Interdisciplinary approach for qualitatively monitoring coastline dynamics in North Java Coast, Case study: Karawang Regency Indonesia

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1. Introduction
Environmental issues along the coast are intimately connected to the coastal dynamic. In reality, the coastal formation of a cliff or low coastal plains depends on the geological phenomenon, including stratigraphic & tectonic and hydro-oceanographic processes [1]. However, in the dynamic coastal evolution, the geological factor is commonly playing the role within long-term where its coastline changing has been developed generally at a very slow rate in time order of million years, the second-order corresponds to sea-level change [2] in the order of kilo-years and the third-order plays in decadal time. All these combined factors work on the coastal zone in an interaction between hydrodynamic agitation, including uncertainty storm surge events [3] and the vulnerability of physical coastline characteristics [4] that caused abrasion or erosion [5-6].

Abstract. The coast of north Java is the most rapid development area among other parts of Indonesia. Since the North Java Coast is dominated by mild slope, soft-loose quaternary sediment and provoked by the sea thus the vulnerability of it is the most challenging issue to be assessed. Karawang is the representative area to investigate the scientific reason of coastal dynamics. This study aims to reveal the coastline changing based on RBI (1210-211, 1210-212, 1210-221, 1210-542, 1210-543, 1210-544 and 1210-631) and LPI (1210-04 and 1209-01) maps, hydrodynamics simulation and field measurements associated with abrasion and accretion. The equalizing procedure has been applied for a benchmark of zero coastlines that LPI and RBI data were used to observe the back and forth of coastline changing throughout 2000 and 2018. The results show five districts, Tirtajaya, Pakisjaya, Cilebar, Cibuaya and Pedes have the highest abrasion with an average magnitude of 11.3 m/year, 9.1 m/year, 6.9 m/year, 5.1 m/year and 3.7 m/year respectively within a total 489 ha disappear area. By all integrated analysis data so we can conclude that the dominated monsoonal longshore current is east to west and working on the dominantly terrigenous coastal alluvium and intercalated by carbonatic marine sediment.

Keywords: abrasion-accretion, coastal dynamic, jetty, North Java Coast
The northern coast of Java physiographically consists of a large and long coastal plain classified as the Coastal Plains of Batavia [7]. Karawang, a part of Java's northern coast is a regency in West Java Province (Figure 1). Like other regencies along the coast has faster urban development that influences coastline zone characteristics or changes besides natural controls. Since decadal years ago, these coupled natural and artificial activities altogether have been dominating to stabilize the coastline zone. The recent circumstance of this northern coastline zone is observed in a steadying coastal resilience among abrasion and accretion processes resulting in coastline retreat or/and coastline increment. Moreover, it is very worrying in some places [8]. The previous studies of coastal dynamics in the area commonly discussed the interactive working among hydro-oceanographic processes and coastline zone characteristics [9-12] without any influencing effect of offshore-onshore curtain sediment and coastal infrastructures. Hence, the objective of this paper is to explain the phenomenon of short-term coastal dynamics on the Karawang coastline zone from the point of view of coupled natural resilience process and the hydrodynamic effect of coastal infrastructures. In this study, we do not consider the existing coastal protection, e.g.: mangrove plantation, artificial sand-bar, breakwater, etc., along beaches that are mainly some urban interests in protecting coastline zone against abrasion.

Figure 1. (A) Map of research location, at Karawang Regency as a part of the northern coast of West Java Province (B) The study area Karawang Regency is a very flat flood plain of the Citarum deltaic system.
1.1. Tectonic setting
The regional tectonic of Karawang can be explained as a part of the northern West Java basinal area, which is a relatively stable platform area, part of the Sundaland, with N-S trending rift basin offshore and adjacent onshore, overlain by Miocene and younger shallow shelf deposits [13-15]. In Sundaland where its core includes inner Indonesian waters, there is considerable tectonically quiescent as inferred from lack of seismic activity related to fault systems occurrences [16]. Furthermore, although the Northwest Java basin area is currently positioned in a back-arc setting, the West Java rift system did not form as a back-arc basin [15]. Thus, it can be considered that Karawang Regency tectonically stays a stable area.

The very flat and wide flood plain of coastal river Citarum at Karawang is obvious evidence of the steady area (Figure 1). Therefore, the coastal dynamic of northern Java within second-order since kiloyears ago (ka) has been controlled by the global eustatic sea-level changes. In other correlative studies revealed that between 20 kiloyears ago before present (ka) and 6 ka, melting of these ice sheets raised Global Mean Sea Level (GMSL) by more than 120 m while in 20 ka, the GMSL was around –120 m that called as the LGM (Last Glacial Maximum) [17-19]. The rate of sea-level rise was 0.6 cm/year, while from 6 ka until today, the rate is only 0.1 cm/year [20]. Thus, it means that the coastal dynamic of northern coastal Java since 6 ka has been being controlled by slower rising sea-level in the same period of all delta’s formation.

1.2. Coastal morphology and seabed sediment distribution
Like on the other coastal zones of northern Java, the topography of the Karawang coastal zone is very flat with a slope range, 0 – 2% laying on 80.44% of the Regency [21]. The most of onshore area (Figure 2) is occupied with terrigenous flood plain alluvium of Citarum River deltaic system that generally covered by topsoil and precisely at the beach-line zone is lying coastal alluvium, shallow marine sediment, swamp deposit and beach ridges deposits, that all these deposits are dominated by sandy sediments [22]. This flood plain of the Citarum deltaic system has most probably been being formed as well since 6 ka. The bathymetry of adjacent coastal waters is also having a very gently inclining [23-24] and the infilling sediments of the seafloor mainly consist of coastal alluvium sandy silt and some silt and gravelly sand [25].

Figure 2. Composite map by modification of seafloor sediment distribution [25], onshore lithology [22] and 11 locations of data acquisition are marked on the figure consisting of field investigation, the picture captures and sediment samplings.
2. Materials and Methods
As traditionally known that shoreline is three-dimensionally mapped utilizing stereography on aerial photographs that, where available, are used to detect past shoreline position [26]. Consequently, applying an interdisciplinary approach has advantages over the traditional approach. In this study, the methods applied are to collect secondary and field observation data. The secondary data were obtained from several reports, published papers and maps. The collected time series maps are from 2000 to 2018 [27-28]. The analysis of overlaying maps was using the software ArcGIS Desktop v.10.5. Despite the methods in the field to collect primary data [29-30] were deploying a drone, a digital camera, beach sediment sampling, GPS handheld tracking and marking and interviews and observations that all those activities were conducted in November 2020. The sediments then were microscopically analyzed to observe the composition of rock, mineral and/or mollusc shells. In addition, hydrodynamic model analysis has been completed for two dominant current speeds and waves within the west and east monsoon. All the data of interdisciplinary approaches are processed following the arranged flowchart (Figure 3) until obtaining the final results illustrated in several maps abrasion-accretion and calculations. Still, since extreme oceanography conditions data such as a short wave and anomaly water level that caused an inundation is rare to obtain so in this study, we do not include the extreme current and wave that caused the inundation in the Karawang coastal area. In analyzing the sea-current of Karawang northern waters, it was performing hydrodynamic modelling using software Mike 21 HD and SW to approach the understanding of monsoonal oceanic current and current longshore dimension.

Figure 3. The flowchart of data processing, running from the interdisciplinary approaches until the maps of coastal dynamics represented by the abrasion-accretion zonation.

3. Results and Discussion
The results of secondary data collection to be compiled and analyzed are mainly containing the maps of the coastal environment (LPI) of Muara Gembong and Cilamaya [27], the landform maps (RBI) of subdistricts in Karawang Regency [28], the Geological Map of Karawang [22] and the Compilation Map of Surficial Sediment Distribution of the Java Sea, Western Indonesian Waters [25]. The first two maps are the most important data to be compiled and analyzed, technically by computerized overlying the time-series maps in the same orthogonal projection system. Then, the following two kinds of maps are important for analyzing the scientific reasons and with several field data in achieving the comprehensive of the coastal dynamic at Karawang as a part of northern coastal Java.
Figure 4. The photos represent the modern condition locations of abrasion (A, B, C), accretion & stable zone (D, E, F) and accretion-abrasion anomaly by a permanent jetty (G, H, I).

Figure 5. Microscopic photos of Karawang beachline zone alluvium that consists of non-organic material sands (A, B) and with coastal organic shells (C, D).

Field acquisition data as the primary data is certainly important in the completion of investigation and analysis. These are field capturing photo spots of characteristic coastal features (Figure 2) and beach sediment sampling of the photo spot location. Figure 4 represent the current coastline condition where the locations of A, B and C can be identified in Cemarajaya sub-district Cibuaya (Figure 2 number 6 and 7), furthermore the locations of D, E and F can be met in Ciparagejaya sub-district Tempuran, Tanjungbaru-Pasirjaya sub-district Cilamaya Kulon (Figure 2 number 9, 10 and 11).
moreover, G, H and I can be found around Sungaibuntu sub-district Cilebar (Figure 2 number 8). The samples are then microscopically observed to identify the composition of sediments with several decisive fragmental materials like volcanic materials, as can be seen in Figure 5A and 5B where its location can be found in Figure 2 number 1 and 4 and/or organic matters, as can be seen in Figure 5C and 5D where the sampling locations can be noticed in Figure 2 number 11 and 4. These actual data are necessary as the modern condition or produces of current coastal dynamic processes. Along the beach line of Karawang Regency, the coastal process couples of abrasions-accretions are not unceasingly, at some places there are stable areas that generally with coastal protections with mangrove plantations or some coastal permanently or temporary constructions (Figure 4).

The evidence of coastal dynamic in decadal time-scale at Karawang coastal zone are investigated very actual and exhibited as the impacts of abrasion and accretion current processes along the beach line. The overlying time-series maps of LPI and RBI from 2000 to 2018 were done in the same scale and orthogonal projection system of World Geodetic System (WGS) 1984 UTM zone 48S. The locations of abrasion-accretion along the beach-line are contiguous depending on geographic products of marine hydrodynamic works on the distinct coastal types of Karawang [24]. The recapitulation of abrasion-accretion locations is displayed in Table 1. On this table, it was evident that along 79.86 km length of Karawang Regency, there 79.85 km length of the dynamic coastal phenomenon are happening since 2000. It means that 99.99% of Karawang's beach-line is not stable facing the hydrodynamic agitation process on coastline characteristics type of Karawang. Furthermore, the discussion will be engaged for represented abrasion-accretion zonation.

The overlaying of the maps 2000-2018 are fruitfully acquiring several nice zonations of abrasion and accretion products along Karawang beachline (Figure 6). Hydrodynamically, these products result from combined oceanographic factors (wave, tide & longshore current) that work on along Karawang beachline, in the framework of seal-level changes since 6 ka [20]. To validate this process results, it needs several pieces of information of field facts, such as to question urban peoples about the historical beachlines onshore. Overall, the coastal dynamic along the beachline of Karawang has been being dominated by abrasion activity.

**Table 1.** The recapitulation of abrasion-accretion impacts at every subdistrict in Karawang Regency during the period 2000-2018.

| No. | Subdistrict     | Beach-line length (km) | Abrasion     | Accretion  |
|-----|-----------------|-------------------------|--------------|------------|
|     |                 |                         | Length (km)  | Retreat maximum (m) | Length (km) | Area (Ha) |
| 1   | Pakisjaya       | 10.73                   | 7.42         | 705        | 3.31       | 8.880     |
| 2   | Batu Jaya       | 0.9                     | 0.9          | 98.3       | 0          | 0         |
| 3   | Tirta Jaya     | 6.45                    | 4.9          | 445.7      | 1.54       | 15.616    |
| 4   | Cibuaya         | 21.93                   | 15.16        | 290.9      | 6.77       | 71        |
| 5   | Pedes           | 5.25                    | 2.58         | 134.9      | 2.67       | 28.35     |
| 6   | Cilebar         | 10.15                   | 4.69         | 329.7      | 5.19       | 176.133   |
| 7   | Tempuran        | 6.74                    | 3.81         | 143.7      | 2.79       | 56.405    |
| 8   | Cilamaya Kulon  | 5.8                     | 3.69         | 155.7      | 2.09       | 4.704     |
| 9   | Cilamaya Wetan  | 12.34                   | 3.59         | 142.7      | 8.75       | 185.45    |
|     | Total of Karawang Regency: | 80.29                  | 46.75        | 33.11      |            |           |
Figure 6. The maps of the abrasion-accretion zonations of Karawang Regency from west to east. A: the coastal process abrasion-accretion zones with 2 observation stations (black dots) covering the beachline of subdistricts Pakisjaya, Batu Jaya, Tirta Jaya and Cibuaya. B: the coastal processes with 5 observation stations occupy Tirta Jaya, Cibuaya and Pedes. C: with 2 observation stations is covering Pedes, Cilebar, Tempuran and Cilamaya Kulon. D: with 2 observation station is scoping Cilamaya Kulon, Cilamaya Wetan.
3.1 Coupled abrasion-accretion zones

The products of the coastal process equilibrium of Karawang overall are dominated with the zones of coupled abrasion-accretion, and only some places have the stable area mostly by artificial construction (Fig. 4, Fig. 6). At least for the last decadal period since 2000, the beachline still shows off some coastal hazards due to dominated abrasion. By the lateral pattern of the beachline, then is experienced the coastal zone resiliency with appearing the zones accretion. However, according to the acquisition data, the abrasion is lateral wider and longer than the accretion (Table 1).

To understand this phenomenon, two environmental domains (onshore & waters) might be verified. The dominant flood plain morphology of Karawang that almost without inclining slope comprises cohesive sediments and loose sandy materials. This lithology seems favourable for developing the Citarum deltaic flood plain since the terrigenous volcanic sediments are already commonly in fine sand size. Thus, in arrival on the coastal zone, the terrigenous sediments are very fine sand or silt (Figure 5), even from the rice fields or crops onshore, it transports some light clayey materials. On this condition, the abrasion can work effectively for then followed by accretion at the adjacent area. That’s why as well the development of the Citarum bird-foot delta is occur facilely toward the north and the northwest. Secondly, on the domain of Karawang offshore, there is working the continuous hydrodynamic processes which the playing roles there are monsoonal oceanic currents and waves (Figure 7).

![Figure 7](image-url)

Figure 7. The hydrodynamic modelling results of northern Karawang waters. (A) The Coastal current velocity pattern of west monsoon, and (B) on east (southeast) monsoon. Arrows show the average current speed in the west monsoon. (C) The condition of wave height at the west monsoon and (D) for the east monsoon wave. The arrows show the wave directions.

Figure 7 shows that the eastern monsoon (B) is more dominant than the western (A) in current speed and wave height. This is ‘in line with the previous study on the Java Sea that the western monsoon is longer than the eastern [31]. In the agitation of oceanic factors (wave, tide & longshore current) on the beachline, the dominant monsoonal oceanic circulation may control the dominant abrasion than accretion.
3.2 Anomaly coastal process

The anomaly of abrasion-accretion resiliency happens at the local capital of Cilebar Subdistrict, where one large-long jetty was constructed in 1984-1985 and is still there until today (Figure 4G, Figure 4H, Figure 4I and Figure 6C). The dominated accretion is well performed at the east side of the jetty toward the east until the Tempura subdistrict for along ±5.5 km. In contrast, the west side is protected by the settlements and abrasion develops toward the west until the administrative border with Pedes. Like in the discussion above, here the eastern monsoonal current was controlling longshore current to transport coastal alluvium and deposited it there. This jetty construction demonstrates that the eastern longshore current can accumulate sediments at the east side of a beach obstacle and should be coupled with abrasion at the west side to reach a coastline equilibrium [32-33]. Regarding the duration of jetty since 1984, thus the dimension of the accretion here is approximately comparable with abrasion at the other locations.

4. Conclusion

The costal dynamic of Karawang Regency morphologically can be exhibited as the product zonation of abrasion-accretion within decadal substage, in the framework of Last Holocene – Recent sea-level changes or since 6 ka. The abrasion-accretion processes are performed by working of several oceanographic factors (wave, tide and current speed) on the coastal characteristic that is dominated by loose sediments such as coastal alluvium, shallow marine fine sediment and terrigenous fine and cohesive sediment. While at stable shoreline zones, several coastal protections correspond to some urban settlements and/or ponds. Concerning the regional atmospheric circulation of west and east monsoons in the Java Sea that derives the dominant longshore current on the Karawang coastline zone, thus the dominant abrasion process is more controlled by westerlies wind from the east monsoon. The anomaly morphology of abrasion-accretion due to jetty construction may change and coastline dynamic pattern on a small scale to reach a new coastline equilibrium.

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Author Contributions

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