The Calculation of Erosion and Sedimentation Rate in Coastal Zone Using Satellite Imageries (Case Study: Kecamatan Muara Gembong, Kabupaten Bekasi, West Java)

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Abstract. Coastal zone is a transition area which always influenced by the changes of the land and ocean. The changes may occur due to the tide, current, wave, wind, sea water intrusion, runoff, contamination, or continental shelf area. As an effect, erosion and sedimentation phenomenon are occurred and could cause the changes of coastline shape. Kecamatan Muara Gembong which belongs to Kabupaten Bekasi is located in the Northern Coast of Java Island. Due to its geographical location, this area is threatened by the risk that is caused by erosion and sedimentation in the coastal zone. Therefore, study in this area is needed in order to identify the changes of the coastline. Coastline mapping through spatio-temporal LANDSAT-7 ETM+ satellite imageries is one of the methods to conduct this study. It uses satellite images from year 2000 – 2012. These images were processed by two visual image enhancement methods, named ratioing and BILKO algorithm, so that the visual differences between the land and the ocean could be identified. After the images were processed, coastline digitizing could be done annually from both methods. The result of this study is that there is a significant amount of erosion occurred in the coastal zone of Desa Pantai Bahagia and Desa Pantai Sederhana with the value of 139.05 Ha and 91.65 Ha from the ratioing method whereas the result from BILKO algorithm method is 141.56 Ha and 103.82 Ha. Desa Pantai Mekar has the least reduces, that is 30.44 Ha from ratioing method and 26.27 Ha from BILKO algorithm method. Based on Net Coastline Changes, the area of Kecamatan Muara Gembong from year 2000–2012 has reduced 346.54–349.56 Ha with the speed average of erosion that has been obtained is 28.88–29.13 Ha/year.

Keywords: *coastline changes, LANDSAT-7 ETM+ satellite imageries, erosion, sedimentation*

1. Introduction

Kabupaten Bekasi that lies between latitudes 5°54’50”S–6°29’15”S and longitudes 106°58’5”E–107°17’45”E has 23 sub-districts and one of them is Kecamatan Muara Gembong. This sub-district lies between latitudes 5°54’25.83”S–5°57’22.52”S and longitudes 106°58’52.45”E–107°2’59.72”E. By 11% from 127,288 Ha area of Kabupaten Bekasi is Kecamatan Muara Gembong.

Muara Gembong consists of six villages, namely Jayasakti, Pantai Bakti, Pantai Bahagia, Pantai Sederhana, Pantai Mekar, and Pantai Harapanjaya (Figure 1). All villages are coastal zone except Desa Jayasakti. The distance that is required to reach Muara Gembong from the center of Bekasi City is as far as 64 km. Its infrastructures unfortunately are inadequate.

Based on Act No. 27 of 2007 Article 1 (2), coastal zone is a transition area which always influenced by the changes of the land and ocean. Coastline according to Act No. 4 of 2011 about information of geospatial is the assembly line between the land and the ocean that influenced by the tide. Generally, coastline changes periodically along with natural changes, for instance wave activity, wind, tide, current, erosion, or sedimentation.

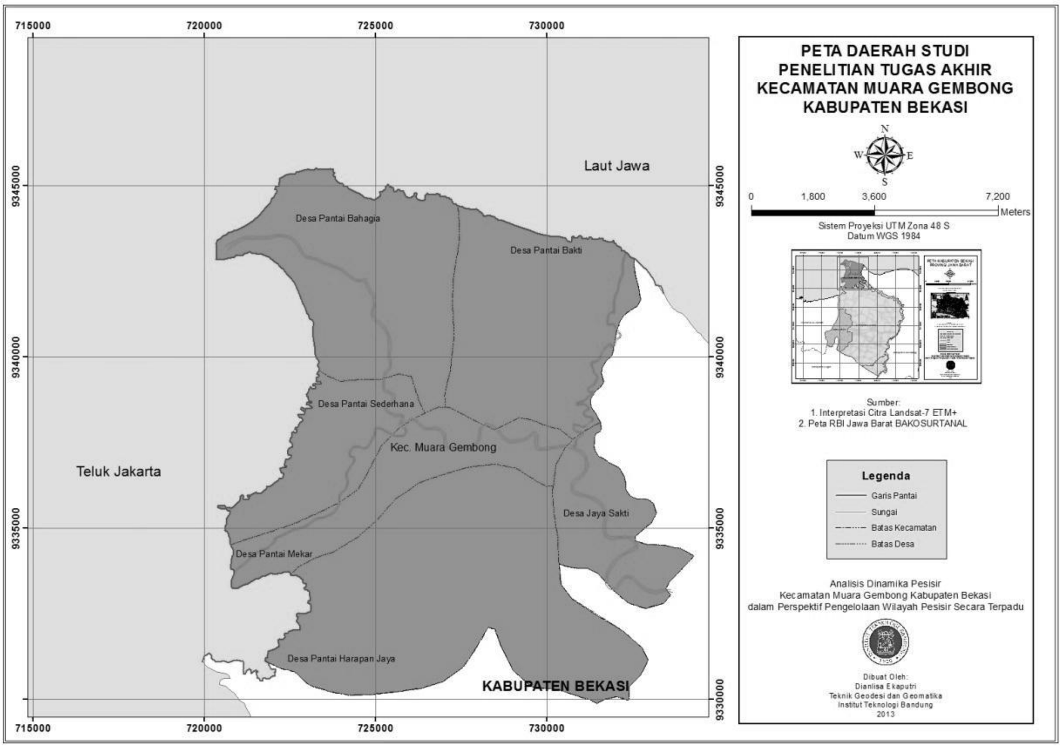

Figure 1. Case Study Area

Erosion is reduction process of the coast by the ocean dynamics. Because of open sea dynamics is greater than coastal zone dynamics, the erosion rate will be greater in the open sea area. Sedimentation is sediment process of material that transported by water, wind, ice, or glacier.

A coastline changes is one of the problems in Kecamatan Muara Gembong that occurs every year. Suwargana (2008) found that the result of overlay coastline from classified imageries of Kecamatan Muara Gembong from year 2007 and 1990 stated that there were erosion and sedimentation phenomenon. There were many mangroves disappeared in erosion area while there were thrived in sedimentation area.

The purpose of this research is to analyze coastline changes along the coastal zone of Kecamatan Muara Gembong using LANDSAT-7 ETM+ satellite imageries. These images were processed by two image enhancement methods, namely ratioing and BILKO algorithm so that the speed average of erosion and sedimentation could be calculated.

This research was part of a research titled "Coastal Dynamic Analysis of Kecamatan Muara Gembong in Perspective of Integrated Coastal Zone" by Coastal Zone Science and Engineering System Research Group of Geodesy and Geomatics Engineering in ITB innovation and research of 2012.

2. Methods

Schematically, the methodology of this research is described in Figure 2. The beginning of the process is study of literature from text books, undergraduate and graduate thesis, journal research, articles, and websites. Later is downloading satellite imageries year of 2000 – 2012 for obtaining the primary data for this research. Then the image is corrected by some image corrections. The first is stripping image correction for satellite imageries data, second is doing geometric correction for satellite imageries data to RBI map of west java, and then doing tidal correction. Later is the process of annual image enhancement by two methods, ratioing and BILKO algorithm. After that, the coastline is also digitized annually then doing the coastline changes mapping. Later is calculating the speed average of erosion and sedimentation. The last process is to analyze and making conclusion.

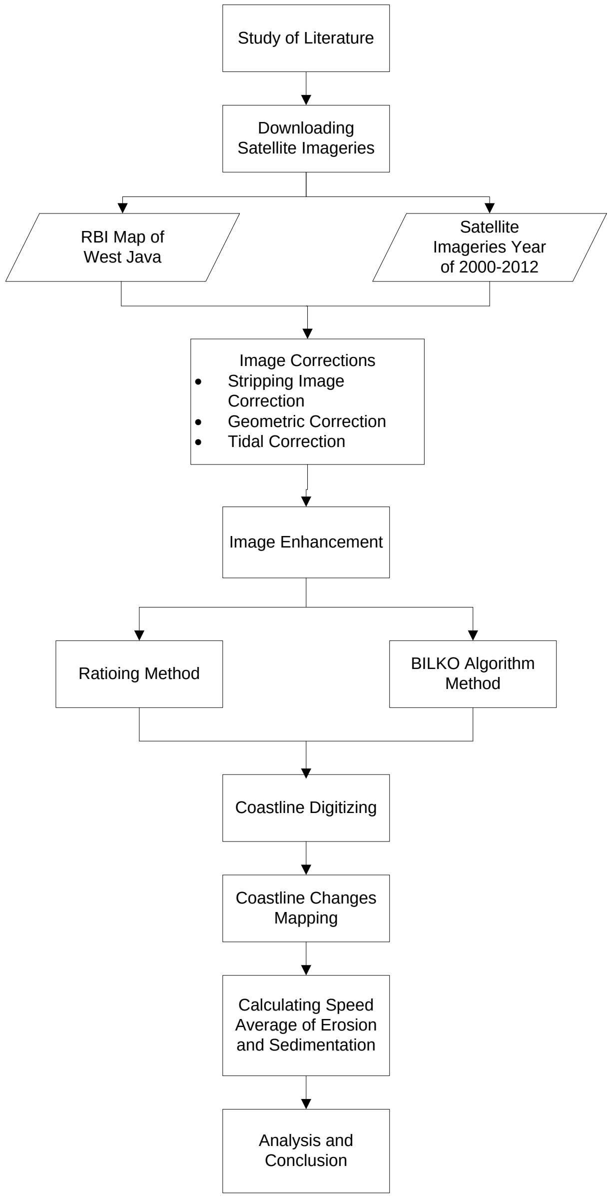

Figure 2. Flow Chart of Research Methodology

The Data

There are two kinds of data for this research, namely RBI Map of West Java from BIG (BAKOSURTANAL) with 1:25,000 scale and LANDSAT-7 ETM+ multi temporal satellite imageries from year 2000 – 2012.

Image Corrections

Corrections for LANDSAT satellite images are required before processing them. There are stripping image correction, geometric correction, and tidal correction. Radiometric correction was not required because it has been corrected in LANDSAT-7 ETM+ satellite imageries.

a. Stripping Image

Scan Line Corrector's (SLC) failure of ETM+ on May 31, 2003 caused its line of sight along the satellite ground track traces a zigzag pattern so there will be stripes on the images. There is a software, frame_and_fill, that recommended by NASA to improve stripping image problem. The input image is the image that was recorded before May 31, 2003. This research applied the image of March, 2003 as the input image for images of 2004–2012. The stripes still could be seen if the image was enlarged although the striped image has been corrected. The effect may influence georeference and digitizing process. The sample image before and after stripping image correction could be seen in Figure 3.

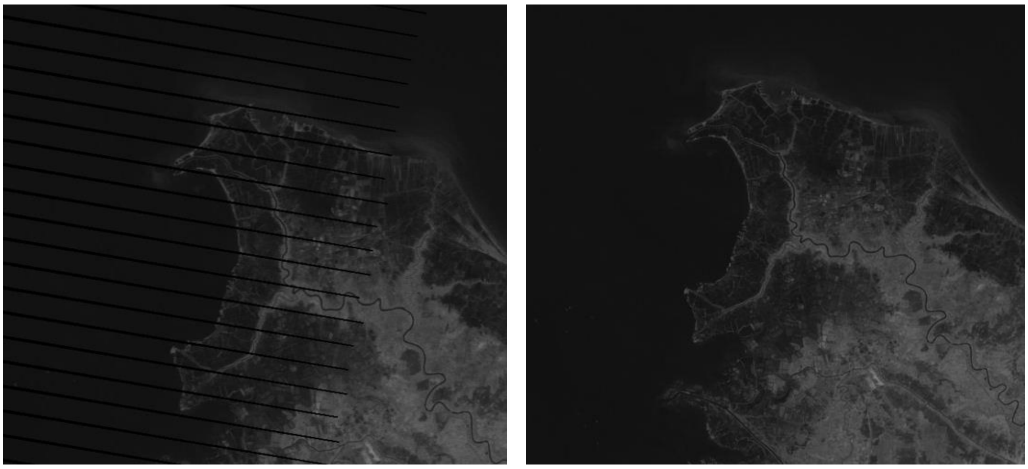

Figure 3. The Sample Image Year of 2004 Band-4 Before Stripping Image Correction (Left) and After Stripping Image Correction (Right)

b. Geometric Correction

Geometric correction applied was georeferencing using ILWIS software by image to image geocorrection. Process of georeference requires 10 Ground Control Points (GCP) and the coordinates were known. GCP should be located in recognizable location around Kecamatan Muara Gembong.

As the adjustment of 10 GCP's in order to get residual below 0.5 pixel, so the GCP's are different in each image. From different GCP's each year, it was obtained different residual. Standard error of GCP could be calculated from the known residual. It could be define as the root of mean square of the errors and is given by:

$$\sigma_{\text{GCP}} = \sqrt{\frac{\sum_{i=1}^{n} Vi^2}{n}} \qquad (1)$$

Where:

Vi = residual from each image

n = the number of images

For verifying the accuracy of image coordinates (Root Mean Square Error (RMSe)) that has been corrected geometrically, comparison with reference map (RBI Map) could be done. This step needs Independent Check Point (ICP) that still lies within the scope of GCP's. Total ICP was 5 points. Mathematically, RMSe could be calculated by equation:

$$\text{RMSe} = \sqrt{\frac{(x' - x_{orig})^2 + (y' - y_{orig})^2}{n}} \qquad (2)$$

Where:

(x', y') = image coordinate

(x_{orig}, y_{orig}) = the actual coordinate

n = the number of observations

From the calculation, standard error of GCP in this research is 0.355 pixels. Because the resolution of one pixel of the image is 30 × 30 meters, so the standard error of GCP in the field is 10.65 meters. Because the value of standard error of GCP does not exceed the image resolution, the geometric correction process meets the criteria level of accuracy. RMSe of the annual images is presented on Table 1.

Table 1. RMSe Value of ICP

Year of Satellite Image	Reference	RMSe (m)
2000	RBI Map of West Java	23,83
2001	Satellite Image Year of 2000	33,47
2002		26,20
2003		24,39
2004		22,93
2005		27,36
2006		24,43
2007		32,40
2008		23,13
2009		24,27
2010		18,56
2011		21,53
2012		22,78

c. Tidal Correction

The coastline that recorded on Landsat satellite imageries is in real time condition. The time is different based on when the image was recorded. Therefore, tidal correction is needed so that the real time water level condition on Landsat satellite imageries could be reduced to mean low water.

Tidal range is the range between high water level and low water level. Geofana (2012) stated that the tidal range of Kecamatan Muara Gembong is 0.81 meters while the slope is 3° (Adrian, 2006). From this information, the width of the area affected by the tides could be calculated using trigonometry equations. Figure 4 shows the illustration of the area width affected by the tides.

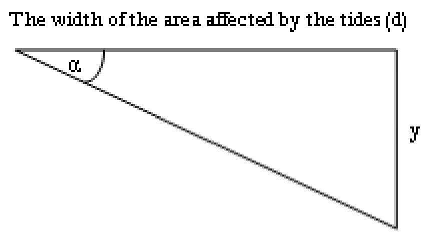

Figure 4. The Illustration of The Area Width Affected by The Tides

$$\text{Tan } \alpha = \frac{y}{d} \qquad (3)$$

Where:

α = slope

y = tidal range

d = the width of the area affected by the tides

The width of the area affected by the tides from the calculation is 15.46 meters. It can be concluded that the tidal effect to real time water level could be ignored in Kecamatan Muara Gembong.

Information Extraction of Coastline

Image enhancement process is applied in remote sensing for enhancing the view of the image in order to be visually analyzed either by people or software. Gumilar (2011) found that ratioing and BILKO algorithm methods were two image enhancement methods that gave the closest result from the data of coastline survey. Therefore, both methods were applied in this research.

Image enhancement process with ratioing and BILKO algorithm methods only used band-2, band-4, and band-5 so beside these bands were not applied in data processing.

a. Ratioing Method

Ratioing is a comparison process between two images. The differences in Brightness Values (BV) are caused by topographic conditions, shadows, or seasonal changes of sunlight illumination and intensity. Transformation in this ratio may reduce the effect of that environmental condition. Besides, ratios may also provide unique information that not available in a single band. This ratio may discriminate soils and vegetation.

The equation of ratio function is:

$$BV_{ijr} = \frac{BV_{ijk}}{BV_{ijl}} \qquad (4)$$

Where:

BV_{ijr} = The output ratio value for the pixel at row i, column j

BV_{ijk} = BV in the same location in band k

BV_{ijl} = BV in band l

Bands that were used in this method are band-5 as the numerator and band-2 as the denominator. This ratio is useful for identifying all water bodies and provides some subtle wetland information (Jensen, 1986). Generally, the lower the correlation between the bands, the greater the information contained from this process.

b. BILKO Algorithm Method

BILKO is a special program developed by UNESCO for determining the border between the land and the ocean. The determination of this border is held by utilizing BV from the land and the ocean. Therefore, the lowest BV of the land and the highest BV of the ocean are required.

The final results of this method are BV of the ocean became 1 and BV of the land became negative. Band that was inputted in this method is band-4. BILKO algorithm step can be defined as the equation below and the extraction information results from both methods are shown in Figure 5.

$$((INPUT\ 1/((30\times2)+1))\times(-1))+1 \qquad (5)$$

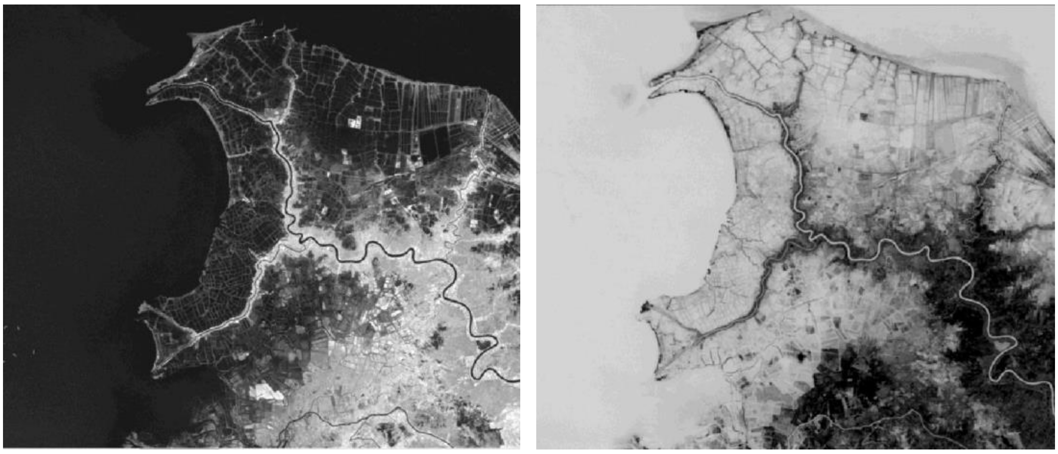

Figure 5. The Image Extraction Information Result in 2000 by Ratioing Method (Left) and BILKO Algorithm Method (Right)

Manual Interpretation of Coastline

After going through the process of image enhancement by both methods, the process of coastline interpretation was done by digitizing annual coastline manually using ILWIS software. This process requires high accuracy so that the coastline can be clearly interpreted. The coastline was mapped using ArcGIS software afterwards. Later is calculating the erosion and sedimentation value.

3. Results and Analysis

From the results of coastline digitizing, the area of erosion and sedimentation can be calculated using ArcGIS software. The calculation results of coastal erosion and sedimentation from both methods are described in Table 2 and Table 3.

Table 1. The Calculation Results of Coastal Erosion and Sedimentation by Ratioing Method

YEAR	PHENOMENON	COASTAL EROSION AND SEDIMENTATION VALUE (Ha)					TOTAL (Ha)
		DESA					
		Pantai Bakti	Pantai Bahagia	Pantai Sederhana	Pantai Mekar	Pantai Harapan Jaya	
2000-2001	Erosion	4.31	44.12	15.72	6.65	9.93	80.73
	Sedimentation	6.93	12.24	7.28	2.68	10.55	39.69
2001-2002	Erosion	16.23	86.76	18.38	10.04	16.05	147.47
	Sedimentation	5.02	12.76	6.94	2.99	5.53	33.24
2002-2003	Erosion	11.69	12.10	6.74	0.70	1.29	32.52
	Sedimentation	0.50	19.37	17.62	10.65	27.22	75.36
2003-2004	Erosion	1.66	44.97	20.16	10.17	49.94	126.90
	Sedimentation	17.30	23.89	2.90	1.12	0.00	45.21
2004-2005	Erosion	13.30	26.77	8.42	4.10	8.57	61.15
	Sedimentation	4.19	27.27	9.91	2.01	4.90	48.29
2005-2006	Erosion	15.72	38.94	29.16	6.41	6.22	96.45
	Sedimentation	2.93	42.27	6.05	6.71	12.10	70.06
2006-2007	Erosion	1.26	9.96	8.04	0.85	0.91	21.02
	Sedimentation	14.95	40.68	10.57	8.22	17.13	91.56
2007-2008	Erosion	21.39	30.27	17.49	12.38	17.61	99.14
	Sedimentation	1.60	21.96	9.78	0.21	2.36	35.91
2008-2009	Erosion	3.60	30.05	21.35	3.76	14.67	73.43
	Sedimentation	9.10	14.03	1.89	3.69	2.13	30.84
2009-2010	Erosion	12.61	17.07	24.20	10.94	6.49	71.32
	Sedimentation	2.56	28.92	8.15	0.40	4.09	44.13
2010-2011	Erosion	3.50	34.52	10.93	1.40	2.18	52.54
	Sedimentation	9.12	4.42	11.12	5.61	11.09	41.37
2011-2012	Erosion	6.73	19.07	12.92	7.79	17.31	63.82
	Sedimentation	4.86	7.74	9.64	0.47	1.60	24.30

Table 2. The Calculation Results of Coastal Erosion and Sedimentation by BILKO Algorithm Method

YEAR	PHENOMENON	COASTAL EROSION AND SEDIMENTATION VALUE (Ha)					TOTAL (Ha)
		DESA					
		Pantai Bakti	Pantai Bahagia	Pantai Sederhana	Pantai Mekar	Pantai Harapan Jaya	
2000-2001	Erosion	4.18	64.65	24.66	2.36	15.89	111.75
	Sedimentation	5.17	11.00	4.82	3.64	3.91	28.53
2001-2002	Erosion	28.10	86.25	24.23	11.68	19.56	169.82
	Sedimentation	0.49	15.90	5.44	0.35	3.88	26.06
2002-2003	Erosion	8.97	38.98	7.68	1.96	16.94	74.54
	Sedimentation	1.81	26.95	11.94	3.00	5.30	48.99
2003-2004	Erosion	1.78	20.20	15.33	2.99	2.82	43.12
	Sedimentation	13.89	26.04	3.66	2.41	4.39	50.39
2004-2005	Erosion	12.15	23.40	6.12	3.48	8.39	53.53
	Sedimentation	4.06	21.17	11.33	1.74	12.54	50.85
2005-2006	Erosion	8.70	35.06	27.84	5.70	11.54	88.84
	Sedimentation	4.82	41.35	5.35	7.45	10.71	69.67
2006-2007	Erosion	3.57	8.05	6.96	1.13	4.09	23.80
	Sedimentation	9.06	23.80	7.43	4.69	7.82	52.79
2007-2008	Erosion	12.79	32.09	14.37	9.90	3.80	72.94
	Sedimentation	7.76	7.69	7.23	0.47	14.87	38.02
2008-2009	Erosion	6.54	36.47	25.34	5.97	7.36	81.68
	Sedimentation	16.75	12.10	2.75	2.80	19.05	53.45
2009-2010	Erosion	14.62	13.03	12.09	6.18	24.18	70.10
	Sedimentation	2.50	28.55	11.25	0.83	2.28	45.41
2010-2011	Erosion	12.98	18.10	15.00	0.67	4.28	51.03
	Sedimentation	3.25	20.23	8.09	6.27	8.74	46.58
2011-2012	Erosion	4.29	11.48	10.73	8.87	13.64	49.01
	Sedimentation	7.49	11.42	7.28	0.97	2.71	29.86

Erosion value from ratioing method tends to fluctuate every year. The coastal erosion speed in Kecamatan Muara Gembong is 77.21 Ha/year whereas the coastal sedimentation speed is 48.33 Ha/year. Erosion value from BILKO algorithm method is more fluctuating irregularly than ratioing method with speed 68.47 Ha/year. Sedimentation value in this method tends to be constant and never exceeds 70 Ha so the speed is 41.58 Ha/year. Coastal erosion and sedimentation graph from ratioing and BILKO algorithm methods are shown in Figure 6 and Figure 7.

From Figure 6, it is shown that sedimentation value tends to not exceed the erosion value. When the erosion achieves the lowest values, that are from 2002 – 2003 and 2006 – 2007, the sedimentations are in the highest values. Although in Figure 7 is shown that erosion values are not as high as the previous method, it remains fluctuating.

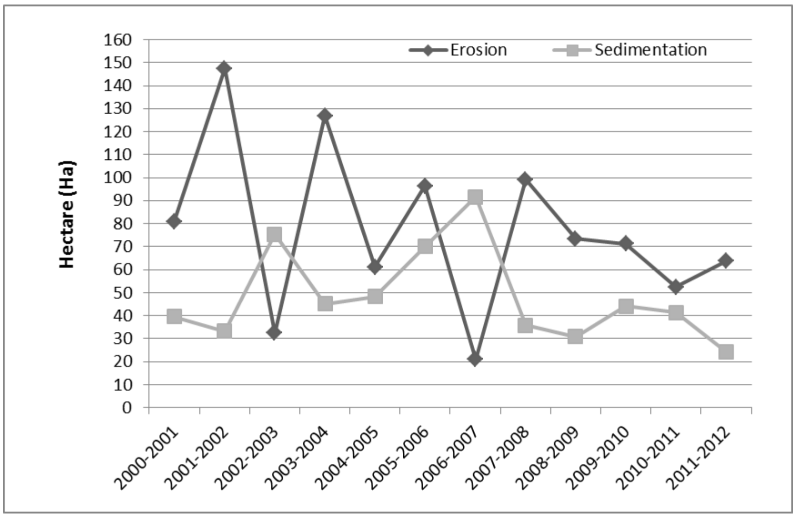

Figure 6. Coastal Erosion and Sedimentation Graph by Ratioing Method

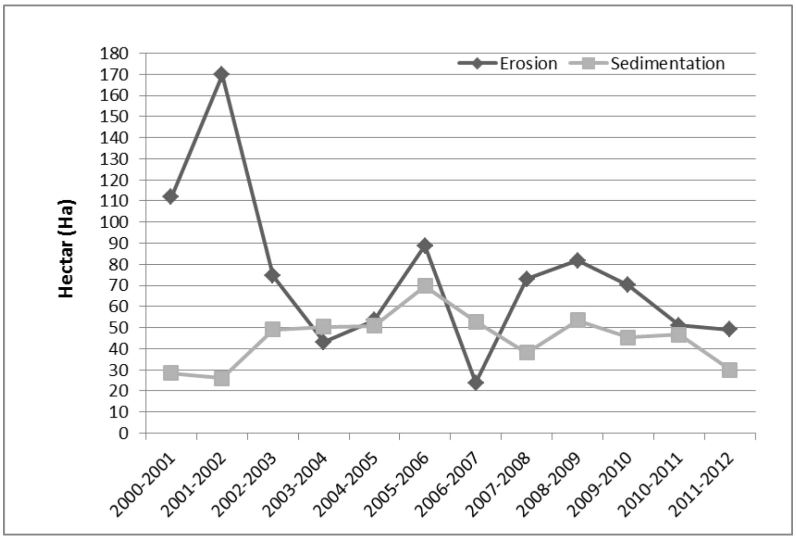

Figure 7. Coastal Erosion and Sedimentation Graph by BILKO Algorithm Method

The Net Coastline Changes (NCC) of Kecamatan Muara Gembong can be obtained by calculating the differences between erosion and sedimentation value. The calculation results of NCC from both methods are described in Table 4 and Table 5 while Figure 8 and Figure 9 show the NCC value in form of graphs.

Table 3. The Calculation Results of Net Coastline Changes by Ratioing Method

YEAR	NET COASTLINE CHANGES (Ha)					TOTAL (Ha)
	DESA					
	Pantai Bakti	Pantai Bahagia	Pantai Sederhana	Pantai Mekar	Pantai Harapan Jaya	
2000-2001	2.62	-31.88	-8.43	-3.97	0.63	-41.04
2001-2002	-11.21	-74.01	-11.44	-7.05	-10.52	-114.23
2002-2003	-11.19	7.27	10.88	9.95	25.93	42.84
2003-2004	15.64	-21.08	-17.26	-9.06	-49.93	-81.70
2004-2005	-9.11	0.50	1.49	-2.08	-3.67	-12.87
2005-2006	-12.78	3.33	-23.11	0.29	5.88	-26.39
2006-2007	13.69	30.72	2.53	7.37	16.22	70.54
2007-2008	-19.79	-8.31	-7.71	-12.17	-15.25	-63.23
2008-2009	5.50	-16.02	-19.45	-0.08	-12.54	-42.59
2009-2010	-10.06	11.85	-16.05	-10.54	-2.40	-27.19
2010-2011	5.62	-30.10	0.19	4.21	8.91	-11.17
2011-2012	-1.88	-11.33	-3.28	-7.32	-15.71	-39.51
Total from Each Village	-32.94	-139.05	-91.65	-30.44	-52.47	-346.54

Table 4. The Calculation Results of Net Coastline Changes by BILKO Algorithm Method

YEAR	NET COASTLINE CHANGES (Ha)					TOTAL (Ha)
	DESA					
	Pantai Bakti	Pantai Bahagia	Pantai Sederhana	Pantai Mekar	Pantai Harapan Jaya	
2000-2001	0.98	-53.65	-19.84	1.28	-11.99	-83.22
2001-2002	-27.61	-70.35	-18.79	-11.33	-15.67	-143.75
2002-2003	-7.16	-12.03	4.25	1.04	-11.64	-25.55
2003-2004	12.11	5.84	-11.68	-0.58	1.58	7.27
2004-2005	-8.09	-2.23	5.21	-1.74	4.15	-2.68
2005-2006	-3.88	6.29	-22.50	1.75	-0.83	-19.17
2006-2007	5.48	15.75	0.46	3.56	3.73	28.98
2007-2008	-5.03	-24.40	-7.14	-9.42	11.08	-34.92
2008-2009	10.21	-24.37	-22.59	-3.17	11.70	-28.22
2009-2010	-12.11	15.53	-0.85	-5.35	-21.90	-24.69
2010-2011	-9.73	2.13	-6.91	5.60	4.47	-4.45
2011-2012	3.21	-0.07	-3.45	-7.90	-10.94	-19.15
Total from Each Village	-41.63	-141.56	-103.82	-26.27	-36.28	-349.56

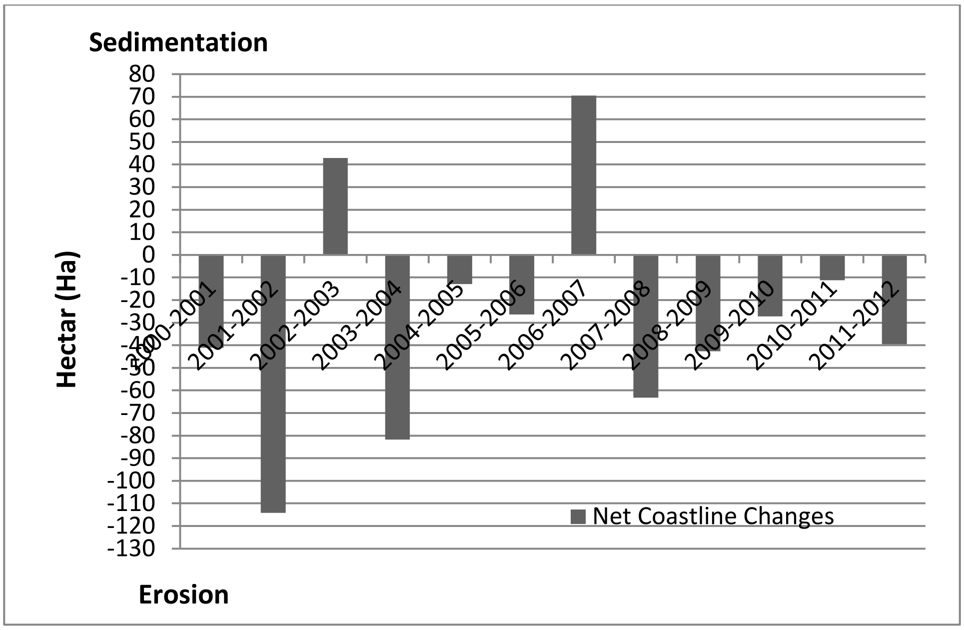

Figure 8. Net Coastline Changes Graph by Ratioing Method

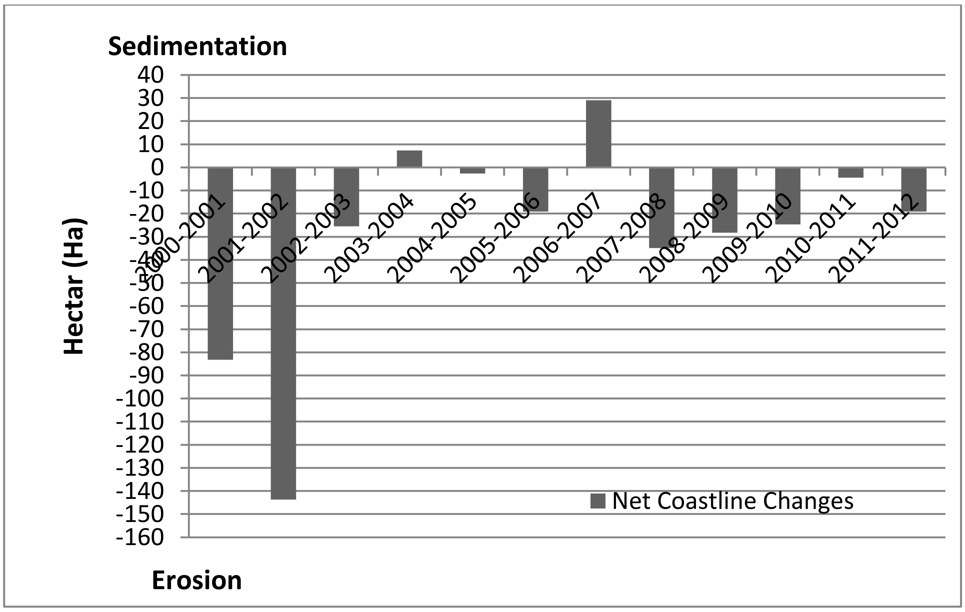

Figure 9. Net Coastline Changes Graph by BILKO Algorithm Method

The positive ordinate at NCC graphs refer to sedimentation value is greater than erosion value. It indicates that the whole coastline is progressing. Conversely, the negative ordinate refer to erosion value is greater than sedimentation value that generates the coastline setback. Figure 8 shows that from 2002–2003 and from 2006–2007 the coastline was progressed in ratioing method. Table 5 and Figure 9 show that the coastline was progressed from 2003–2004 and from 2006–2007 in BILKO algorithm method.

From both methods, the sedimentation value from 2006–2007 is high. The documentation of West Java Provincial Government stated that floods have occurred 125 times in West Java. The high NCC from 2006-2007 may be the impact of the flood. The major cause is its high rainfall intensity.

Erosion and sedimentation phenomenon were generated by tides, coastal morphology, sea current, wave, wind, sediment characteristic, and rainfall intensity. There is a significant amount of erosion occurred in the coastal zone of Desa Pantai Bahagia and Desa Pantai Sederhana with the value of 139.05 Ha and 91.65 Ha from the ratioing method whereas the result from BILKO algorithm method is 141.56 Ha and 103.82 Ha. Desa Pantai Mekar has the least reduces, that is 30.44 Ha from ratioing method and 26.27 Ha from BILKO algorithm method.

Firmana (2012) stated that sea wave in coastal zone of Desa Pantai Mekar and in part of Desa Pantai Sederhana came from the southwest, west, and northwest. The wave height is 0–20 cm up to 60–80 cm. The northwest wave height is >80 cm and may cause the coastline constantly regress in that zone. The sea wave height in northern coastal zone of Desa Pantai Bahagia is up to >80 cm. This wave came from northwest, north, northeast, and east. The high erosion values in this area are due to the high wave.

Based on NCC, the area of Kecamatan Muara Gembong from year 2000–2012 has reduced 346.54–349.56 Ha. The difference of total NCC between both methods is 3.02 Ha with the speed average of erosion that has been obtained is 28.88–29.13 Ha/year.

The calculation differences are due to georeference process. The trace of stripping image correction may create multiple objects in the image are not clearly visible so that the GCP on each image may vary. In addition, the custom GCP in order to get residual value < 0.5 pixel may also effect the calculation differences. The variation of the image recording time can affect the image visualization, such as the cloud. This process requires high interpretation ability. The software used in this process does not allow automatic digitizing process.

4. Conclusions

Refer to the process and analysis of this research, it can be concluded that:

a. The width of the area affected by the tides is 15.46 meters to the real time water level in Kecamatan Muara Gembong and could be ignored in identifying the coastline from satellite imageries with 30 m resolution.

b. Coastal zone of Kecamatan Muara Gembong from 2000–2012 is dominated by erosion with the Net Coastline Changes (NCC) amount of 346.54–349.56 Ha.

c. In ratioing method, the coastal erosion speed is 77.21 Ha/year and the coastal sedimentation speed is 48.33 Ha/year whereas in BILKO algorithm method the coastal erosion speed is 68.47 Ha/year and the coastal sedimentation speed is 41.58 Ha/year.

d. Based on NCC, the speed average of coastal erosion in Kecamatan Muara Gembong is 28.88–29.13 Ha/year.

5. REFERENCES

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