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Sedimentation at the Rokan River Estuary Bagansiapiapi Riau Province Indonesia

Musrifin Galib[1], Rifardi[2], Syafriadiman[3], Syafruddin Nasution[4]

[124] Marine Science Department, Faculty of Fishries and Marine, University of Riau, Kampus Bina Widya, Jl. HR Subantas, km 12.5, Simpang Baru, Tampan, Kota Pekanbaru, Riau 28293, Indonesia

[3]Aquaculture Department, Faculty of Fishries and Marine, University of Riau, Kampus Bina Widya, Jl. HR Subantas, km 12.5, Simpang Baru, Tampan, Kota Pekanbaru, Riau 28293, Indonesia

Abstract: ***The aim of this study was to analyze the characteristics of sediments and estimate the accumulatin rate of sediment at the Rokan River estuary . The results showed that the bottom estuary of the Rokan River are dominated by the mud sediment fraction. This type of mud sediment occupies almost the entire bottom of the estuary. This type of mud consists of a classification of coarse, medium, fine and very fine mud. Skewness of sediment are only very skewed and very fine skewed classification. The majority of sediment sorting goes into poorly sorted classification. Generally, sediments include into the classification of extremely leptokurtic. The sedimentation area for 72 years reaches 27,441.9 ha with accumulation rate of 343,0 ha/year. The highest sedimentation occurred in the coastal of Bagansiapiapi, sediment accumulation rate of 144.5 ha/year, the lowest in Halang Island 5.1 ha/year. On the right of the estuary of the Rokan River formed 3 islands namely Berkey Island, Serusa Islan, and Baru Island. Berkey Island estimated formed 1943 accumulated sediment rate of 114.2 ha/year. Serusa Island estimated formed 1966. Baru Island estimated formed 1997. Sedimentation of the right side of the estuary is greater than the left estuary.***

Keywords: Sediment, sediment accumulation, sedimentation rate.

1. Introduction

Estuary in nature is a distinc landscape. Estuary is part of the sea that juts into the mainland and meet with the mouth of the river [1]. The mouth of the Rokan River on the east coast of Sumatera meet to the Strait of Malacca. The intensity of transportation activities, intensive use of areas as ports, farms, residential areas, industries, and government centers put great pressure on and affect the sustainability of resources in these waters.

This pressure caused the emergence of various problems, namely the retreat of the coastline due to abrasion, formed the land due to sediment leading to the advance of the coastline [2, 3]. Sedimentation process that occurs continuously on the estuary will inhibit the flow of rivers and raise the water level in the upstream. In addition, this condition will also make fishing activities and production in Bagansiapiapi decline and large tonnage ships can only sail at high tide.

The estuary of the Rokan River is well known for its nutrient overflow from the river. Therefore, Bagansiapiapi was once the largest fish producer in Indonesia even number two in the world after Bergen Norway in the Dutch East Indies (1930s) era. At that time, Bagansiapiapi port overlooking the Malacca Strait landed 300,000 tons of fish per year. But the fish production did not survive until now, as fishery products began to decline since the 1970s [4]. Reduced fish catch in Bagansiapiapi waters, one caused by the sedimentation process.

Sedimentation occurring at the estuary due to the activity in the watershed, among others, the conversion of forest into plantation land that causes erosion [5, 6].

2. Literature Survey

The rapid development of social and cultural communities on land such as the opening of areas for settlements, industry, tourism, agriculture, landclearing, and other forms of land conversion [5] result in erosion of surface layers of terrestrial sediments and will affect the sedimentation process in coastal waters, and the sea [7].

Some coastal waters undergo a silting process due to the accumulation of erosion results from the mainland. In some river estuaries formed delta in a short time as the forerunner of the birth of new sedimentation islands. One example of the interesting sedimentation case is that occurring at the mouth of the Rokan river on the East coast of Sumatera Island where in this region within decades new deltas formed and the coastline increased into the sea. One of the emerging new islands is thought to be the result of this sedimentation process is Berkey Island. The sedimentation process has changed the basic shape of the ecology of the waters around the estuary of the Rokan River [7].

Sedimentation at the estuary of the Rokan River is influenced by sediment imports from the Rokan River due to natural processes and artificial phenomena and sedimentation results due to the characteristics of the Malacca Straits currents and waves. Sediment characteristics, the mean size distribution dominated by fine sand with a poorly sorted grain uniformity. The tendency of sediment distribution in deep areas shows very fine skewed and shallow areas occupied by very coarse skewed [8].

Based on the analysis of shoreline changes, the total increase of land area in Rokan river estuary is 240.096.862,77 m^2,

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total accretion 280.492.425,46 m^2, and total abrasion 27,935,195,86 m^2. From the calculation of total sediment that goes per year compared to total accretion per 60 years, known absolute sedimentation rate equal to 0,13 cm/year. In addition, Berkey Island is thought to be an island formed by sedimentation [8].

Changes in the Rokan River flow are characterized by changes in grooves in river meandering, straight, tidal flat, and delta. The change is due to erosion and deposition. Erosion is more common in the meandering river channel with medium river width and is located quite far from the sea. While the deposition is more prevalent in the delta and large river channel and is located close and meet directly with the sea. The amount of deposition at the mouth of the river from 1988 to 2012 was 5,331 ha (222.1 ha/year). Erosion in the basin 614 ha for 24 years (25.6 ha/year) [9].

The bottom of the estuary of the southern part of Bagansiapiapi estuary is composed by the subpopulation of sediments from the class of very fine sand with a low organic material content of 10%. The size of these sediment grains describes the condition of the waters as they settle and are not in accordance with the current conditions where the current velocity is very fast (0.35-0.74 m/sec). These estuary waters receive sediment feeds from 3 sources namely Sumetera land via Rokan River, coastal abrasion, and the Malacca Strait through tidal streams [7].

3. Methods

Sediment samples were taken from 24 stations at the estuary of the Rokan River in November 2016. Station positioning using Global Positioning System (GPS). Sediment sampling using Grab Sampler. Sediment samples were analyzed by grain size using graphical methods according to Folk and Ward [10]. Calculation of sediment characteristics includes mean diameter (Mz ø), Skewness (Sk_i), coefficient sorting ($Ó_i$) and kurtosis (K_G) sediment.

The maps used to estimate the area of sediment accumulation were maps published by Army Map Service, United State of America (US) Army, Washington DC, 1935, 1944, 1954, and 1957. While the image used were Landsat 5, 1979, 1991, 1999 , 2013, and Landsat 8 in 2015. Image data obtained from US Geological Survey (USGS) downloaded at www.earthexplorerer.gov. Data were analyzed using Semi-Automatic Classification Plugin (SCP) from ENVI 4.5 and ArcGIS 10.4.1.

The process of analysis and interpretation of maps and image data includes data classification, radiometric correction, band stacking, image reinforcement, digitization, and overlapping. The results of the analysis and interpretation are used to calculate and estimate the accumulation of sediment and sedimentation rate.

Figure 1: Study Area

4. Results and Discussion

The bottom of the estuary of the Rokan River is dominated by the mud sediment fraction. This type of mud sediment occupies almost the entire bottom of the estuary. Only 1 station has the type of sandy sediment that is Station 6 to the north of Halang Island. The mud fraction for the highest mud sediment type reached 95.83% (St 15) located in the western part of Berkey Island.

The distribution of sediment types is divided into 3 types of sediments: mud, sandy mud, and sand. The mud sediment type spreads from the northern part of Pendamaran Island to the mouth of the Rokan River in the Malacca Strait. The type of sandy mud sediment exists from the central part of the Pendamaran Strait 1 and 2 to the northern end of Pendamaran Island.

This type of mud consists of a classification of coarse, medium, fine and very fine mud. Very fine mud dominates the bottom of the water, almost half of the existing mud sediment (46%). Coarse mud is only 12.5%, the rest is medium mud and fine mud. Coarse mud is found in the upper reaches of the estuary, the southern part of Pendamaran Island (St 22, 23 and 24). Current velocity in this region is quite high (1.04 - 1.32 m/sec). Under such current velocity conditions only coarse mud can deposited.

The fine mud dominates the Rokan River estuary from North Pendamaran Island to the mouth of the estuary in the Malacca Strait. However, in the western part of Halang Island and Berkey Island, there is a very fine mud at St 12 and 15. Likewise in the Eastern part of Kubu there are some very fine muds, namely St 1 and 10. In St 16 also found very fine mud. This gives an indication that in these waters the current strength to transport sediments is weak.

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Table 1: Mean Size, Skewness, Sorting, and Kurtosis Value

St	*MeanSize (Mz Ø)*	*Skewness (Sk_1 ϕ)*	*Sorting (δ_1 Ø)*	*Kurtosis (K_G)*
1.	7.20	-0.430	0.96	1.02
2.	6.77	-0.823	1.44	9.15
3.	7.30	-0.762	0.93	10.86
4.	5.57	-0.898	2.22	2.19
5.	6.03	-0.900	1.90	12.50
6.	5.23	-0.905	2.44	0.51
7.	7.23	-0.338	1.09	13.11
8.	7.23	-0.694	0.92	7.38
9.	6.20	-0.875	1.76	12.30
10.	7.20	-0.443	0.90	10.86
11.	6.53	-0.871	1.60	9.02
12.	7.27	-0.583	0.80	6.56
13.	5.73	-0.889	2.03	2.24
14.	7.27	-0.597	0.73	5.87
15.	7.33	-0.146	0.32	2.19
16.	7.20	-0.436	0.81	6.42
17.	6.77	-0.831	1.30	11.89
18.	7.20	-0.450	1.01	8.20
19.	6.17	-0.890	1.77	-12.09
20.	7.20	-0.450	0.98	11.89
21.	5.43	-0.900	2.29	0.69
22.	4.53	0.600	1.83	2.72
23.	4.60	0.500	1.86	0.56
24.	4.03	0.680	2.07	0.51

The value of skewness of sediment at the estuary of the Rokan River is only 2, namely the very coarse skewed and very fine skewed classification. Almost entirely classified as very coarse skewed is St 1 - 21. Only St 22, 23 and St 24 are classified as very fine skewed ie the station located at the upper reaches of the Rokan River estuary, in the Southern part of the Pendamaran Island. The extent of sediment distribution with coefficient very skewed indicates that in this region there are influences of currents and waves.

The sediment sorting value at the Rokan River estuary ranges from 0.32 Ø - 2.44 Ø which consists of 4 classifications that are very poorly sorted, poorly sorted, moderate sorted, and well sorted (11). The majority of sediment sorting goes into poorly sorted classification. Moderate sorted classification is spreading on the east coast of Kubu and Pekaitan, the western part of Halang Island and the western part of Berkey Island. Distribution of poorly sorted sediments spread in the mouth of the estuary towards the Strait of Malacca, the North West Halang Island and North Berkey Island. Then spread also to the southeast of Halang Island and South Berkey Island.

In general it is seen that the distribution of sediments with the classification of leptokurtic both extremely and very dominate 75% of the bottom estuary of the Rokan River. The rest is a mesokurtic, platicurtic, and highly platicurtic sediment classification that, among other things, spreads in the southern part of Pendamaran Island on St 23 and St 24.

The most intensive sedimentation process took place on the western coast of Bagansiapiapi where the formation of Berkey Island and the increase of land to the west along the 2.94 km from the old fishing port built in the Dutch era. Sedimentation also occurs in Pendamaran Island but not as intensive as Berkey Island. While the lowest sedimentation found in Halang Island because on this island in addition to sedimentation also occur abrasion by the scouring of the waves because the island is facing directly with the Strait of Malacca.

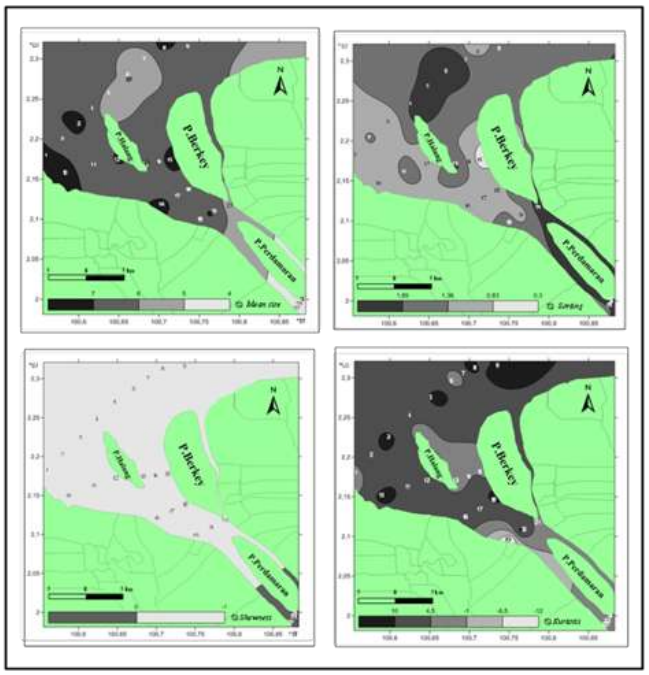

Figure 2: Distribution of Mean Size, Sorting, Skewness, and Kurtosis

The results of this study indicate that rapid and high sedimentation in the Rokan River estuary occurs on the Bagansiapiapi Coast. Sedimentation occurs in the western part of Bagansiapiapi. The highest increase of coastal area occurred in the period of 1957 until 1979 which reached 5,655.3 ha within 22 years with sediment accumulation 257,0 ha/year. The accumulation of this sediment is the highest sediment accumulation. While the lowest sediment accumulation was 20.5 ha/year occurred in the period 1999 to 2015 for 14 years. The average sediment accumulation of Coastal Bagansiapiapi from 1935 to 2015 was 144.5 ha/year. The accumulation of sediment is the highest sediment accumulation at the estuary of the Rokan River. The lowest sediment accumulation occurs in the period 2013 to 2015 which is only 20.5 ha/year.

Judging from the long dimension, the shift from waters to the highest land occurs at the northern port of Bagansiapiapi which reaches 5.0 km or 200 m/year on average. Sedimentation at the Bagansiapiapi port area in the Dutch era reached 2.94 km westward, reaching to the Berkey Strait with an average sedimentation of 117.0 m/year. Thus it can be said that on the west coast of Bagansiapiapi where Bagansiapiapi port is located, there has been sedimentation or silting an area of 11,557.7 ha or wider than Berkey Island.

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Table 2: Development of Sedimentation (ha) Area at Halang Island, Pendamaran Island, Berkey Island, and Serusa Island 1935-2015

Year	Area (ha)			
	P. Ha-lang	P. Penda-maran	P. Berkey	P. Serusa
1935	0.0	0.0	-	-
1944	80.2	933.3	109.5	-
1954	28.2	201.9	-	-
1957	14.7	223.1	244.4	-
1979	108.0	1,635.8	3,555.4	663.5
1991	163.7	4.7	104.7	214.1
1999	0.0	185.7	2,939.6	774.9
2013	10.9	185.7	601.4	0.0
2015	0.0	632.6	656.5	0.0
Total	405.7	4,002.8	8,211.5	1,652.5
Ave	5.1	50.0	114.2	50.0

Table 3: Development of Sedimentation Area (ha) at Baru Island., Kubu Coast, and Bagansiapiapi Coast

Year	Area (ha)		
	P. Baru	Psr. Kubu	Psr. Bagansiapiapi
1935	-	0.0	0.0
1944	-	88.0	332.0
1954	-	327.4	1,967.5
1957	-	30.0	771.2
1979	-	220.3	5,655.3
1991	-	156.3	2,262.2
1999	39.2	149.9	241.6
2013	276.7	284.4	286.9
2015	39.5	0.0	41.0
Total	355.4	1,256.3	11,557.7
Ave	19.7	15.7	343,0

This high sedimentation occurs along the Bagansiapiapi Coast, starting from North Pendamaran Island, then Bagansiapiapi port, up to the north that is to the Malacca Strait. Sedimentation and siltation is happening on the right side of the estuary of the Rokan River, the west coast of Bagansiapiapi.

Sedimentation is almost entirely and is located on the right side of the estuary of the Rokan River or west of Bagansiapiapi. While on the left side of the estuary of the Rokan River sedimentation occurs only a small part. According to [8], the accretion or sedimentation that occurred during the 25 years, from 1954 to 1979 was 16,210.2 ha covering the western coastal of Bagansiapi, Serusa Island, Berkey Island, and the northern part of the Pendamaran Island.

The amount of sedimentation that occurred at the estuary of the Rokan River from 1935 to 2015 reached 27,441.9 ha. The average sediment accumulation was 343.0 ha/year. The accumulation of this sediment is not much different from that found early researcher [8]. He explained that in the period of 60 years from 1954 until 2014 there was an addition of land area in the estuary of the Rokan River for 24.009.26 ha or 400.16 ha/year.

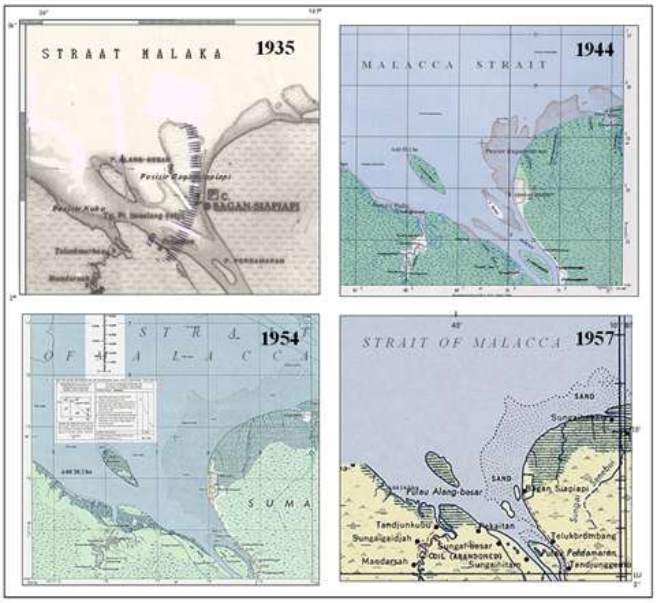

Figure 3: Bagansiapiapi Map 1935, 1944, 1954 and 1957

In the period 1991 - 1999, the highest sediment accumulation reached 525,0 ha/year. The high sedimentation is associated with deforestation and forest conversion into plantation land. The amount of forest converted to plantations in the period 1987 - 1991 was 62,595.2 ha with an average of 15,649,0 ha/year, the period 1991 - 1999 amounted to 94,975.2 ha with an average of 11,872.0 ha/year and the period of 1999 - 2014 is 13,023.0 ha with an average of 868.2 ha/year [12].

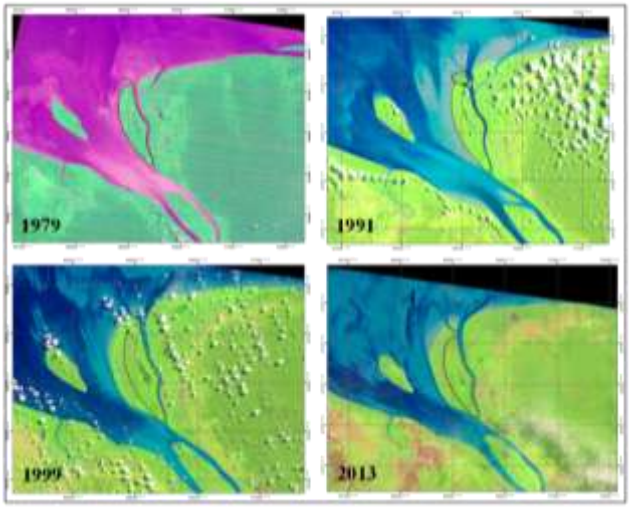

Figure 4: Image of Landsat 5, 1979, 1991, 1999, and 2013

The forest area in Rokan Hilir Regency in 1997 was 796,283.0 ha and in 2009 totaled 645,806 ha. Area deforestation 30.6% with average reduction of forest area 12,539.7 ha/year [9]. The number of forests in Rokan Hilir Regency in 1985 was 514.796.9 ha and in 1997 amounted to 236,685.8 ha. The area of deforestation for 12 years is 278,111.1 ha with an average decline of 23,175.9 ha/year [12].

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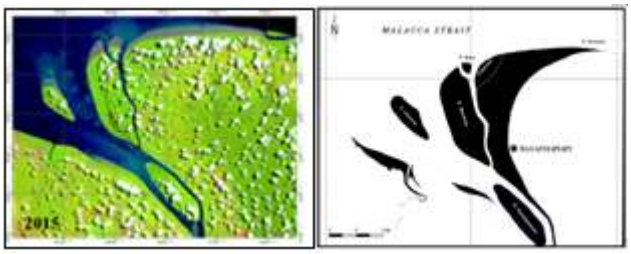

Figure 5: Image of Landsat 8, 2015 and Sedimentation area in 80 years

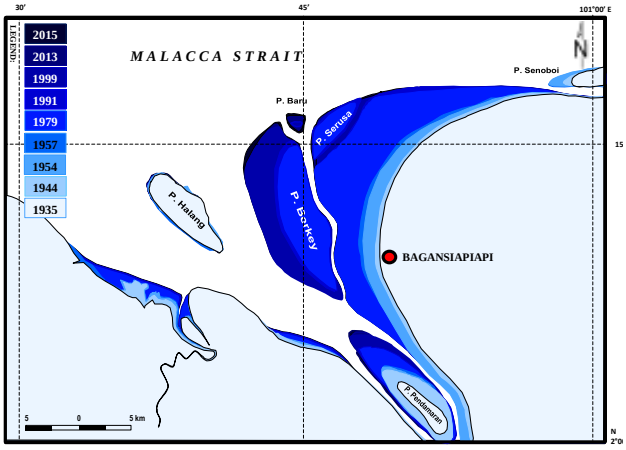

Figure 6: Development of Sedimentation Area 1935-2015

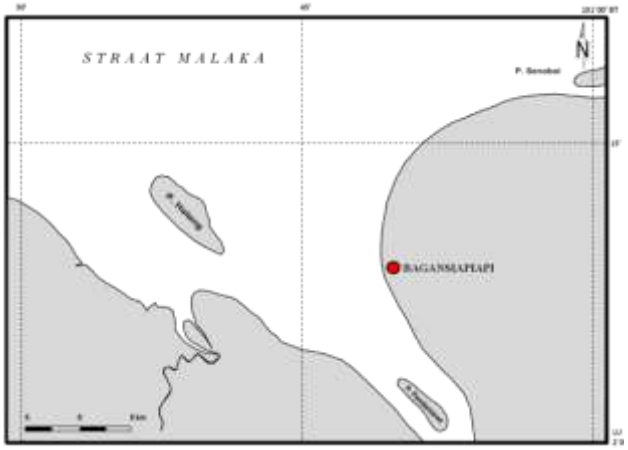

Figure 7: Map of the Rokan River Estuary Bagansiapiapi 1935

If observed on the left side of the estuary of the Rokan River it is seen that the low sedimentation rate is only 4.6% (1,256.3 ha) of the total sedimentation at the estuary. In the central part of Rokan River estuary, Halang Island and Pendamaran Island are 4,408,5 ha (16,1%). Then on the right of Rokan River estuary is Berkey Island, Baru Island, Serusa Island, and Coastal of Bagansiapiapi amounted to 21,777.1 ha (79.3%).

The comparison of the amount of sedimentation between the left and the right side of the estuary is much larger at the right of the estuary, which is 1 to 16. This means that the amount of sedimentation on the right of the Rokan River estuary is 16 times larger than the left side of the estuary.

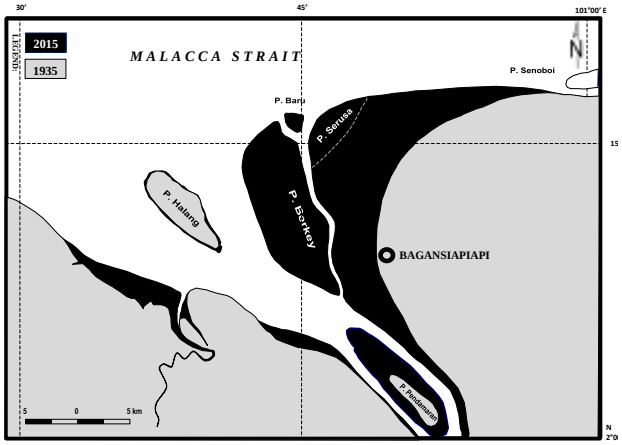

Figure 8: Area of Sedimentation 1935 and 2015

Then, if seen from the accumulation of sediment within 80 years then seen the average accumulation of sediment on the left side of the estuary is only 15.7 ha/year while on the right estuary reaches 272.2 ha/year. This condition is related to the pattern of tidal current which is on the right side of the estuary found the current velocity is lower than that on the left side of the estuary both at low tide and at high tide.

5. Conclusion

The bottom of the estuary of the Rokan River is dominated by the mud sediment fraction. This type of mud sediment occupies almost the entire bottom of the estuary. This type of mud consists of a classification of coarse, medium, fine and very fine mud. Skewness of sediment is only very skewed and very fine skewed classification. The majority of sediment sorting goes into poorly sorted classification. Generally, the sedimentary estuaries of the Rokan River enter into the highly leptokurtic classification.

Sedimentation area for 80 years reaches 27,441.9 ha with accumulation of sediment 343,0 ha/year. The highest sedimentation occurred at Bagansiapiapi coast with accumulated sediment 144,5 ha/year, the lowest in Halang Island with accumulation of sediment 5,1 ha/year. On the right of the estuary of the Rokan River formed 3 islands namely Berkey Island, Serusa Island, and Baru Island. Berkey Island estimated formed 1943, accumulated sediment rate of 114.2 ha/year. Serusa Island estimated formed 1966, accumulation rate of 50.0 ha/year. Baru Island estimated formed 1997 with 19.7 ha/year sediment accumulation. The sedimentation of the right side of the estuary is larger than the left of the estuary.

6. Future Scope

Analysis of sedimentation rate in this research using the result of sediment accumulation from map data and satellite image data. For the determination of the sedimentary rate in absolute terms it is recommended to use the radionucleid ^{210}Pb method and the determination of the sedimentation rate based on the age of the sediment.

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Author Profile

Musrifin Galib, received Bachelor degree in Fishing Technique from Fisheries Faculty , University of Riau in 1983. He received the Engineer (Ir.) degree in Aquatic Resources Management from Fisheries Faculty, University of Riau in 1986. Received M.Sc. degree in Applied Physical Oceanography, School of Ocean Sciences, University of Wales Bangor, United Kingdom in 1991. During 1987 – now, he is lecturer in Marine Science Department, Fisheries and Marine Faculty University of Riau. From 1995 until now he is the Head of Physical Oceanography Laboratory, Marine Science Department, University of Riau, Pekanbaru, Indonesia.

Rifardi., He received bachelor in Water Resources Management in 1989 from Faculty of Fisheries, Riau University, Indonesia and continue his master degree in Marine Science from Ryukyus University, Japan and graduated in 1993. He continue his doctor degree in Marine Production and Environmental Studies, United Graduated School of Aqricultural Science, Kagoshima University, Japan and graduated in 1999.

Syafriadiman received the Bachelor degree in Aquatic Resources Management from Fisheries Faculty, University of Riau in 1985. He received Doctor degree from National University Malaysia (NUM) in 1999, Master degree in 1997. From 1999 – now he is the Head of Soil and Water Quality Management Laboratory, Aquaculture Department, University of Riau, Pekanbaru, Indonesia.

Syafruddin Nasution, he received the bachelor degree in Aquatic Resources Management from Fisheries Faculty, University of Riau in 1985. He received Doctor degree from Queen's Belfast University, United Kingdom in 2000. From 2014 – now he is the Head of Marine Biology Laboratory, Marine Science Department, University of Riau, Pekanbaru, Indonesia.

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