The Lost of Semarang Coastal Areas due to Climate Change and Land Subsidence

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Abstract **-** Semarang is the capital of Central Java Province, located in the northern part of Java Island, Indonesia, with an area of about 374 km^2 and inhabited by about 1.57 million people. It has been reported for some time that coastline of Semarang is retreated. This backwards movement is mainly due to coastal erosion triggered by climate change effects, land subsidence, and coastal structures jutting to the sea. During the last two decades (1990-2010) the annual rainfall has increased 18.66 mm per year, while the maximum daily storm increased 0.82 mm/year, and the storm intensity increased annually by 0.4 - 0.5 mm/hour. Consequently, the runoff is estimated to increase by 8% to 30%, and the flooded area increased about 5% to 15% for the next two decades. Based on sea level data recorded in Tanjung Emas Harbor during the period of 1985 up to 2008, it was found the annual relative sea level rise and land subsidence on the station are 5.536 cm/year and 5.165 cm/year consecutively, and the sea level rise is 3.7 mm per year. Interpretation of satellite imagery in 1991 and 2009 showed that 25.6 km of the total 36.6 km is eroded. This erosion has removed the coastal plain area of 1,764.5 ha. This paper is aimed to discribe and discuss the lost of Semarang Coastal Areas and sum up with concluding remarks.

Keywords**:** climate change, coastline retreat, coastal area, land subsidence

1. INTRODUCTION

Semarang, the capital of Central Java Province, is located in the northern coast of Java Island, Indonesia (Figure 1). Geographically, it is located at 6º50'-7º10' south latitude and 109º35'-110º50' east longitude, and covers an area of about 373.67 km^2. It is inhabited about 1.57 million people in 2013 (BPS, 2014). Topographically, Semarang consisted of two major distinct landscapes, lowland-coastal area in the north and hilly area in the south. The northern part, where the city centre, harbour, airport and railway stations are located, is relatively flat with topographical slopes ranging between 0 and 2 %, and altitude between 0 and 3.5 m; while the southern part have slopes up to 45% and altitude up to about 360 m above sea level. The northern part, called old city, has relatively higher population density and also has more industrial and business areas compared to the southern part. The land use of southern part is usually consisted of residential, office, retail, public use and open space areas. However, over the last two decades, the development of the southern part is very fast, especially the development of new residential and retail. The migration of some college campuses from northerm to southerm part is one of the triggers development of the southern region.

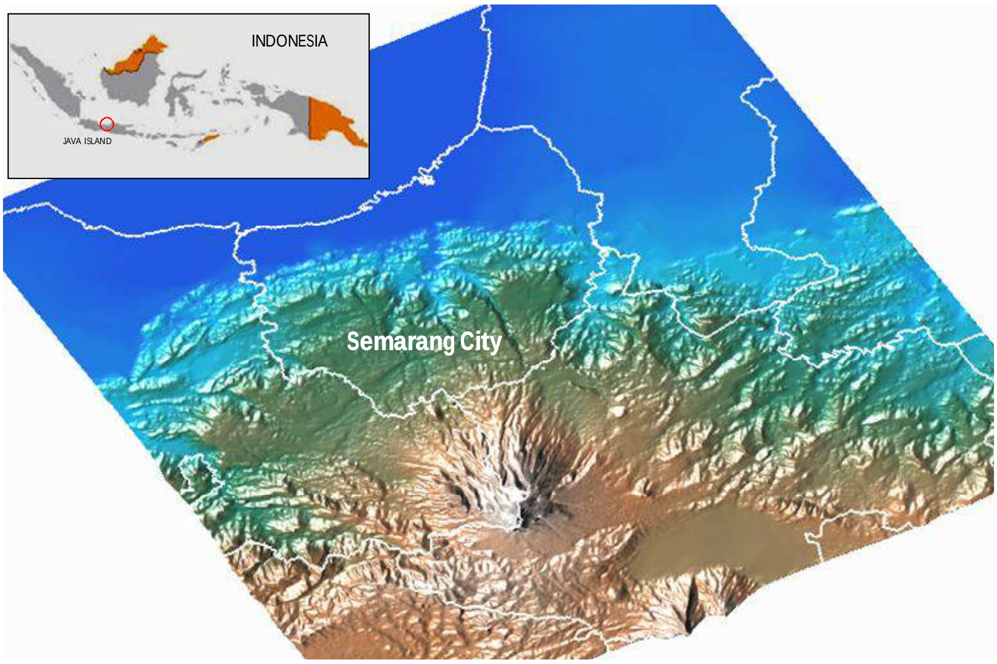

Figure 1. Geographical Location of Semarang City (Raw DEM; Space Shuttle Data, NASA. 2000)

Geologically, Semarang has three main lithologies, namely: volcanic rock, sedimentary rock, and alluvial deposits. The basement of Semarang consists of Tertiary Claystone of the Kalibiuk Formation. Overlying this Formation is the Notopuro Formation which consists of Quaternary volcanic material. The two formations crop out in the southern part of the Semarang area. The northern part of the Semarang area is covered by Kali Garang deltaic alluvium up to a depth of 80 to 100 m in the coastal area. Aquifers are found at depths ranging from 30 to 80 m in this alluvium (Sukhyar, 2003).

As reported by Van Bemmelen (1949) that the shoreline of Semarang progresses relatively quick towards the sea, it is about 2 km during 2.5 centuries or about 8 m/year (Figure 2). The soil is composed by very young alluvium with high compressibility. Therefore it can be expected that natural consolidation process still occurred until now, causing land subsidence in the coastal area of Semarang. Later, the fast infrastructure development and reclamation by land fill increase the rate of land subsidence.

Various studies related to climate change (CCROM-IPB, 2010, DKP, 2008 and 2010), land subsidence (Sutanta et al, 2005; Marfai and King, 2007; Sarkowi et al., 2005; Fukuda et al, 2008;

Murdohardono et al, 2009) have been conducted in Semarang city. This paper combines and discuss the results obtained and then relates them to the sinking and lost of Semarang Coastal Area.

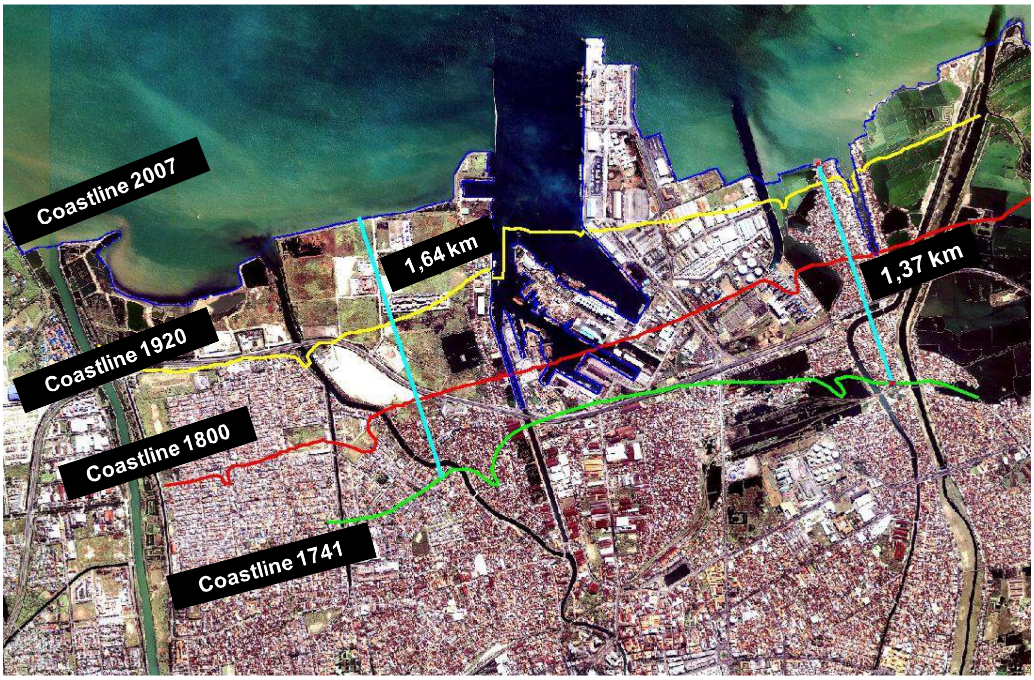

Figure 2. Progress of Semarang Coastline for the year 1741-2007 (Anggoro, et al, 2014)

2. CLIMATE CHANGE

Climate change is no longer just as the issue, but it has become a reality that we can feel in everyday life. Based on the data extracted from the CRU TS2.0 for Semarang, CCROM-IBB (2010) found that during the last 100 years, the mean temperature increased from 25.9 to 26.3^{o} C in the wet season, and it increased from 25.3 to 26.3^{o} C in the dry season. The increasing trend is also occurred for daily maximum temperature. In the wet season, the maximum temperature increased from 31.4 to 31.9^{o} C, while in the dry season it increased from 31.2 to 32.2^{o} C. In addition, the range between the high temperature and low temperature decreasing, meaning low temperature increase faster than the increase in high temperatures.

In line with the CCROM-IPB finding, study conducted by DKP (2008) using 30 years of data (1977-2007) showed a similar conclusion, the average air temperature monthly for 3 decades increased by 0.62^{o} C or at 0.02^{o}C per year. Therefore, the air temperature in Semarang City is predicted to increase 2.7^{o}C for the next 100 years from 2007 air temperature. Meanwhile, studies by CCRON-IPB (2010) mentions that the increase in temperature is estimated range between 1.9-2.9^{o}C in 2100.

Changes in air temperature is followed changes in rainfall characteristics. Based on 50 years rainfall data (1960-2007) recorded in Siliwangi Station-Semarang by Meteorology and Geophysics Agency (BMKG), it was found that though the maximum daily rainfall is very volatile (

Figure **3**), in general it is found that the maximum daily rainfall is increased. The increasing maximum daily rainfall from the year 1960 – 2010 is 40,90 mm, with an average annual maximum daily rainfall increament is 0.82 mm/year.

The rainfall intensity is also tend to increase continuously both an hour rainfall duration and two hours rainfall duration (

Figure **3**). For an hour rainfall duration the intensity increase from 57 mm/hour in 1960 to 85 mm/year in 2007. While for two hours rainfall duration, the intensity increase from 35 mm/hour in 1960 to 55 mm/hour in 2007.

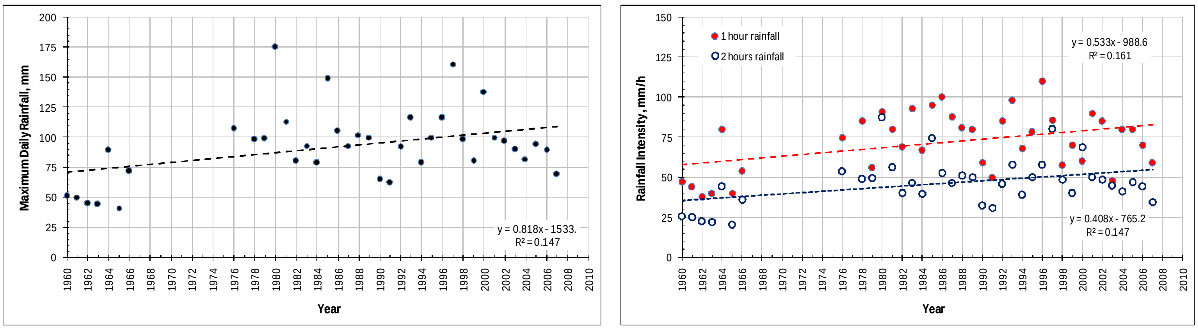

Figure 3. Trend of Maximum Daily Rainfall (left), and Rainfall Intensity (right) in Semarang City year 1960-2007

changes in rainfall characteristics, both the increase in the maximum daily rainfall and rainfall intensity, will increase flood hydrograph. With regard watershed characteristics do not change, the change of rainfall characteristics will increase the flood hydrograph about 8% to 30%. Figure 4 shows the predicted changes in river flood hydrograf Plumbon current state and the next two decades. While the flood inundation area is predicted to increase by 5% to 15% for the same period.

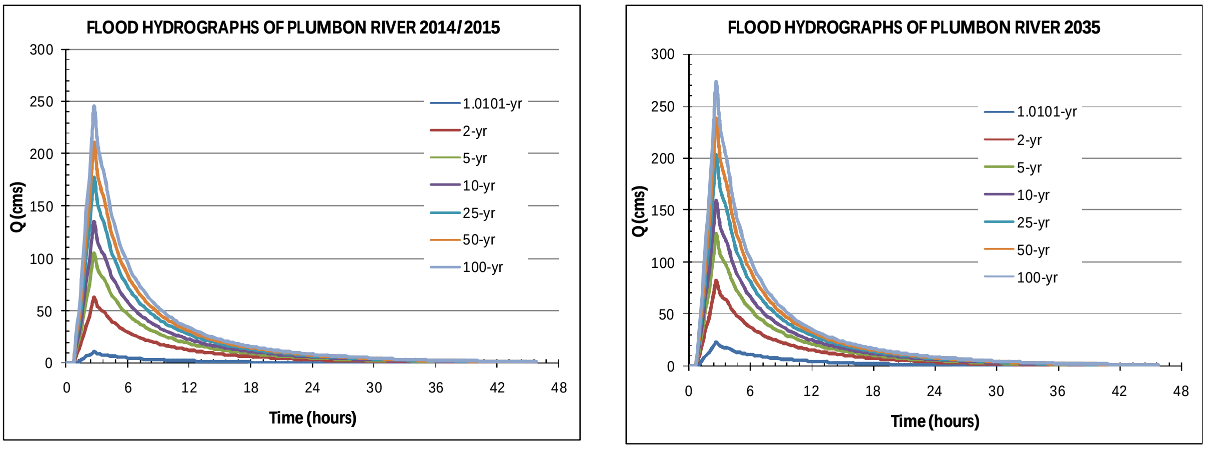

Figure 4. Predicted Flood Hydrographs of Plumbon River for Present Condition (left), and Next Two Decades (right)

3. LAND SUBSIDENCE AND SEA LEVEL RISE

Land subsidence is not a new phenomenon anymore for Semarang. It has been known since more than 100 years ago (Abidin, et al, 2010). Over the past two decades, land subsidence known more widely by the people, for the more obvious and widespread impacts. It causes extensive and costly damage to urban drainage, infrastructure and buildings, and also the deterioration of environmental quality. Some examples of land subsidence impacts can be seen in Figure 5.

Figure 5. Some Example of Land Subsidence Impacts in Semarang City (Soetrisno, et al, 2014)

The cause of the land subsidence in Semarang, researchers still disagree. However, in general it can be said that there are several dominant causes of land subsidence in Semarang, namely the consolidation of young alluvial soil in coastal areas both naturally and due to the load of the building, and excessive groundwater abstraction. Several investigations for the prediction and modelling of land subsidence in Semarang have been carried out by researchers using various methods and approaches, i.e., leveling and GPS (Marfei & King, 2007), PSI using state points network (Koehn et al, 2009). The rate of the subsidence reported is also different. Kuehn et al (2009) reported that based on Synthetic Aperture Radar (SAR) data recorded from 2002 to 2006, the higest rate of land subsidence in the northern part of Semarang is about 8-9 cm/year. Based On levelling, InSAR and microgravity data, Abidin et al (2010) found that the subsidence with the maximum rate of up to about 15 cm/year were observed during the period 1979 -2006. Levelling derived land subsidence in Semarang is shown in Figure 6.

Based on Figure 6 maximum land subsidence rate reaches 9 cm/year, of which occurred in the area of Ahmad Yani International Airport, inner pool of Tanjung Emas Harbor. While the rate of land subsidence at station of sea level monitoring, which is located on the east side of the harbor, ranging from 5 to 6 cm / year.

Although the results vary, it can be concluded that the highest rate of land subsidence in Semarang ranges from 8-15 cm / year. It occurred along coastal areas, especially the coast of West Semarang and North Semarang, and further to the south vanishingly small.

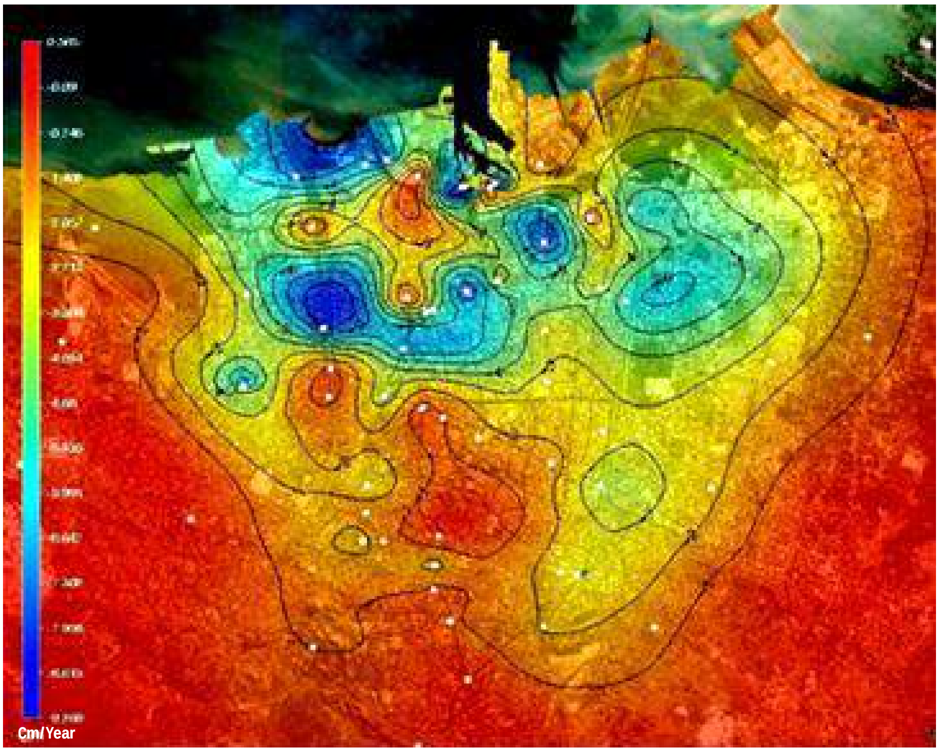

Figure 6. Land Subsidence Rate in cm per year (Anggoro, 2014)

Different methods and approaches made by Wirasatriya et al (2006), namely by levelling and utilization of sea level elevation data recorded at Tanjung Emas Harbor, to estimate the rate of land subsidence, concluded that the rate of land subsidence in AWLR station of Tanjung Emas Harbor is 5.165 cm per year, and sea level rise was 2.65 mm/year. Another study conducted by ACCCRN (2010) reported that sea level rise in Semarang was 7.8 mm/year. This value is much higher than global sea level rise, that was about 2.8 up to 3.6 mm/year (IPPC, 2013). To to assure the accuracy of the value of sea-level rise, the analysis performed on the data tidal, with a longer duration. The following are the analysis results.

Sea level data recorded by PT. (Persero) Pelabuhan Indonesia III Tanjung Emas Semarang is available for the year 1985-2008 (Figure 7). The data show that the elevation of seawater level in general is continued to rise, although in the year 1998-2003 sea level decreased. Later it was known that the instrument in the period of 1998-2003 was modified, and the data are considered not valid, so that these data were not used in the analysis.

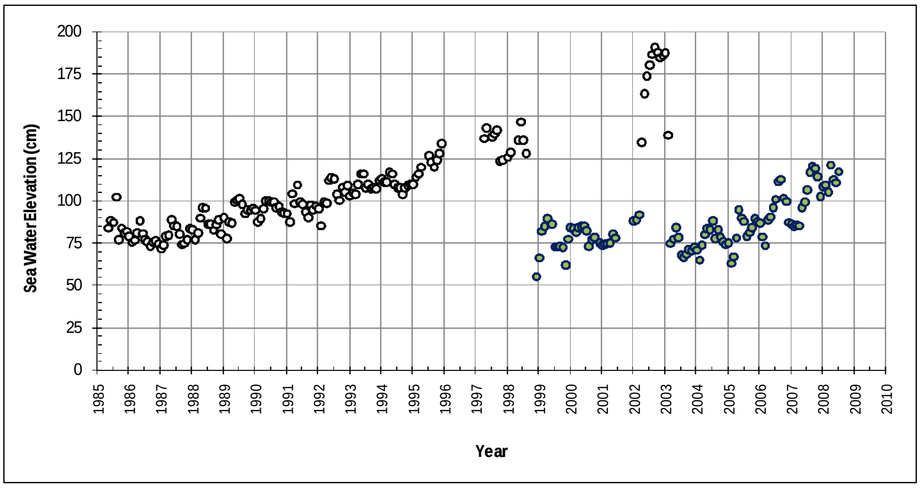

Figure 7. Recorded Sea Water Elevation in Semarang City 1985-2008

By using these data, it can be found that the sea level in Semarang Bay from the year 1995-1998 is 57.2 cm, with an average 4.40 cm annually. While for the year 2003-2008 is 33.36 cm with an average of 6.672 cm per year. The average seawater rise for the period 1985 – 2008 is therefore 5.536 cm per year.

In order to know the rate of sea level rise due to the influence of global warming in Semarang, the difference between the rise of seawater with a total value of land subsidence on the location of tidal station were calculated. The recorded sewater elevation years 1985-2008 were actually the summation of actual sea level rise and land subsidence, as the sea level recorder station is subject to land subsidence. The rate of land subsidence on the station is 5.165 cm/year (Wirasatria, et al, 2006). Therefore, the sea level rise (SLR) due to global warming is about 3.71 mm/year. The value is higher than the results reported by Wirasatria et al (2006), but still within the range of global SLR. It can also be understood that the rate of SLR is likely to increase with time.

The presence of sea level rise and land subsidence will expand seawater inundation area (tidal inundation or rob). Table 1 shows the prediction of sea water inundation area due to sea level rise and land subsidence for the next 10 years and 20 years. The distribution of inundation areas can be seen in Figure 8.

Table 1. Predicted Seawater Inundation Area due to Sea Level Rise and Land Subsidence (ha)

Next	**10 years**		**20 years**	
Type of land use	**Without land subsidence**	**With land subsidence**	**Without land subsidence**	**With land subsidence**
Building	244.64	378.64	272.46	608.58
Fishpond	449.82	654.14	597.78	1,190.11
Settlement	24.06	297.89	59.49	854.63
Rice field	27.93	27.93	38.89	38.89
Total	746.45	1,358.63	968.62	2,692.21

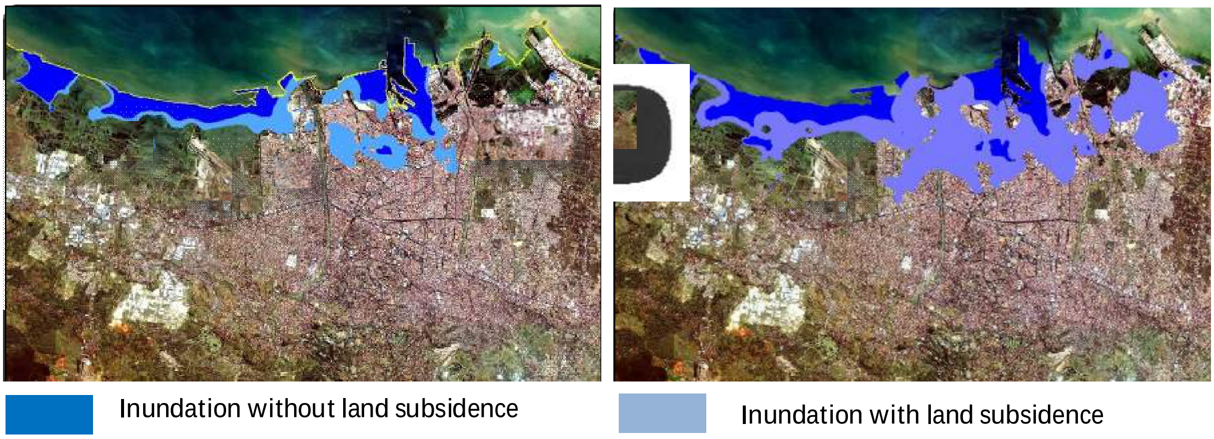

Figure 8. Estimeted Seawater Inundation in Semarang City in the Next 10 Year (left) and 20 Year (right).

4. COASTAL EROSION

Since the last three decades, the movement of the shoreline of Semarang reverse direction, from the beginning to move in the direction of the sea (coastline forward) to move towards the land (coastline retreat). Satellite image mapping results showed that in the past 10 years, some segments of shoreline in Semarang setback few meters. Severe erosion occurs in the District Tugu, West Semarang, and Genuk (Figure 9). Eroded area covers an area 1,764.5 ha, spread over four districts, namely: District Tugu 1,211.2 ha; District West Semarang 247.5 ha; District North Semarang 90.4 ha; and Disrict Genuk 215.4 ha.

Studies conducted by some researchers with various methods and approaches, such as modeling, serial interpretation of satellite imagery, and field survey, stated that Semarang coastal erosion is caused by several factors, namely: land subsidence, sea level rise, destruction of mangrove forests, and coastal structures jutting to the sea. Land subsidence and sea level rise resulting in widening tidal inundation, and increasing the waves hight propagation into the coastline. Mangrove area as a green belt in Semarang have decreased significantly, from 325 ha before 1980s reduced to only 83.7 ha in 2009 (DKP, 2010). The reduction of mangrove area is caused by the harvesting of mangroves for aquaculture intensive areas around the 1980s; reclamation activities which lead to coastal erosion, land ownership, and the lack of regulations pengenai mainly mangrove coastal management. Mangroves are natural coastal protection against wave action, mangrove loss means a loss of coastal protection, so it is easy coastal area erosion occurred.

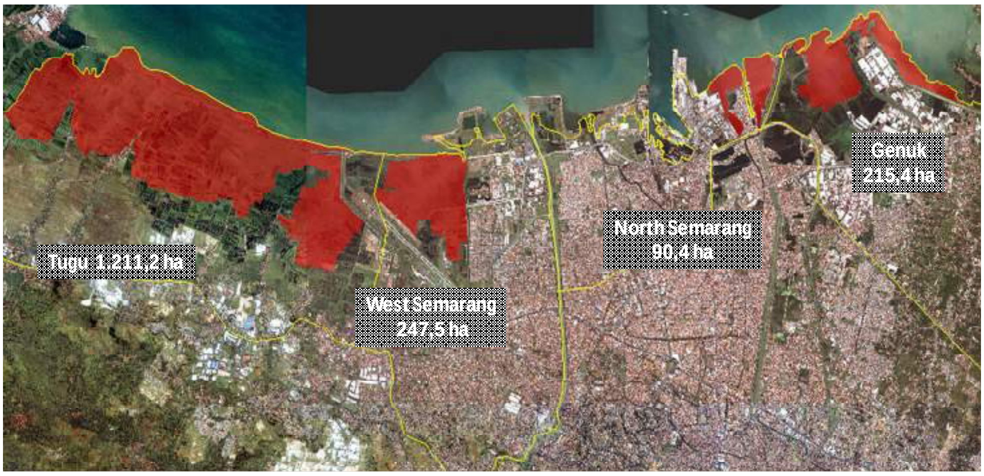

Figure 9. Erosion of Semarang Coastal Area (Anggoro, et al, 2014)

Other coastal erosion terigger, and which is considered as the main cause, is the structure jutting into the sea. There are two main structures, namely the development of the wood processing plant of PT. KLI in Kaliwungu and breakwater Tanjung Emas Harbour in Semarang. Dominant waves in the bay Semarang is northwest, so the presence of these structures could lead to erosion on the east side of the structure. In the case of Semarang Bay, the length of beach eroded is nine times longer than the length of the structure jutting into the sea. Structure of PT. KLI causing coastal erosion in District Tugu, while breakwater of Semarang Harbor resulted in coastal erosion in Tambakharjo until Bedono Village-Demak Regency.

Erosion in District Tugu includes a coastline of approximately 9 km, with an area of 1,221.2 ha. The coastline retreat at about 1.7 km. This area was originally in the form of traditional fishponds protected naturally by mangrove. Ponds suffered serious damage due to ersion. The erosion begins from the depletion of mangrove forests that allegedly due to the development of PT. KLI structure jutting into the sea (Figure 10).

Figure 10. Erosion of Coastal Area in Tugu District (ALOS AVNIR 22 Aug 2009) (left), and Mangrove Condition in 2010 (right)

Breakwater of Tanjung Emas Harbor, which is approximately 1000 meters jutting into the sea, resulting in erosion on the east, starting from adjacent areas, ie villages Bandarharjo continue to east until the District Sayung-Demak (Figure 11). During the period 1991 to 2009, the coastal erosion in District Sayung-Demak occured along 9.8 km, with an eroded area of 1,122.7 ha. The rate of shorline retreate reaches 3.2 km or 178 m/year.

Figure 11. Coastal Erosion of Tambakharjo Coastline 2003-2009 (left) and

5. CLOSING REMARKS

The erosion of Semarang Coastal Area is believed to be caused by combination of climate change, land subsidence, coastal structures, and mangrove destruction. Due to this coastal erosion, most of the coastline of Semarang that was once experienced progress towards the sea, now reversed setbacks towards the land. This erosion process takes place slowly but surely, thousands of ha ponds have been lost, buildings and infrastructure sink, so that part of the city of Semarang will be lost. The problems of coastal erosion is very complicated and cause resulting enormous losses. Therefore these issues must be addressed, otherwise it will move the shoreline of Semarang retreat back into position in the 17th century, however, the handling should be done carefully and comprehensively, with the involvement of experts from various fields and all stakeholders.

References:

Abidin, H.Z, H. Andreas, I. Gumilar, T. P. Sidiq, M. Gamal, D. Murdohardono, Supriyadi, and Y. Fukuda (2010), Studying Land Subsidence in Semarang (Indonesia) Using Geodetic Methods. *FIG Congress 2010, Facing the Challenges – Building the Capacity Sydney, Australia, 11-16 April* 2010.

ACCCRN (2010). *City Resilience Strategy: Semarang's Adaptation Plan in Responding to Climate Change*. The Rockefeller Foundation: ISET and Mercycorp Indonesia.

Anggoro, S., Sugianto, D.N., and Hilmi, M. (2014). Kondisi Wilayah Pesisir dan Laut di Teluk Semarang, Provinsi Jawa Tengah (Indonesia). *Paper presented at Diskusi Panel Penanganan Permasalahan Pantai di Teluk Semarang. Semarang, 14 Mei 2014*.

BPS (2014). *Semarang dalam Angka Tahun 2014*. Badan Pusat Statistik Kota Semarang.

CC-ROM IPB (2010). *Vulnerability and Adaptation Assessment to Climate Change at Semarang City*. Mercy Corps Indonesia.

DKP (2008). *Strategi Adaptasi dan Mitigasi Bencana Pesisir sebagai Akibat Perubahan Iklim terhadap Pesisir dan Pulau-pulau Kecil*. Kementerian Kelautan dan Perikanan, Jakarta.

DKP (2010). *Inventarisasi Data Pesisir dan Kelautan tahun 2009*. Pemkot Semarang.

Dinas Kelautan dan Perikanan Pemerintah Kota Semarang (2010). Pemetaan Potensi, Kerusakan dan Model Rehabilitasi Kawasan Pesisir Kota Semarang. *Laporan Akhir*, Dinas Kelautan dan Perikanan Pemerintah Kota Semarang, Indonesia.

DKP (2012). *Identifikasi Kerusakan dan Perencanaan Rehabilitasi Pantura Jawa Tengah.* Kementerian Kelautan dan Perikanan, Satuan Kerja Dinas Kelautan dan Perikanan Provinsi Jawa Tengah.

Fukuda, Y, T. Higashi, S. Miyazaki, T. Hasegawa, S. Yoshii, Y. Fukushima, J. Nishijima, M. Tanigushi, H.Z. Abidin, R.M. Delinom (2008). Groundwater and Land Subsidence Monitoring in 3 Mega-Cities, Indonesia, by Means of Integrated Geodetic Methods, *Paper presented at the AGU Fall Meeting 2008, San Fransisco, 15-19 Decembe 2008.*

IPPC (2013). Climate Change 2013: *The Physical Science Basis. Available at*: http://www.ipcc.ch/pdf/unfccc/cop19/3_gregory13sbsta.pdf. downloaded at February 10, 2014, 10:00 PM.

Kuehn, F. , D. Albiol, G. Cooksley, J. Duro, J. Granda, S. Haas, A. Hoffmann-Rothe, and D. Murdohardono (2009), Detection of land subsidence in Semarang, Indonesia, using stable points network (SPN) technique, *Environmental Earth Sciences, DOI 10.1007/s12665-009-0227-x*

Marfai, M.A. and L. King (2007). Monitoring land subsidence in Semarang, Indonesia, *Environmental Geology, Springer Verlag, Vol.53, pp. 651–659.*

Murdohardono, D., G.M. Sudradjat, A.D. Wirakusumah F. Kühn, F. Mulyasari (2009), Land Subsidence Analysis through Remote Sensing and Implementation on Municipality Level; Case Study: Semarang Municipality, Central Java Province, Indonesia, *Paper presented at the BGR-GAI-CCOP Workshop on Management of Georisks, 23-25 June 2009, Yogyakarta*.

Sarkowi, M., W.G.A. Kadir, D. Santoso (2005), Strategy of 4D Microgravity Survey for the Monitoring of Fluid Dynamics in the Subsurface, *Proceedings of the World Geothermal Congress 2005, Antalya, Turkey, 24-29 April.*

Sukhyar, R. (2003). Status and Progress of Urban Geology In Indonesia, Atlas and Urban Geology Vol. 14 : The Ground Beneath Our Feet: a Factorin Urban Planning, *United Nations ESCAP, New York, pp. 335 – 340.*

Sutanta, H., A. Rachman, Sumaryo, Diyono (2005). Predicting Land Use Affected by Land Subsidence in Semarang Based on Topographic Map of Scale 1:5.000 and Leveling Data. *Proceedings of the Map Asia 2005 Conference, Jakarta, 22-25 August 2005.*

Wirasatria, A., Hartoko, A. and Suripin (2006). Kajian Kenaikan Muka Laut Sebagai Landasan Penanggulangan Rob Di Pesisir Kota Semarang. *Thesis Magister Sumber Daya Pantai-UNDIP* (un published).

Van Bemmelen, R.W. (1949). The Geology of Indonesia. Vol. IA, Government Printing Office, Martinus Nijhof, The Netherlands.