Analele Universităţii din Oradea, Seria Geografie Year **XXII**, no. **1/2012** (June), pp. 5**4 - 65**
ISSN **1221-1273**, E-ISSN **2065-3409** Article no. **221106-558**

MONITORING THE CHANGE OF LAND SUBSIDENCE IN THE NOTHERN OF SEMARANG DUE TO CHANGE OF LANDUSE ON ALLUVIAL PLAIN

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Abstract: As the number of residents increasing to more than 1.4 million inhabitants, the use of land for the housing and industry could not be avoided in Semarang. The objectives of the study were to analyze and evaluate the changes of the amount and direction of land subsidence on the alluvial plain due to the change of land use from the year of 2000 to 2010. The land subsidence monitoring was conducted by superimposing several maps, namely the map of soil embankments, map of confined aquifer, map of carrying capacity, and map of the thickness of alluvial sediment. It can be shown from the results of the research that there is an increase of land subsidence in Semarang due to land use change.

Key words: land subsidence, loads over alluvial plain, soil mechanics

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INTRODUCTION

Semarang, the capital city of Central Java province, has an administrative area of 373.4 sqkm having 16 districts and 117 regents. This city has the birth rate 1.86 percent every year (Semarang, 2008a; Semarang, 2008b). Geographically speaking, Semarang is divided into 2 unit of morphology, while the southern side consists of volcanic and denudational-structural hilly landform, while in the northern side is alluvial plain. The downtown of Semarang consisted of alluvial plain - upper Holocen that was dominated by non-granular soil. Hence, the soil is still suffering compaction by nature. The rise of construction by government and residents of Semarang generates problems such as land degradation in the southern of Semarang (upper city) and land subsidence in the northern of Semarang especially in the swampy alluvial plain.

In 1975, developers started to build the real estate of Tanah Mas, continued in 1984 by building the real estates of Puri Anjasmoro, Marina and Pekan Raya Pembangunan Propinsi

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(PRPP) Central Java. These constructions were done by burying marshland as high as 2 - 4 m. The rise of this activity done by government and residents has caused land destruction in the southern of Semarang and land subsidence in the northern one, especially on alluvial plain.

The result of research by Tobing et al. (2000), Tobing et al. (2001), Tobing et al. (2003), and Marfai and King (2007), explained that alluvial plains in Semarang experienced land subsidence with the rates varied from 5 to 8 cm/year. In addition, according to Sayekti and Murdohardono (2000), the land subsidence along coastal area or in the area of harbor was more than 20 cm/year. Land subsidence in the most parts of Semarang, particularly in the old residential area, was a serious problem. Owing to this, residential land surface level sank. As a result, residential areas adjacent to a sea suffered from tidal flood, and this condition became worsen when tidal flood combined with raining. Since Semarang is the catchment area of Garang river, Kripik River and Kreo River, housing and infrastructures in low level topography, especially alluvial plain suffer from destruction after high-intensity rainfall (Soedarsono, 1997).

The change of land use from swamp to housing caused land subsidence on alluvial plain in the northern of Semarang increased. It generated more flooding area in locations just adjacent to ocean and in low level topography. For that reason, much destruction in housing and infrastructures in five regents covering area 941.14 Ha.

OBJECTIVES

The objectives of the study were: 1) To analyze the magnitude of land subsidence on the alluvial plain. 2) To evaluate the change of magnitude of land subsidence area in the year of 2000 and 2010 on alluvial plain due to the change of land use. 3) To analyze the direction of land subsidence in the year of 2000 and 2010 on alluvial plain due to the change of land use.

METODOLOGY

Land subsidence has much studied by many experts, i.e. Poland and Davis (1969), Holtz and Kovacs (1981), Whittaker and Reddish (1989), Johnson (1991), Fulton (1997), Yin et al. (2006), Carbogin (2003), Donelly (2006), and Phien and Natalaya (2008). They explained the general causes of land subsidence, such as the drop of aquifer, clay consolidation, mining activity, embankment and building loads.

A study conducted by Setyarini and Agarsugi (2008) described land subsidence related to groundwater over pumping was natural phenomena that commonly occurred in big towns lying in sea neighborhood or alluvial plain such as Jakarta, Semarang, and Surabaya. The amount of subsidence relies on geological condition, hydrology, suction intensity and soil-rock mechanical behavior.

To analyze and monitor the changes of land subsidence rate in Semarang, several steps have been applied. In the first step, data acquisition about the rate of land subsidence occurred in the past was calculated. Then, model development and validation have been done to analyze the land subsidence rate in present condition. Information about the past and present rate of land subsidence was used to monitor the changes of land subsidence in Semarang. The detailed steps of the method used are as follows:

Analysis of past land subsidence rate

Information about the rate of land subsidence occurred in the past has very important role in monitoring the changes of land subsidence in Semarang. Information about the rate of land subsidence occurred in the past has acquired using secondary data from the Directorate of Geology and Environmental Management (Direktorat Geologi dan Tata Lingkungan-DGTL), who has measured the land subsidence rate in 2000 using enormous GPS coordinate plotting over the northern part of Semarang. To match with model developed for the present land subsidence, the data for each analysis unit then classified into three different class, namely low land subsidence (<0.10 m/year), medium land subsidence (0.10-0.20 m/year), and high land subsidence (>0.20 m/year).

Model Development and Validation for Measuring Present Land Subsidence Rate

Calculation of the land subsidence rate in present condition has been done through land subsidence model. In the model development, four variables causing land subsidence, i.e. the thickness of soil embankments, soil carrying capacity, the thickness of alluvial sediment, and the decrease of water table depth on confined aquifer have been used to classify the magnitude of land subsidence. The analysis and validation of soil embankments was conducted using detailed land use map published by Bureau of Regional Development and Planning (BAPPEDA) of Semarang Government in 2006 and then directly checked on the research locations. The analysis and validation of carrying capacity and thickness of alluvium soil were conducted by several samples of boreholes, in which the soil was analyzed in a soil mechanics laboratory to analyze their carrying capacity. The analysis and validation of the depth of confined aquifer was done using map of confined aquifer depth published by Directorate of Geology and Environmental Management (Direktorat Geologi dan Tata Lingkungan-DGTL), then validated by measurement of several observed wells using Automatic Water Level Recording (AWLR). All the data measured using sample point location were interpolated using Geographic Information System (GIS) technology called Inverse Distance Weighting (IDW).

Model development of land subsidence rate was conducted using GIS technology by scoring method. In this method, each parameters were classified into three class based on the maximum and minimum level acquired. Each class then was given score based on their influence to the land subsidence. The classification each parameter and their score are shown in table 1.

Table 1. Classification of Land Subsidence Parameters
(Data source: Sudarsono, 2011)

Parameters	Value	Score
-Thickness of Soil Embankments		
High	>2 m	3
Medium	1- 2 m	2
Low	0 -1 m	1
- Soil Carrying Capacity		
High	>20 tons	1
Medium	15 – 20 tons	2
Low	<15 tons	3
-Thickness of Alluvial Sediment		
High	>50 m	3
Medium	30-50 m	2
Low	<30 m	1
-Decrease of Water Table on Confined Aquifer		
High	15 - 20 m	3
Medium	10 - 15 m	2
Low	<10 m	1

Using one of the geoprocessing analysis built in GIS technology called overlay, the total score calculated from combination of all scores as follows: total score = score of the thickness of soil embankments + score of the soil carrying capacity + score of the thickness of alluvial sediment + score of the decrease of water table on confined aquifer.

The total score then calculated based on lowest and highest value and classified into high, medium, and low land subsidence rate. Next, the validation was held through ground checking from some sampling location to measure the magnitude of land subsidence, in which the classification is shown in table 2.

Table 2. Classification of Land Subsidence Magnitude
(Data source: Sudarsono, 2011)

Magnitude of Land Subsidence	Value	Total Score
High Land Subsidence rate	>0.20 m	≥ 9
Medium Land Subsidence rate	0.10 m – 0.20 m	> 7 - <9
Low Land Subsidence rate	<0.10 m	≤ 7

Monitoring Changes of Land Subsidence Rate

The map of land subsidence rate in the past (in the year of 2000) and the map of land subsidence rate in the present condition are the major sources for land subsidence monitoring in Semarang. Monitoring the changes of land subsidence rate has been done by superimposing the map of land subsidence rate in year of 2000 with the map of land subsidence rate in present condition. Using overlay technique in GIS technology, both of the two maps were superimposed, in which the changes of land subsidence rate can be analyzed.

RESULTS AND DISCUSSION

Land Subsidence in Semarang

The research was conducted in some parts of Semarang in which the land being used for housing, industry, commercial activity, and swamp. Its soil layer is dominated by young alluvial which ages around hundreds years. For that reason, the soil in Semarang is compacted along with time.

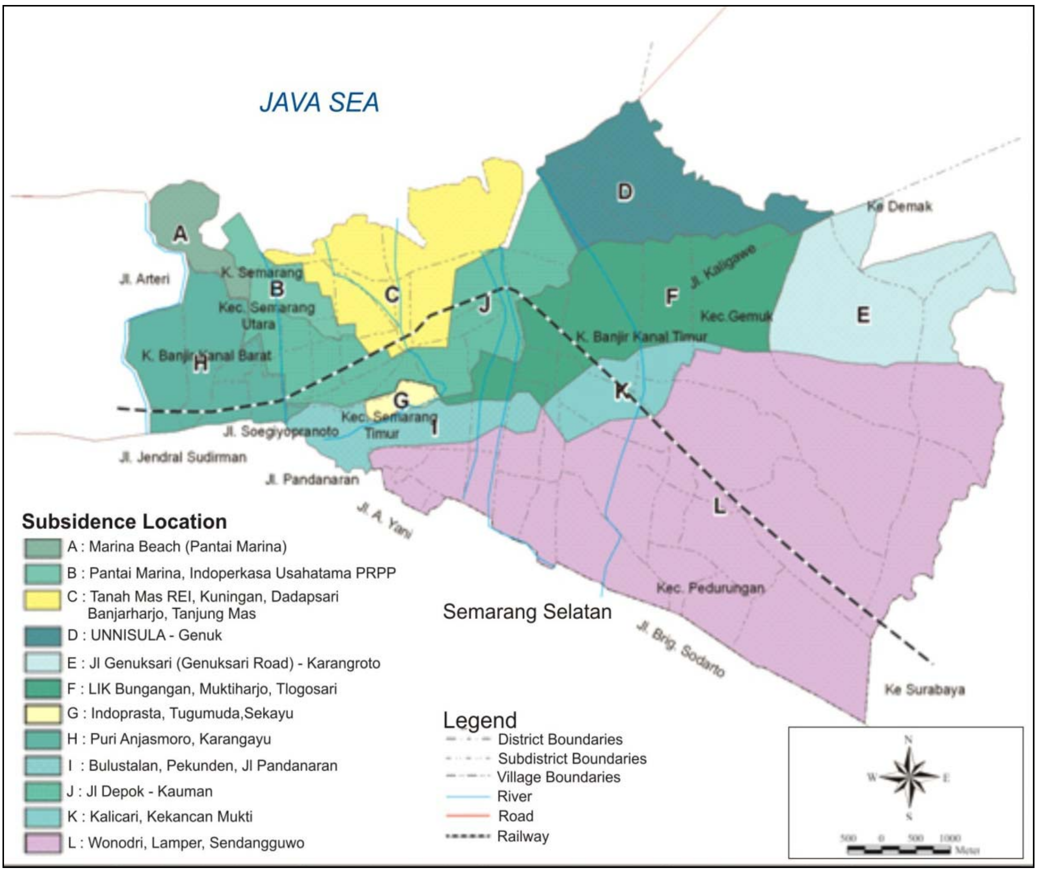

Figure 1. The map of study area division

In detail, the research area has been divided into 12 locations in which each location has different characteristic, land use, and the magnitude of land subsidence. The division of research area is shown in figure 1.

The measurement of land subsidence rate by Directorate of Geology and Environmental Management indicated that land subsidence rate in the northern part was about 0.05-0.20 m/year in 2000. To classify the rates of land subsidence for each 12 mapping location mentioned before, each point measurement of land subsidence rate in 2000 has been interpolated. Each mapping location then assigned with the data from the interpolation map in which the land subsidence rate was classified to low land subsidence rate (<0.10 m/year), medium land subsidence rate (0.10-0.20 m/year), and high land subsidence rate (>0.20 m/year). The map of land subsidence rate in 2000 is shown in figure 2.

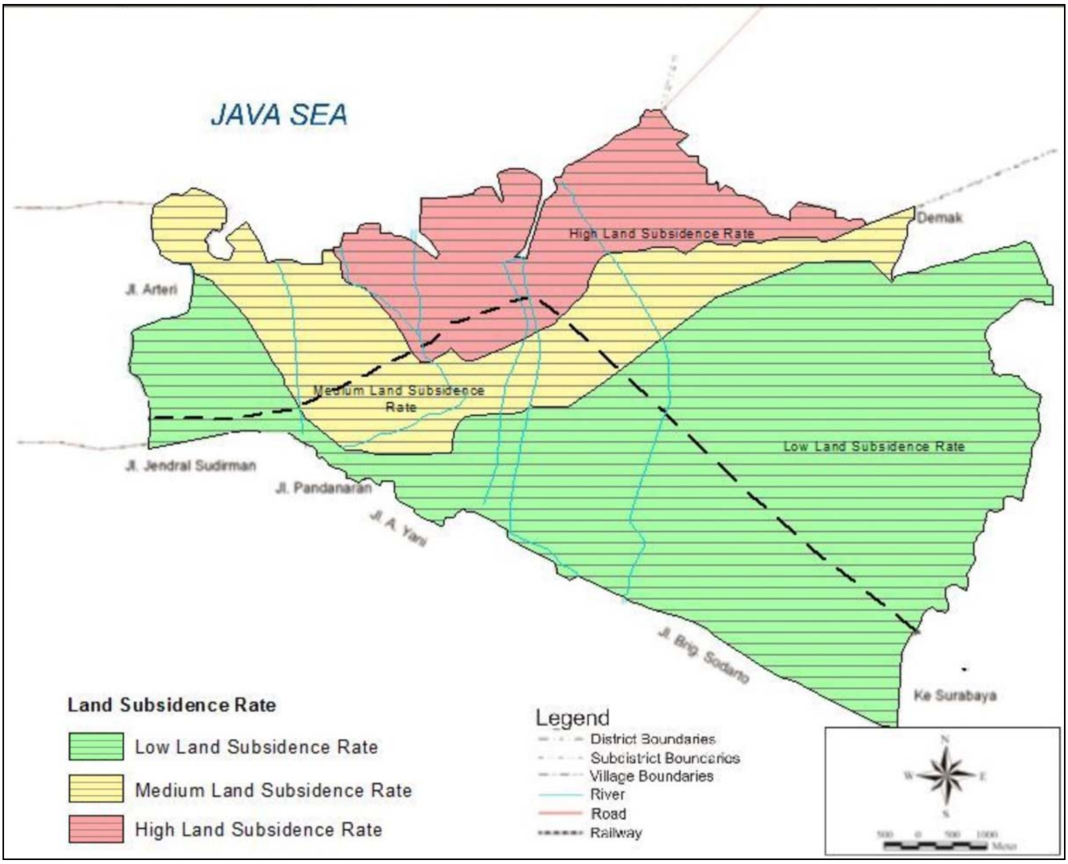

Figure 2. Map of land subsidence rate in the year of 2000

Analysis of present of Land Subsidence Rate in Semarang

Measurement on the four variables causing land subsidence, namely the thickness of soil embankment (γ), carrying capacity (σ), thickness of alluvial sediment and decrease of water table on confined aquifer was done, in which the result is shown in table 3. Scoring for each parameter has been completed in which small weight is given score 1, middle and big ones are given score 2 and 3 respectively. To obtain the combination score, the four variables are superimposed. If the weight is ≤ 7, it is classified as small land subsidence. However, for >7 - <9 and ≥ 9, they are classified as middle and big subsidence respectively (table 4).

Table 3. Thickness of soil embankment, carrying capacity, thickness of alluvial sediment and the decrease of water table on confined aquifer in research area
(Data source: Sudarsono, 2011)

Area	Locations	The thickness of soil embankment	Carrying capacity	The thickness of alluvial sediment	Decrease of water table on confined aquifer
A	Marina Beach (Pantai Marina)	1-2 m	> 20 tons	> 50 m	15 - 20 m
B	Marina, Indoperkasa Usahatama, PRPP	1-2 m	> 20 tons	> 50 m	15 - 20 m
C	Tanah Mas REI, Kuningan, Dadapsari Bandarharjo, Tanjung Mas	> 2 m	> 20 tons	> 50 m	15 - 20 m
D	UNISSULA – Genuk	> 2 m	> 20 tons	> 50 m	15 - 20 m
F	LIK Bugangan, Muktiharjo, Tlogosari	1-2 m	15 - 20 tons	30 - 50 m	10 -15 m
G	Indraprasta, Tugumuda, Sekayu	1-2 m	15 - 20 tons	30 - 50 m	10 -15 m
H	Puri Anjasmoro, Karangayu	> 2 m	15 - 20 tons	30 - 50 m	< 10 m
I	Bulustalan, Pekunden, Jl. Pandanaran	0-1 m	< 15 tons	30 - 50 m	10 -15 m
J	Jl. Depok-Kauman	1-2 m	15 - 20 tons	30 - 50 m	10 -15 m
E	Jl. Genuksari – Karangroto	0-1 m	15 - 20 tons	30 - 50 m	10 -15 m
K	Kalicari, Kekancan Mukti	0-1 m	< 15 tons	< 30 m	< 10 m
L	Wonodri, Lamper, Sendangguwo	0-1 m	< 15 tons	< 30 m	< 10 m

Table 4. Scoring of land subsidence rate parameters and their classification
(Data source: Sudarsono, 2011)

Area	Locations	Score					
		The thickness of soil embankment	Carrying capacity	The thickness of alluvial sediment	Decrease of water table on confined aquifer	Total of weight	Category
A	Marina Beach (Pantai Marina)	2	1	3	3	9	High land subsidence rate
B	Marina, Indoperkasa Usahatama, PRPP	2	1	3	3	9	
C	Tanah Mas REI, Kuningan, Dadapsari Bandarharjo, Tanjung Mas	3	1	3	3	10	
D	UNISSULA – Genuk	3	1	3	3	10	
F	LIK Bugangan, Muktiharjo, Tlogosari	2	2	2	2	8	Medium land subsidence rate
G	Indraprasta, Tugumuda, Sekayu	2	2	2	2	8	
H	Puri Anjasmoro, Karangayu	3	2	2	1	8	
I	Bulustalan, Pekunden, Jl. Pandanaran	1	3	2	2	8	

Area	**Locations**	**Score**					
		The thickness of soil embank ment	Carryin g capacit y	The thickne ss of alluvial sedime nt	Decreas e of water table on confined aquifer	Total of weight	Category
J	Jl. Depok-Kauman	2	2	2	2	8	
E	Jl. Genuksari – Karangroto	1	2	2	2	7	Low land subsidence rate
K	Kalicari, Kekancan Mukti	1	3	1	1	6	
L	Wonodri, Lamper, Sendangguwo	1	3	1	1	6	

Cumulative score resulted from all the four parameters shown that area A, B, C, and D (which have weight ≥ 9) are categorized as area with high land subsidence rate, while area F, G, H, I, J (>7 - <9) and E, K, L (≤ 7) are categorized as area with medium and low subsidence rates respectively. High land subsidence rate is located in the northern of Semarang, elongated from the east to west which is paralel to coast. However, the medium ones are on the centre in which full of old settlement and low ones are on the southern of Semarang, elongated from east to west which is 9-15 km far from coast. The map of land subsidence rate in year 2010 is shown in figure 3.

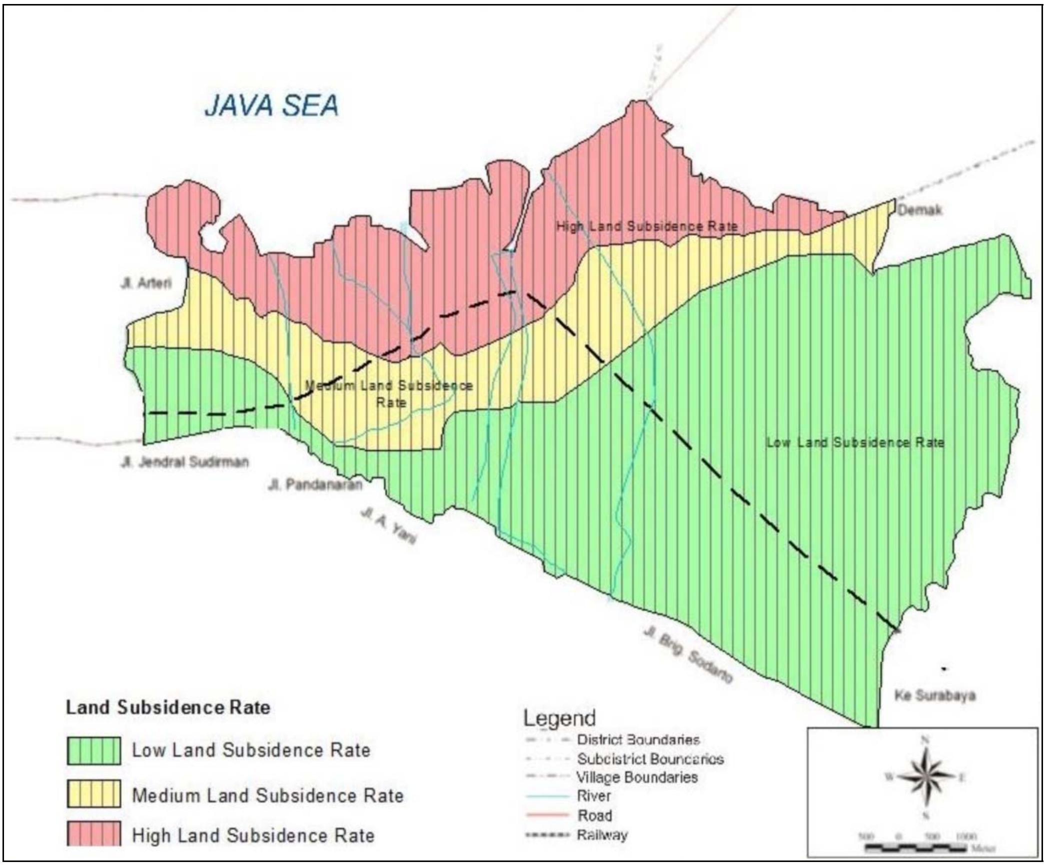

Figure 3. Map of and subsidence rate in the year of 2010

To identify the change of subsidence category and subsidence magnitude, superimposing the subsidence map of year 2000 and 2010 using overlay analysis has been done. The result of overlay analysis is shown in figure 4 and table 5.

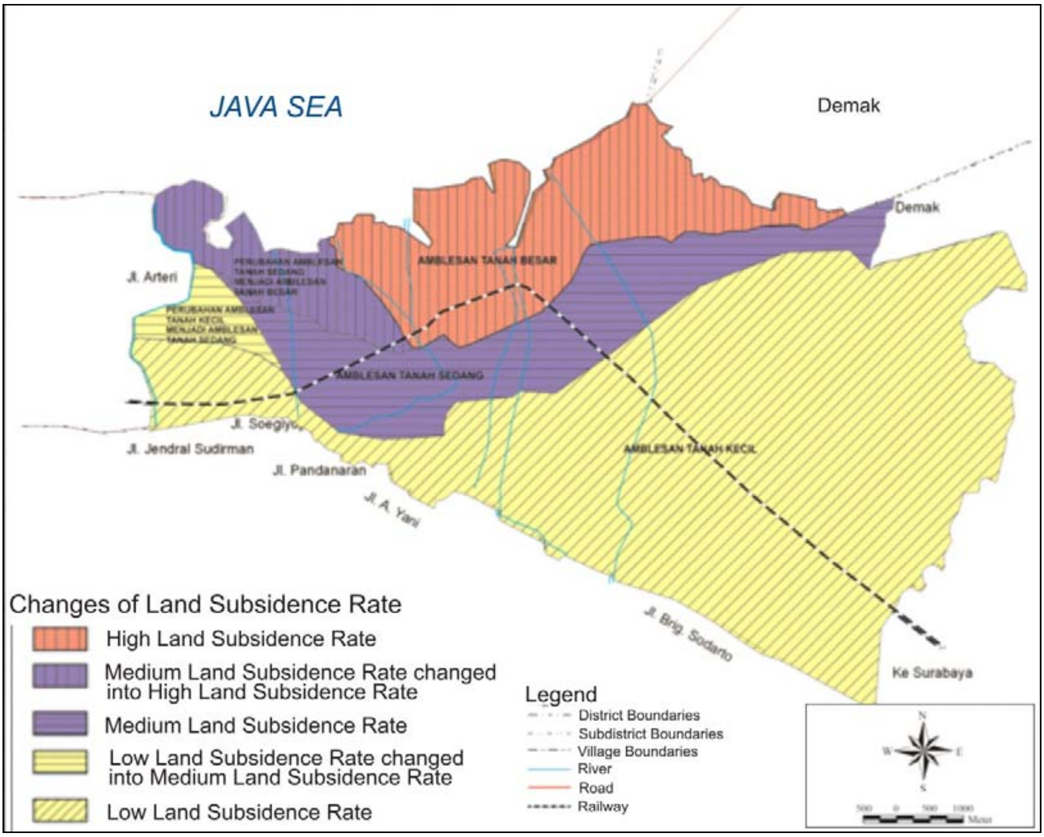

Figure 4. The overlay map of the change of land subsidence rate in the year of 2000 and 2010 in Semarang

Table 5. The change of land subsidence rates in the year of 2000 and 2010 in Semarang
(Data source: Sudarsono, 2011)

Locations		Area (Ha)	Land subsidence Rate in 2000	Land subsidence Rate in 2010	Analysis result
A	Marina Beach (Pantai Marina)	241.75	0.10 – 0.20 m/year (medium land subsidence rate)	> 0.20 m/year (High land subsidence rate)	Changes of land subsidence from medium to high (241.75 ha).
B	Marina, Indoperkasa Usahatama, PRPP	254.75	0.10 – 0.20 m/year (medium land subsidence rate)	> 0.20 m/year (High land subsidence rate)	Changes of land subsidence from medium to high (254.75 ha)
C	Tanah Mas REI, Kuningan, Dadapsari Bandarharjo, Tanjung Mas	1020.08	> 0.20 m/year (high land subsidence rate)	> 0.20 m/year (High land subsidence rate)	No change. still in the category of high land subsidence rate
D	UNISSULA – Genuk	857. 03	> 0.20 m/year (high land subsidence rate)	> 0.20 m/year (High land subsidence rate)	No change. still in the category of high land subsidence rate

E	Jl. Genuksari – Kauman	630.01	0.00 – 0.10 m/year (low land subsidence rate)	0.00 – 0.10 m/year (low land subsidence rate)	No change. still in the category of low land subsidence rate
F	LIK Bugangan, Muktiharjo, Tlogosari	1412.49	0.10 – 0.20 m/year (medium land subsidence rate)	0.10 – 0.20 m/year (medium land subsidence rate)	No change. still in the category of medium land subsidence rate
G	Indraprasta, Tugumuda, Sekayu	70.99	0.10 – 0.20 m/year (medium land subsidence rate)	0.10 – 0.20 m/year (medium land subsidence rate)	No change. still in the category of medium land subsidence rate
H	Puri Anjasmoro, Karangayu	758.93	0.00 – 0.10 m/year (low land subsidence rate)	0.10 – 0.20 m/year (medium land subsidence rate)	Changes of land subsidence from low to medium in Puri Anjasmoro (270.19 Ha)
I	Bulustalan, Pekunden, Jl. Pandanaran	435.53	0.10 – 0.20 m/year (medium land subsidence rate)	0.10 – 0.20 m/year (medium land subsidence rate)	No change. still in the category of medium land subsidence rate
J	Jl. Depok-Kauman	1067.03	0.10 – 0.20 m/year (medium land subsidence rate)	0.10 – 0.20 m/year (medium land subsidence rate)	No change. still in the category of medium land subsidence rate
K	Kalicari, Kekancan Mukti	371.59	0.00 – 0.10 m/year (low land subsidence rate)	0.00 – 0.10 m/year (low land subsidence rate)	No change. still in the category of low land subsidence rate
L	Wonodri, Lamper, Sendangguwo	4134.78	0.00 – 0.10 m/year (low land subsidence rate)	0.00 – 0.10 m/year (low land subsidence rate)	No change. still in the category of low land subsidence rate

It can be shown from figure 4 and table 2, the area A which is adjacent to Marina Beach between year 2000 and 2010 experienced the change of subsidence magnitude from medium land subsidence rate (0.10-0.20 m/year) to the high one (> 0.2 m/year). In the same period, the area B which is located on Marina, Indoperkasa Usaha Tama, and PRPP changed from medium to high subsidence rate, covering area 254.75 Ha. However only the area H in Puri Anjasmoro and Karangayu experienced the change from low land subsidence rate (0-0.10 m/year) to medium land subsidence rate (0.10-0.20 m/year), covering area 270.19 Ha. Therefore in the period of 10 years, there was an increase of subsidence category amounting to 6.81%.

According to the result of analysis and calculation of overlaying between land subsidence zone in the year of 2000 and the map of land subsidence in the year of 2010, some locations experienced the change of magnitude of subsidence. From observation in the field and data analysis using GIS technology, starting from 1975, in the study area has appeared housing and industry such as in Tanah Mas and LIK Kaligawe.

Generally, soil in the study area is dominated by soft to very soft clay. According to Wesley (1997), this type of soil is potential to being subside. It is shown from soil mechanics data (Soil Mechanics Laboratory, 2004) that soil in direction closer to sea, the embankment is thicker (2-4 m), the carrying capacity is lower and soil compression index (Cc) is higher (0.17-1.36), the plasticity index (IP) is higher (14% - 48%), the alluvial sediment is thicker (30 - 50 m) and confined aquifer is lower (- 3,95 - 22,44 m). resulted in the higher land subsidence.

In the area of Tanah Mas, the regents of Dadapsari, Kuningan and Bandarharjo (figure 2, grouped as area C), Unissula and Genuk (grouped as area D) both in the previous study in the year of 2000 and the present study (year 2010) are classified as area with high land subsidence rate. There is no change of magnitude. There was a change of subsidence magnitude in Marina Beach in the year of 2000 and 2010, from medium to high land subsidence rate. It was caused by resting an embankment as high as 4 m for the construction of settlements that still continued. This soil had soil consolidation coefficient (Cc) is 0.79, a little bit high, and confined aquifer is lower (-24.54 m). The same with Marina Beach, Marina and Indoperkasa Usaha Tama (figure 2) area also changed from medium to high land subsidence rate.

The changes of land subsidence magnitude from low to medium have occurred in Puri Anjasmoro and Karangayu area. It is caused by the increase of construction of settlements, governmental offices and trading companies that was lying over embankment as high as 2-3 m. This soil had soil consolidation coefficient (Cc) is 0.41 and confined aquifer is lower (-24.54 m). It was only in Karangayu area (area H, figure 2) that there was no subsidence. In this area, construction is not much and the soil is already compacted. Other locations in this study did not subside since the land is long time ago inhibited so that the soil is already consolidated even though it is dominated by clay. In figure 5 and 6, it is shown how the change of land use happened.

Figure 5. Swamp condition before real estate construction-The western of PRPP
(Source: Sudarsono 2011).

Figure 6. Swamp condition after real estate construction-The eastern of PRPP
(Source: Sudarsono 2011)

It is shown from the result that soil embankment in direction closer to sea is higher (2 - 4 m), carrying capacity is lower and soil compression index (Cc) is higher (0.17 - 1.36). Thickness of alluvial sediment is also thicker (30 - 50 m) since the layer leaned to sea direction before sedimentation process. The depth of confined aquifer is lower (3.95 - 22.44 m) because of groundwater overpumping.

In the study locations in the north next to sea, coast line grew to north direction. According to Marfai et al. (2008a), coast line in the northern of Central Java and also Semarang city had change. Due to their low level topography and saturated soil, the regents of Kuningan, Dadapsari, Bandarharjo and Tanjung Mas (area C, figure 1) suffered from tidal flood. Moreover, the factors such as their locations close to downstream and surrounded by rivers leaded to tidal flood.

Marfai and King (2008a), Marfai and King (2008b), Marfai et al. (2008a) and Marfai et al. (2008b) offered several solutions to minimize flood in the settlements adjacent to sea, such as construction of dike, drainage system, pump stations, polder system, reclamation, and society capacity building. However, even though some means to minimize flood by Semarang government such as the construction of polder and pump stations had done, flooding is still occurred.

CONCLUDING REMARK

The change of land use from swamp to settlements, soil embankment, soil mechanical behavior, the thickness of alluvial sediment, and the drop of confined aquifer in Marina Beach (area A) affected land subsidence growing higher in the period between year 2000 and 2010 with covering area 241.75 Ha. In addition, land subsidence in Marina area (area B) changed from medium to high with covering area 254.75 Ha in the period between year 2000 and 2010. Naturally growing settlements in the area of Tanah Mas, the regents of Dadapsari, Kuningan, and Bandarharjo (area C), LIK Kaligawe and Genuk (area D) covering area 1020 Ha both in the previous study in the year of 2000 and the present study (year 2010) are still classified as area with high land subsidence rate. The change of land use from swamp to settlements and governmental offices, soil embankment, soil mechanical behavior, the thickness of alluvial sediment, and the drop of confined aquifer in Marina and Puri Anjasmoro area (area H) also caused land subsidence changed from low to medium subsidence covering area 270.19 Ha from year 2000 and 2010. Other locations in this study did not subside since the land is long time ago inhibited so that the soil is already consolidated.

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Submitted:	Revised:	Accepted and published online
December 07, 2011	January 25, 2012	April 11, 2012