayam, Pawan, Ketungau, Landak, Jelai, Kendawangan, and Sekadau. The highest average TSS concentration occurred in 2005 (25.25mg/L), in 2020 the value has decreased to 15.98mg/L (Table 7 and Fig. 11). In terms of its spatial distribution in 1990, the highest TSS was concentrated around Sambas, Kubu Raya, Kayong Utara, and Katapang Selatan. In 2020, there was another change in the distribution of TSS. The medium to high TSS category is located on the coasts of Sambas, Kubu Raya, and Katapang. From 7 (seven) segments, Singkawang and Bengkayang have low TSS concentrations (Fig. 12).

Table 7. Central Tendency of TSS 1990-2020

Parameter	Year		
	1990	**2005**	**2020**
Maximum	74.67	74.97	74.98
Minimum	5.75	5.41	5.73
Mean	20.32	25.25	15.98
Range	68.92	69.56	69.25
Standard deviation	11.09	14.10	12.06

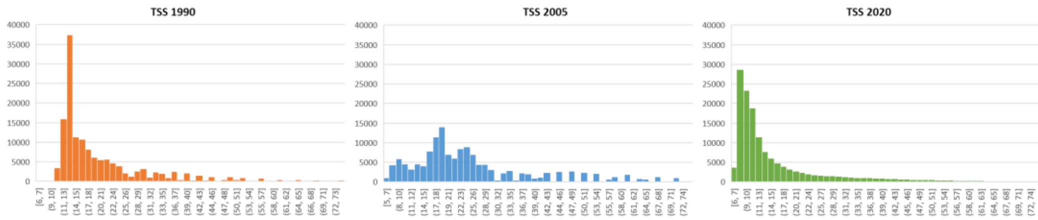

Fig. 11. TSS histograms in West Kalimantan

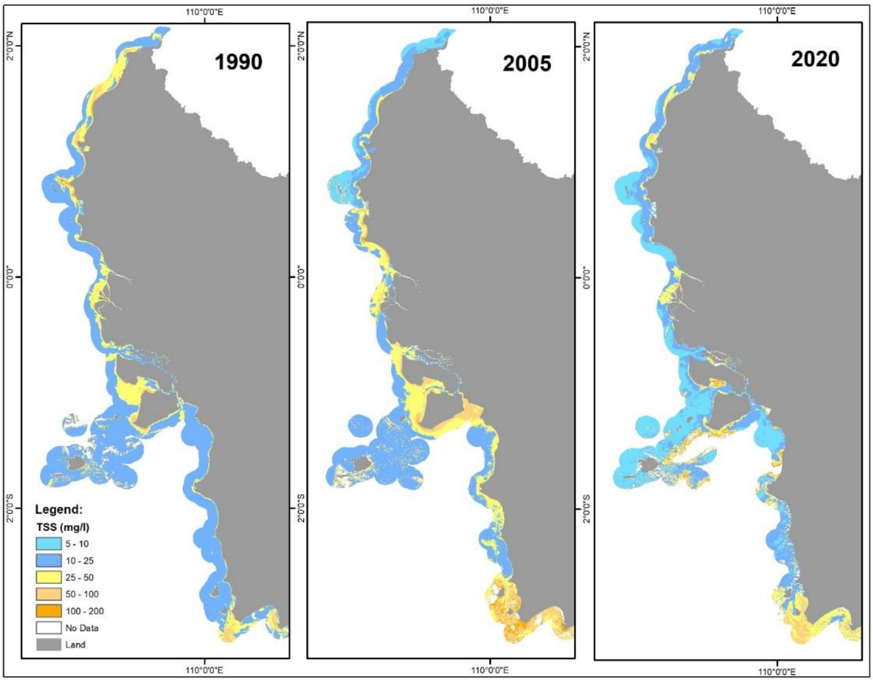

Fig. 12. TSS Distribution in West Kalimantan

High TSS concentrations are associated with land conversion activities in upstream, middle, and downstream of watersheds [27]. Forest in West Kalimantan has complex trend of changing into production forest, oil palm plantations, mining, agricultural land, residential areas, and urban expansion, these resulting in environmental degradation. TSS concentration in 2020 is decreasing on average even though maximum value than previous years. This condition should be focus on protection and restoration of degraded ecosystems due to the massive land-use changes that occurred in 1970-1990 [28, 29].

Shoreline changes and TSS

The dynamics of shoreline changes are linear with TSS concentrations in West Kalimantan, especially in 1990 and 2020. The two years have a significant positive correlation due to unsustainable logging and land conversion activities (Table 8).

Table 8. Correlation of TSS and Shoreline Changes

TSS and shoreline	r-value	Sig.
1990	0.18	0.01
2005	-0.01	0.90
2020	0.17	0.05

A different happened in 2005, which was the transitional year where logging activities began to decrease, instead, production forest was converted into oil palm plantations [30]. In 2020, Kalimantan overgrown with oil palm thus reinforces imbalance in morphodynamic process. A significant positive correlation between TSS and shoreline changes in the period 1990 and 2020 indicates that accretion events can occur in shallow water areas that have high TSS concentrations. As a potential location for nuclear power plants, shoreline changes and waters with high TSS are certainly not feasible because they can cause operational activities to be suboptimal, by reducing use of water as reactor coolant [31-33]. Moreover, waters with high TSS levels generally have high temperatures as well, because it contains solid particles that cause heat propagation to be faster [8].

Conclusions

The integration of remote sensing satellite imageries and historical maps is able to provide information for shoreline changes analysis in West Kalimantan. During 1945-2040, shoreline in this region underwent a dynamic change from 1117.89km to 1073.35km (reduced by 4 percent). This study states that period 1945-1990 has accretion reach 209.84km^2. This phenomenon is inversely proportional to period 1990-2005, shoreline was decreased reach 56.56km^2. The most stable area is in segment 3 (Bengkayang) because annual shoreline changes are close to zero meters per year, although TSS concentration is also high for this area. The highest distribution of TSS was found near river estuaries. Uniquely, TSS only has a positive correlation with shoreline changes in 1990 and 2020. Coastal dynamics studies, especially shoreline changes and TSS were carried out in order to find suitable nuclear power plant locations, both in terms of its development and operation. In addition, this information can be used as input for stakeholders for coastal and marine conservation activities in prospective locations for nuclear power plants.

Acknowledgments

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