Comparison of delta model in the north coast of Central Java using remote sensing techniques (Case study in Delta Comal, Delta Bodri and Delta Wulan)

Comparison of delta model in the north coast of Central Java using remote sensing techniques (Case study in Delta Comal, Delta Bodri and Delta Wulan)

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Abstract. There are many deltas that are grown and developed relatively quick in coastal area of North Java. The development of the delta region is characterized by the occurrence of sedimentation processes that cause the emerge land. The sedimentation process in the delta region is influenced by the sediment supply from the erosion of the upstream watershed. The land use change will potentially affect the rate of erosion, resulting in a sedimentation process in coastal areas. This study aimed to compare the morpho dynamic model of Delta on the north java coast used multi-temporal remote sensing techniques, namely 1987, 1992, 1997, 2002, 2007, 2012 and 2017. The study locations were Delta Comal, Delta Bodri and Delta Wulan. This research was descriptive-explanatory, which was trying to find the widest possible data in order to study the dynamics of Delta, as well as trying to explain the relationship between the factors that influence it. In support of the study used Landsat satellite imagery, Indonesia Topographic Map, ER Mapper 7.0 software, GIS Arc, GPS and other equipment. The results showed that the morphodynamical model of the study area varied. At the beginning of its development, all of the three deltas showed the shape of cuspate but subsequently develop into different morphological forms. In Comal Delta originally cuspate, then developed into Lobate, then tends to cuspate again. In Delta Bodri, from cuspate originally developed into Lobate. While, in Delta Wulan originally cuspate developed into foot bird Delta. Based on the change of delta area, for Delta Comal and Delta Bodri tends to increase, while Delta Wulan tends to fluctuate.

1. Introduction

Delta has a major role in environmental balance. Delta also has enormous benefits because of its highly fertile physical properties as a result of alluvial sedimentation processes which carry high nutrients. Therefore, this area is very suitable for various activities ranging from land conservation (mangroves), aquaculture, and other exploitation such as for settlements and industrial areas. These activities cause almost all of the delta problems in the world that experienced environmental disturbances due to the pressure of human activities that are still depend on natural resources utilization [1].

There are many river deltas with varying widths in the North Coast of Central Java. Some of relatively large and wide river deltas are Comal River Delta, Bodri River Delta and Wulan River Delta. All of the three deltas have different shapes and morphodynamics. On some sides of the delta, it extends to the sea (accretion) as a result of a fairly large sedimentation process, but in other places there are coastal areas that experience the opposite problem, namely abrasion [2].

Monitoring of river delta should have conducted to maintain the balance of the coastal environment. The efforts to monitor dynamic growth of Delta could be done using remote sensing technology. Remote sensing technology could simply use to analyzed large areas. It could use to analyze the development of the delta region in a multi-temporal method. The description of objects in the sensory image also makes it easier to think spatially so that it helps in the analysis of the interrelationships between spaces which in this case is the link between the upstream, the middle, the downstream part of the watershed with the coastal dynamic processes that occur in the Delta region.

Research on the management of the delta region is very important because some of the cities in Java are located in the north coastal areas of Java. Delta landforms have a strategic position and have the potential to develop various uses such as industrial areas, tourism, aquaculture, and settlements. This study aims to analyze the morphodynamic models of deltas in the North Coast of Central Java, namely Delta Comal, Delta Bodri, and Delta Wulan, with multi temporal remote sensing techniques.

According to Reineck and Singh [3], Delta is a subaerial and submerged mass of sediment deposited on the body of water (sea or lake) mainly by river activity. Wright [4] defines the delta as an accumulated area in the coastal region, both subaquenous and subaerial, the material comes from river deposits and secondary deposits from the sea formed by various agents, such as waves, currents or tides. Then Selby [5] defined the delta as an almost flat lowland, located at the mouth of a river where sediment deposits accumulate. In the Oceanography dictionary [6], it is explained that the delta is a sedimentary deposit that originates from land formed at the mouth of a river bordering the sea or lake.

The Delta landform on the North Coast of Java is formed by long-lasting sedimentation. The development process of the delta region is quite dynamic, sometimes experiencing relatively rapid growth so that emerging lands arise, but sometimes experience an abrasion process so that the coastline changes backwards towards the land. Research related to delta morphodynamics has been carried out in various coastal areas of Indonesia. The methods used to determine changes in coastal dynamics also vary, ranging from field studies, such as those conducted by Bird and Ongkosongo [2], Sidarto (1997) in Sanjoto [7] or by remote sensing methods such as those conducted by Doydee [8], Sohail [9] Dewayany [10], and Subagio [1]. The research methods used also vary. In research conducted by Bird [2] and Sidarto (1997) in Sanjoto [7] many use field data and in many data representations are done manually. Then in the research by Doydee [8], Sohail [9], Dewayany [10] and Subagio [1] using remote sensing imagery, which uses satellite imagery with varying shooting times and the oldest was taken in 1985.

Related to the analysis method, the author used time series overlay analysis method with ER Mapper 7.0 software. This was result of the overlay method development which made by Hartoko (2009) in Sanjoto [11]. If the overlay method carried out by Agus Hartoko used 3-time series, then in this study used 6-time series of Landsat Image of 1992, 1997, 2002, 2007, 2012 and 2017.

The dynamic development of river delta influenced by many geomorphic processes. Summerfield [12] has created a diagram (figure 1) that illustrated the influence of fluvial processes, wave processes and tidal effects on various types of deltas formed in the world. If the influence of the fluvial process was dominant, then it will tend to be in the form of Bird's Foot Delta (Elongate), like the Delta of Mississippi in USA. If the influences of fluvial and waves were almost balanced, they will form Cuspate Delta, like the Ebro River Delta in Spain. But if the fluvial and tidal influences were almost balanced it will form a Fan Delta like the Mahakam Delta in Kutai, Borneo.

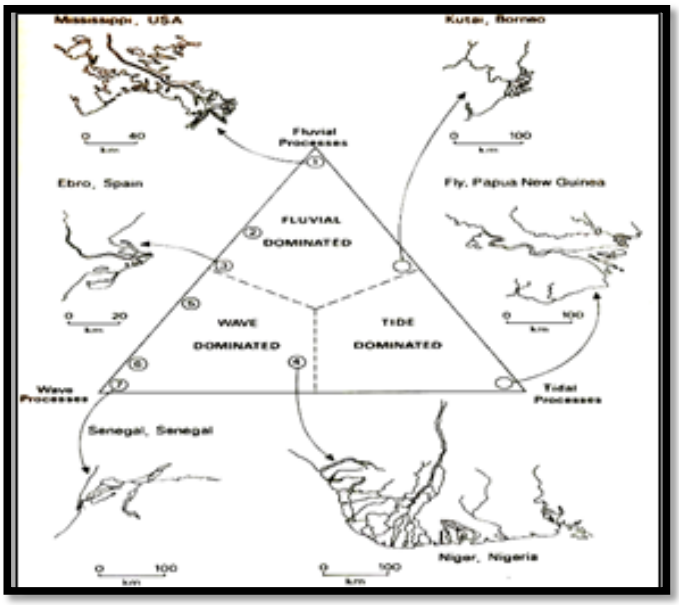

Figure 1. Delta type and its relationship with Hydro Oceanographic Power [12]

2. Method

In order to find out the changes in the Delta coastline, the research material needed were topographic maps of 1: 25,000 scale in 2000 and Landsat Image in 1987, 1992, 1997, 2002, 2007, 2012 and 2017. For data processing used ER Mapper 7.0 and ArcGIS 10.3 software, while for field validation used GPS, soil test kit and binoculars. The research stages were described as follows:

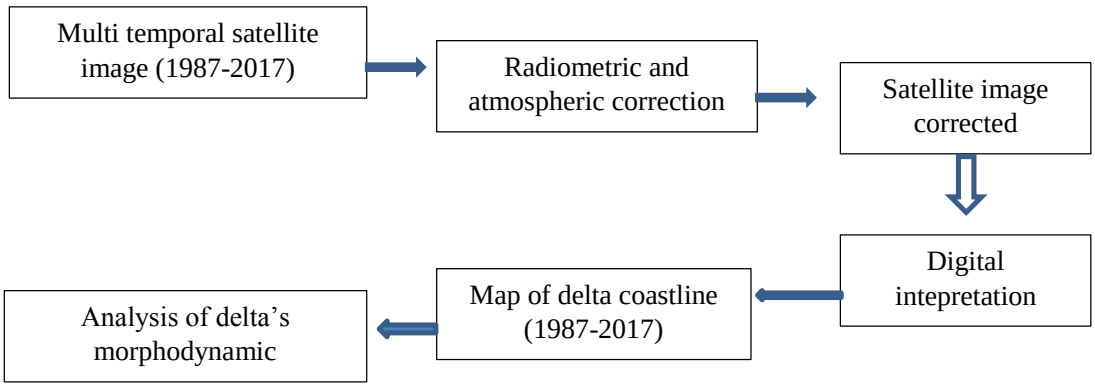

Figure 2. Research flow chart

Analysis technique which used to determine the spatial changes of Comal, Bodri and Wulan Delta coastline was time series data overlay technique with ER Mapper 7.0 software. This method used because the data processing is relatively simple and could involve all data at once. Therefore, the coastline periodic changes could be observed.

3. Results and Discussion

3.1. Morphodynamical change of Delta Comal

Delta Comal is located in the coastal area which is entirely composed of present sediments in the form of a combination of sand beach, mud exposure and mangroves. The sandy beach type was spread mostly in the study area. There were founded some small scale sand dunes in some places which were not mapped. They mixed with mangrove plants or mud exposure.

Shoreline forms are relatively straight and the ocean's wave activity caused by winds was contribute sufficiently to the process of coastal change and formation, beside of tidal factors. In Tegal Beach area until Pecolotan Beach, Pemalang, showed the process of accretion while from the Pecolotan Beach area to the west coast of the Comal River and around the Sragi River estuary, showed the process of abrasion.

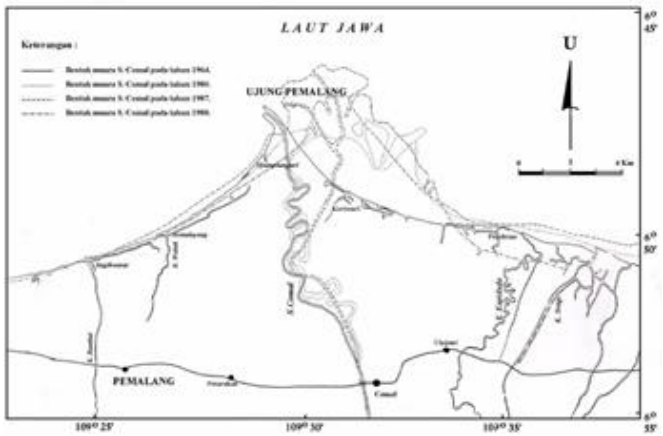

Figure 3. Map of shoreline change of Comal River in 1964 – 1998 [13]

Coastline mapping conducted by Prijantono, et al. [13], along the coast of Tegal, Pemalang and Pekalongan using aerial photographs in 1964, 1980, 1987 and field measurements, showed the coastline changes. Based on aerial photographic data from 1964 to 1987 it was clear that changes in the shape of the estuary had developed eastward. The form of the Comal River estuary was very protruding into the sea and winding to the west, so the sediment material transported by the Comal River was larger deposited to the west of the estuary. Furthermore, based on the Aerial Photograph of 1988, the shape of the Comal River estuary seemed to change a lot.

Based on Figure 3, in 1964 the coastline of the Comal River had one estuary, then in 1988 it changed to three estuaries. Each of the estuaries were formed a delta to the north. The shape of the coastline seems to change where larger land was expanding to the east, and currently the increase in land at the Comal River estuary has been used by the farming community as a pond. Image data from 1987 to 2017 illustrated that the Delta Comal form, in general was relatively same to cuspate form. Nevertheless, the Delta beach model was quite dynamic (figure 4).

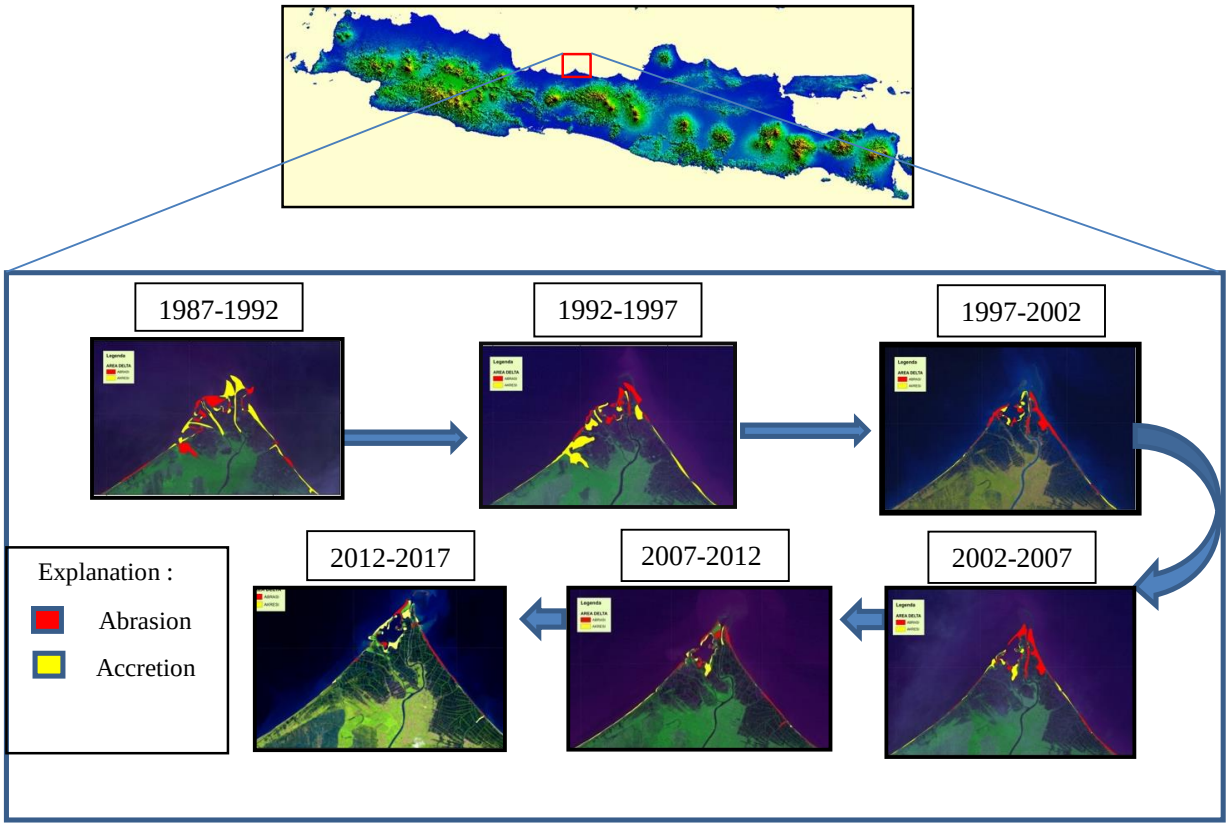

Figure 4. Morphodynamical model of Delta Comal in 1987-2017

Figure 4 provides information about the abrasion and accretion process which occurred intensively at the Comal River estuary. It was happened alternately resulting in changes of the area over time, as presented in table 1. Based on the changes of the area, a trendline of changes in the Delta Comal was shown with linear equations y = 5,0673x - 6702,3 and R2 value = 0,657.

Table 1. Delta Comal Area in 1987-2017

Year	Total area (Ha)
1987	3325,02
1992	3392,70
1997	3492,74
2002	3411,52
2007	3492,01
2012	3478,93
2017	3504,25

Source: analysis, 2017.

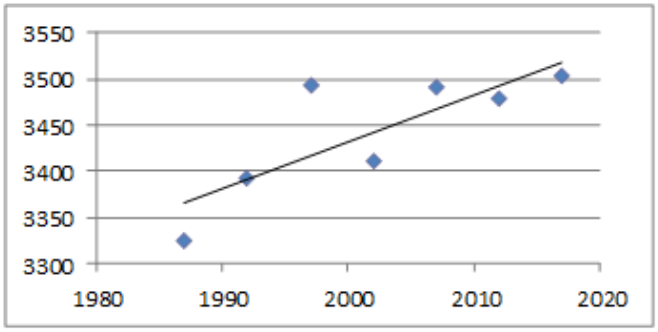

Figure 5. Trendline of Delta Comal growth

3.2. Morphodynamical change of Delta Bodri

The development of Delta Bodri was quite dynamic. This was proofed by the old topographic map of 1910 which described the shape of the Delta Bodri which formed Cuspate (slim). Bird and Ongkosongo (1980) in Sanjoto [7] illustrate the development of Delta Bodri from 1864-1973 (Figure 6).

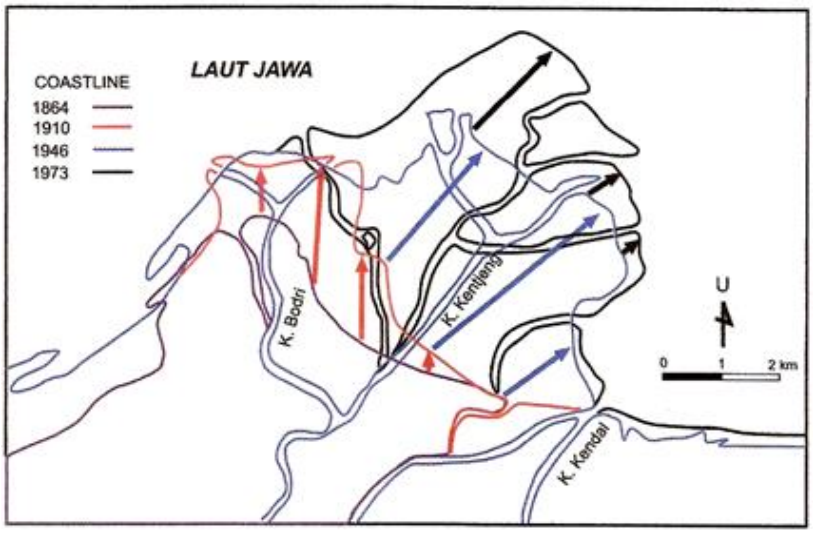

Figure 6. Illustration of Delta Bodri change in 1864–1973 [7]

Based on Delta Bodri's illustration in Figure 6, showed that in 1864-1910 the growth of Delta Bodri's coastline to the North. Then, from 1910-1943-1973 changed to the Northeast. The picture provides information that for 109 years the development of the coast to the Northeast was far more rapid than towards the North. The Bodri River (downstream) also experienced a shift towards the East and then turned to the North parallel to the former flow in 1910. The base of the shifting groove showed a streamline of the river channel first to the North-Northeast. According to Sanjoto, et al. [7], the alignment of the river channel indicates a large river runoff.

Based on the interpretation of the Landsat-1 Image in 1972, an illustration was found that Delta Bodri's morphology in 1972 had developed to form Lobate. Thus, it was estimated that there has been a shift in the delta-forming force, from marines to fluvial, with large volumes and power. Thus, changing of the delta shape which was originally "pointed" (Cuspate) become "fat" (Lobate). Furthermore, from the multi temporal Landsat imagery it could be seen that the development of Bodri River Delta from 1987 to 2017 (over the past 40 years) tends to expand (Figure 7).

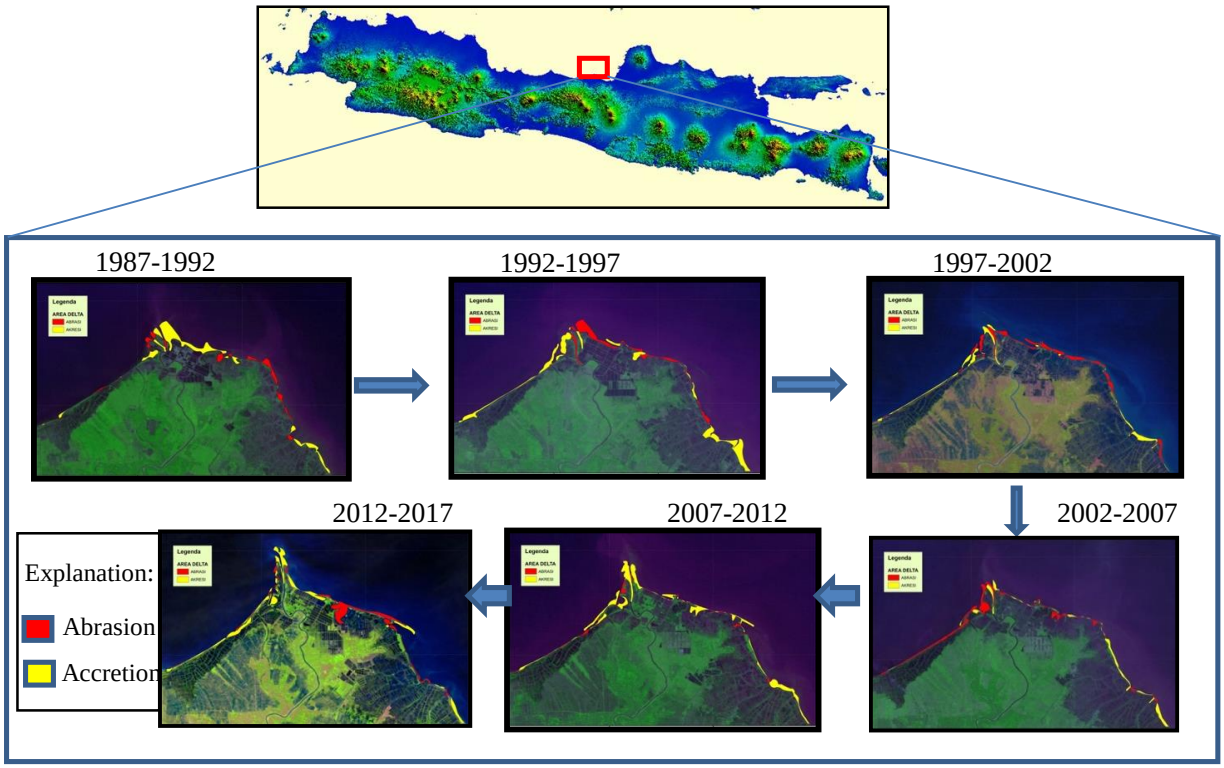

Figure 7. Morphodynamical model of Delta Bodri in 1987-2017

The geomorphological process in the form of abrasion and accretion occurred on the coast of Delta Bodri. It caused changes in area over time. Based on the changes in area, the trend line change of Delta Bodri's showed with the linear equation $y = 0.9553x + 2014.8$ with the determinant value of $R^2 = 0.1934$. Details of the Delta Bodri development and the trend line graph could be seen in Table 2 and Figure 8.

Table 2. Delta Bodri Area in 1987-2017

No	Year	Total area (Ha)
1	1992	3915,591
2	1997	3928,774
3	2002	3907,201
4	2007	3941,942
5	2012	3963,432
6	2017	3921,283

Source: analysis, 2017.

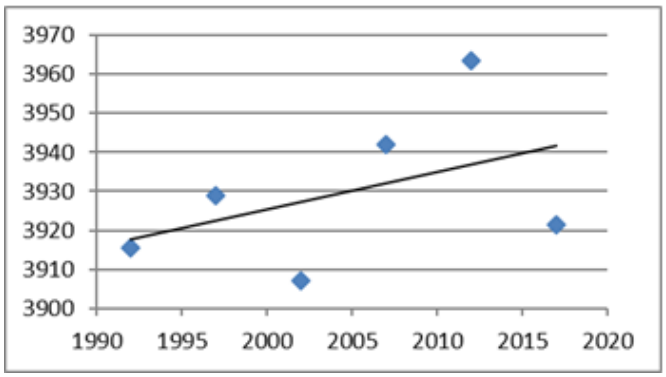

Figure 8. Trend line graph of Delta Bodri development

3.3. Morphodynamical change of Delta Wulan

At the beginning, Delta Wulan was formed because of a scenario to direct the flow of sediment in the Serang River to the south of Jepara Beach through the Wulan Canal in 1892. The Wulan Canal was built for agricultural irrigation purposes in Wedung District, Demak. Before 1892, the coastal area had a straight form of beach. A large amount of sediment transported by the Wulan River keeps Delta Wulan growing. In 1931, the Delta Wulan form was an arcuate type. Subsequently in a 41-year period (1931-1972) significant sediment intake occurred, which changed the shape of the Wulan Delta to Cuspate. The current form of Delta Wulan is the bird's foot (elongate) with a curved coastline [14].

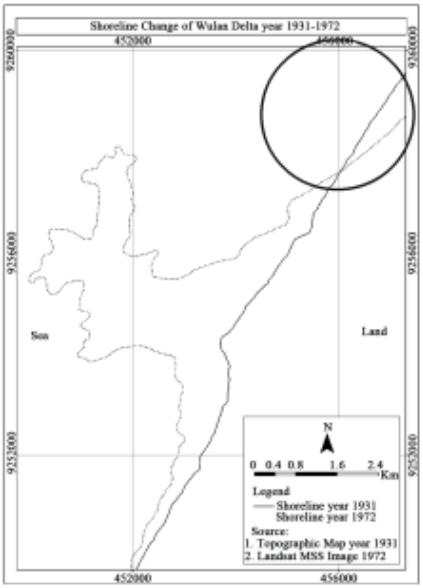

Figure 9. Delta Wulan in 1931-1972 [14]

Based on multi-spectral and multi-temporal interpretation of Landsat satellite imagery in 1987-2017, we obtained the following morphodynamical change of Delta Wulan. The sedimentation process occurs more on the west side of the Delta Wulan compared to the east side. The largest sedimentation process occurred between 1987 and 2017. Sedimentation material mostly came from the upper Serang River, namely Mount Muria and Rembang Hills in the north, also the Kendeng Hills in the south. In the next development between 1992-1997 precisely the abrasion process became dominant. Furthermore, in the period 1997-2002 and 2002-2007 was relatively balanced. According to local information, in the last 10 years there has been no major flooding, so the sediment intake has decreased. As a result, the abrasion process becomes more dominant than the sedimentation process. The Delta Wulan development model from 1987-2017 is presented figure 10.

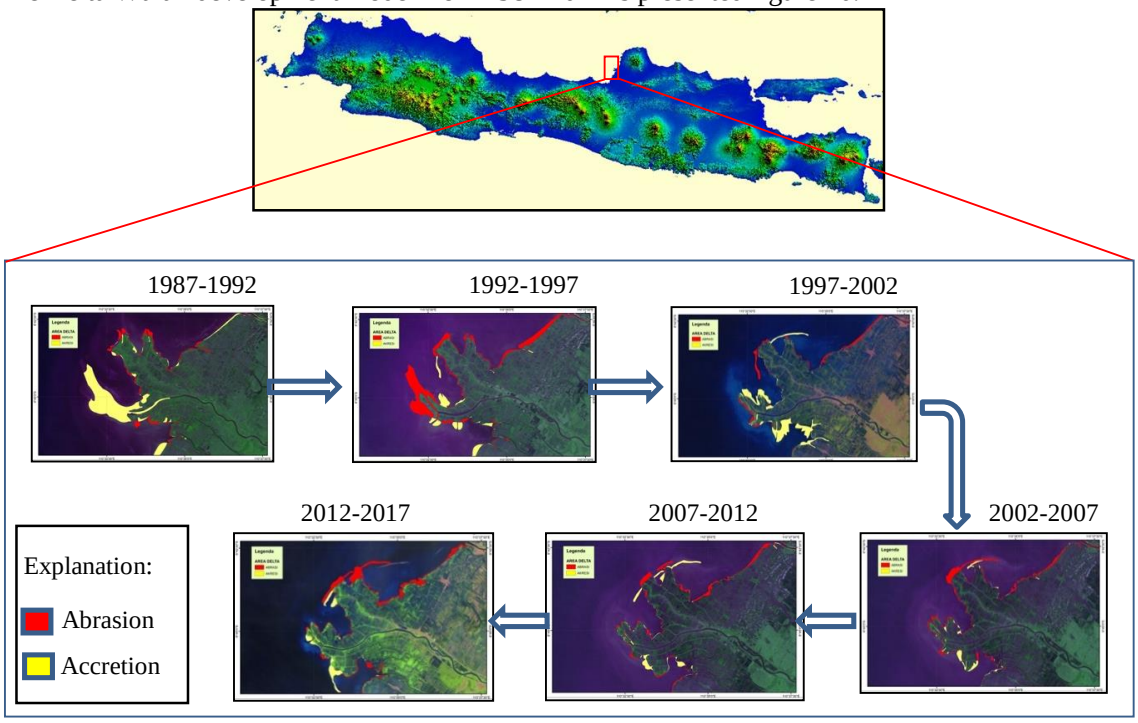

Figure 10. Morphodynamical change of Delta Wulan in 1987-2017

The abrasion and accretion process that occurred in Delta Wulan resulted in changes in the morphology of Delta Wulan both in width and length of the coastline. Based on data from 1987 to 2017, Bodri's Delta area underwent an increasingly widespread change in 1987, covering an area of 5485.55 ha to an area of 5586.88 ha in 2017. The analysis with the trendline line shows the equation of the linear line as follows, y = 0,001x + 5699,5 with a determinant value of R^2 = 6E-09. The development of the Delta Bodri area and the Bodri delta Trendline showed in Table 3 and Figure 11.

Table 3. Delta Wulan Area in 1987-2017

No	Year	Total Area (Ha)
1	1987	5485,55
2	1992	5909,09
3	1997	5663,65
4	2002	5803,93
5	2007	5744,25
6	2012	5716,87
7	2017	5586,88

Source: analysis, 2017.

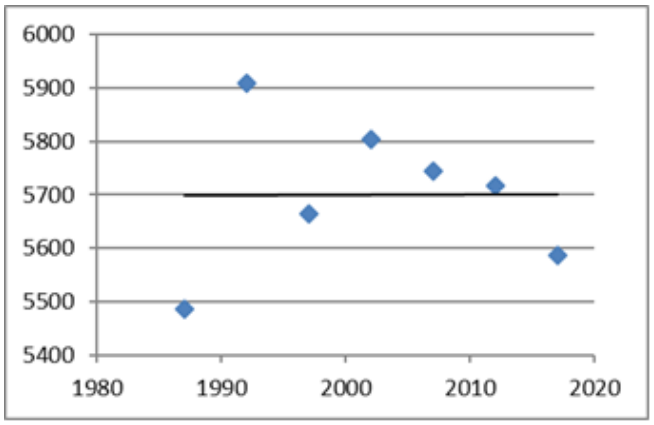

Figure 11. Trend line of Delta Wulan change

3.4. *Dicussion*

Delta Comal's change model shows a dynamic that is quite dynamic both in terms of area and length of the coastline. In terms of its form, Delta Comal still remains unchanged, in the form of Delta Point (Cuspate). This pointed form of Delta indicates that geomorphic power in the form of Wave and Longshore Current is relatively dominant. This results in river sediment material in the estuary being immediately distributed so that material accumulation is rarely found. Nonetheless, based on the trend line, Delta Comal's area shows a high increase in area. This also proved that the sedimentation process takes place effectively.

Delta Bodri's development model also shows a dynamic change, even more dynamic compared to Delta Comal, both in terms of area and length of coastline. This can be seen from the more sloping Trend line chart. From the aspect of its form, the Bodri delta still does not experience change, namely in the form of Delta Lobate (Fat). The shape of a fan-like Delta indicates geomorphic power in the coastal Delta Bodri is dominated by wave and tidal forces. This results in river sediment material in the estuary being directly distributed and deposited on either side of the estuary regularly. If you look at the changes in the form of deltas, the distribution of sedimentation is more eastward. In other words, the eastern part of Delta Bodri is more dynamic than the western part of the delta.

Morphodynamics of Delta Wulan show the most dynamic changes compared to Delta Comal and Bodri. The change in area and length of the Wulan delta coastline from 1987 to 2017 is very volatile. Based on its shape, the Wulan delta still does not experience changes, namely in the form of Delta Kaki Burung (Elongate). The fat Delta shape resembling a bird's foot indicates relatively low and constructive wave power, small coastal currents, and high suspension material. This results in sedimentation of the river in the estuary will be deposited on the left and right of the estuary regularly. The interesting thing about this Delta Wulan is that the changes in area that occur are fluctuating, so the Trend line chart shows a balance in the area.

4. Conclusion

The morphodynamical model of Delta in the North Coast of Central Java is divided into three, namely Delta Comal in the form of Cuspate, Delta Bodri in the form of Lobate, and Delta Wulan in the form of Elongate. The fastest development of delta area is Delta Bodri, followed by Delta Comal, while Delta Wulan is relatively volatile. There needs to be further research linking Delta development with watershed quality.

Acknowledgment

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