Mapping And Evaluating The Impact Of Land Subsidence In Semarang (Indonesia)

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Abstract. Semarang is the capital of Central Java province, located in the northern coast of Java island, Indonesia. Land subsidence in Semarang has been widely reported and its impacts can be seen already in daily life. Based on the estimation from Levelling, Interferometric Synthetic Aperture Radar (InSAR), Microgravity and Global Positioning System (GPS) survey methods, land subsidence with rates of up to about 19 cm/year were observed during the period of 1999 up to 2011. Results derived from GPS since 2008 up to 2011 show that land subsidence in Semarang has spatial and temporal variations, with spatial average rates of about 6 to 7 cm/year.

Based on the site visit surveys, the impacts of land subsidence can be seen in several forms such as cracks in buildings, damage of infrastructure (road and bridges), tilting and damaged houses, and wider expansion of coastal flooding (tidal flooding). Tidal flooding and tilting and damaged houses frequently occurs in the area where the subsidence rate is high (northern part of Semarang). Cracks in buildings and damage of infrastructure (road and bridges) occur in the boundary of large subsidence area and the less.

Keywords : *GPS , land subsidence, damages, coastal flooding, Semarang*

1. Introduction

Semarang is the capital city of Central Java Province, located in between 6 ° 50 '- 7 ° 10' Latitude and 109 º 35 '- 110 º 50' Longitude (Figure 1) with an area of 373.70 km^2. North boundary is the Java Sea, South boundary is Semarang District, East is Demak District, and west is Kendal District. Semarang has a very strategic location; divided into two parts, on the northern part consists of coastal lowlands and alluvial deposits, mud exposure and mangroves. The northern side is utilized for transport activity (Tanjung Mas, Ahmad Yani Airport and Tawang Station), aquaculture, industrial, residential, trading and agricultural. Meanwhile, the southern topography is hilly and now, predominantly turned into land up (build area). This area is used for educational events, trade, services, housing, and on the un-build land (unbuild area) is used for agriculture.

Geologically, Semarang has three main lithologies which are volcanic rock, sedimentary rock, and alluvial deposits. According to *Sukhyar* (2003), 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.

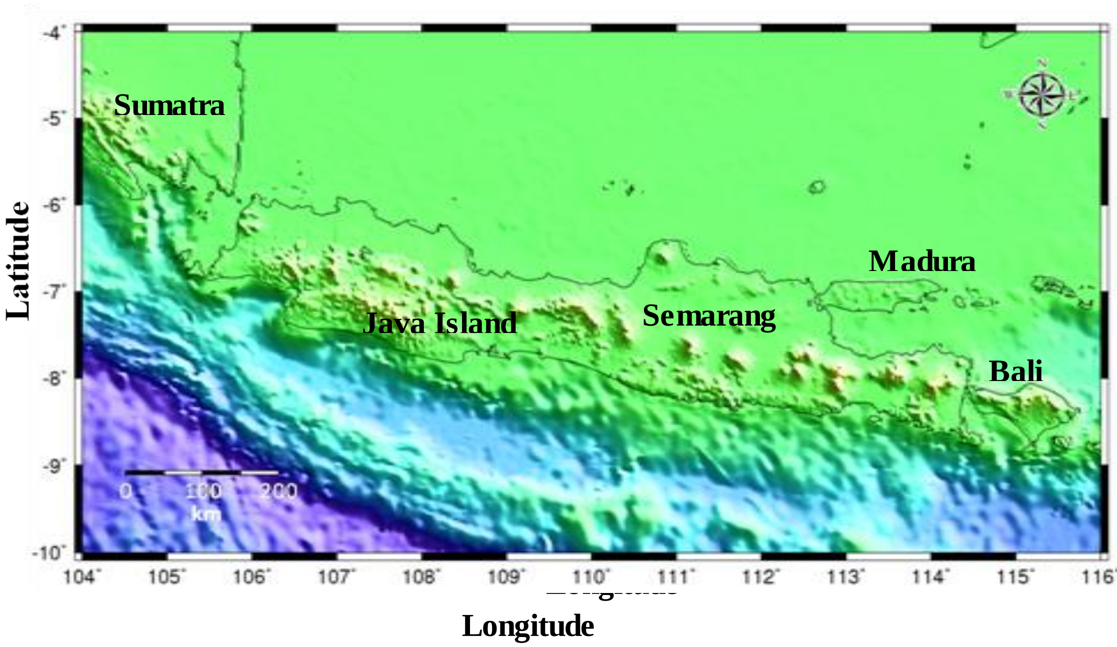


Figure 1. Geographical location of Semarang

Semarang is one of the largest cities in Indonesia and now experiencing the expansion of land subsidence caused by groundwater abstraction, natural consolidation of alluvial soil and construction loads (Marfai and King, 2007). Some areas that are experiencing enormous number of the subsidence in Semarang can be seen in Figure 2.

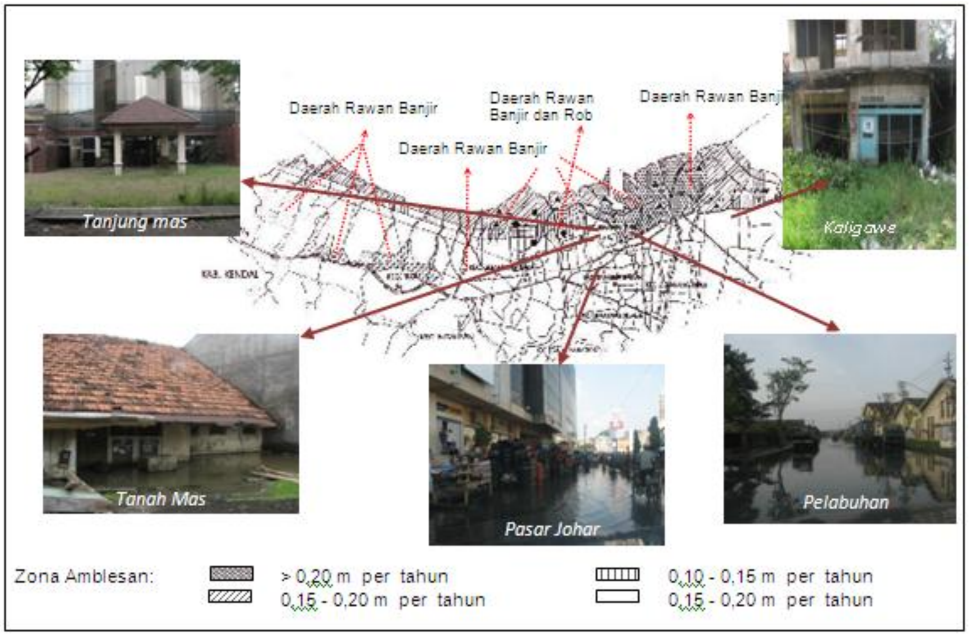


Figure 2. Maps of subsidence and flood prone land in Semarang (Bappeda Semarang (2002) in Arbriyakto dan Kardyanto (2002)), photos (Gumilar, 2009)

According to the Directorate of Environmental Geology and Mining Areas, Ministry of Energy and Mineral Resources, in 2001 the average rate of land subsidence in Genuksari and its surrounding areas are about 11.25 mm per year. Though, the average rate in Bangetayu region is higher, that is about 58.50 mm and the Pedurungan Tengah 88 mm per year. The most significance rate of land subsidence occurs in Bandarharjo with the average is about 171 mm per year. In the northern of Tanah Mas is about 128 mm, whilst in the southern part is about 130 mm per year. Due to some experts, the impact of the subsidence is the expanding of tidal flooding. In 2003, flooding area is about 1200 ha, along with the subsidence process estimation for next five years is more or less about 1346 ha (Bappeda, 2004). Besides flooding, subsidence which occurred in Semarang caused physical damage both buildings and infrastructure. Some physical evidence due to land subsidence in Semarang region can be seen in Figure 3.

Figure 3. Examples of subsidence impacts in Semarang

2. LAND SUBSIDENCE IN SEMARANG

Several methods have been conducted to monitor the subsidence in Semarang, including Levelling method, PS InSAR, and gravity methods. Based on levelling method by Centre of Enviromental Geology from 1999 to 2003, it determined that a significance rate of subsidence on near Semarang port, Hasanuddin cottage, Bandar Harjo, and near Tawang Station are between 1-17 cm / year (Tobing and Murdohardono , 2004; Murdohardono et al, 2007). The leveling data results showed land subsidence zone as shown in Figure 4a. Zoning is based on the change in height from 28 monitoring points. It should be noted that this zoning is the result of generalization (interpolation) of the data. Figure 3a shows the northern coast of Semarang has been decreasing about more than 8 cm / year. This area is dominated by swamp and soft clay.

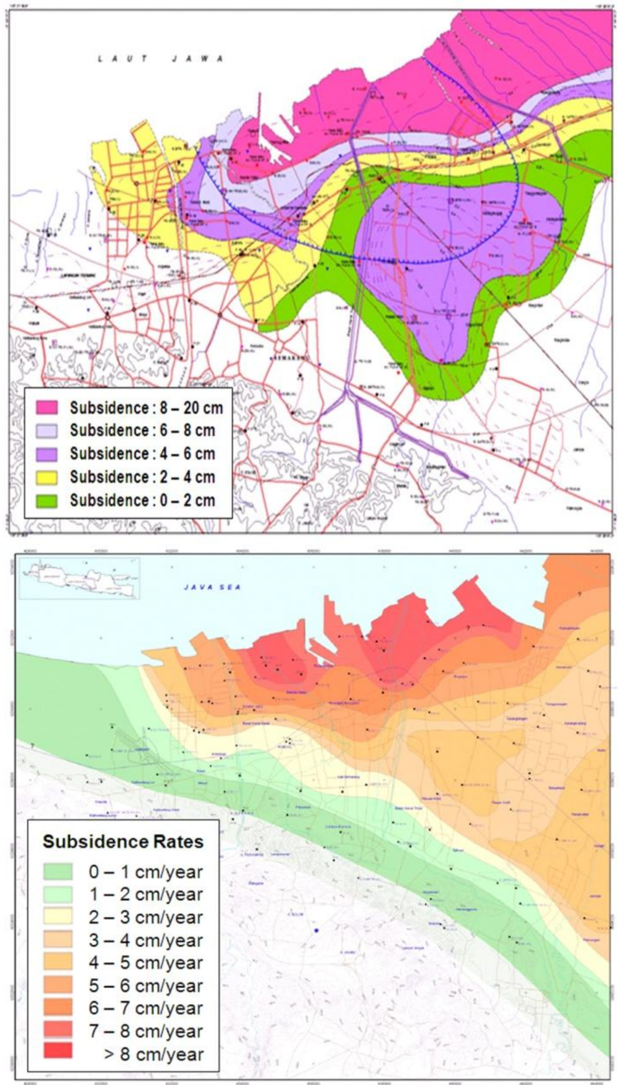


Figure 4. Subsidence in Semarang areas based on Levelling method ([*Murdahardono et al.*, 2007] (a) dan PS InSAR ([*Murdahardono et al.*, 2009) (b)

PS InSAR estimation of subsidence showed similar trends that northern area has decreased with rate number about more than 8 cm / year [Murdahardono et al., 2009, as shown in Figure 3b. Land subsidence in Semarang also has been carried out by the Department of Geophysics ITB using gravity time lapse methods (time lapse microgravity). Based on this method, in range time of September 2002-November 2005, maximum numbers of subsidences are 48 cm in the northern area of Semarang). These results are alignment with the maximum speed up to 15 cm / year (Supriyadi, 2008).

Since 2008, the Geodesy Research Group ITB began to study land subsidence in Semarang by using GPS surveys and InSAR methods. The GPS derived results are presented in the following section.

3. GPS-Derived Land Subsidence in Semarang

Global positioning system is a passive, all-weather, satellite-based navigation and positioning system, which is designed to provide precise three-dimensional position and velocity, as well as time information on a continuous worldwide basis (Wells et al. 1986, Abidin 2007, Hofmann-Wellenhof et al. 2007). Using the GPS survey method, several monuments were placed on the ground covering the city of Semarang and its surroundings, and accurately positioned relative to specific stable reference points. The precise coordinates of the monuments are periodically determined using repeated GPS surveys at certain time intervals. By studying the characteristics and rate of change in the height components of the coordinates from survey to survey, the land subsidence characteristics can be derived. For monitoring land subsidence, when the expected subsidence is of very small magnitude, the ideal positioning accuracy to be achieved is at the mm level. In order to achieve this level of accuracy, the GPS static survey method based on dual-frequency carrier phase data processing should be implemented, with stringent measurement and data processing strategies (Leick 2004, Abidin et al. 2012).

The principle of land subsidence monitoring with GPS is to determine the coordinates of some points on the periodically selected locations with conducted intervals time using GPS survey methods. The soil characteristics and the number of land subsidence will be known by studying the pattern and speed of change in ellipsoid height's points from one survey to another survey,

GPS survey for monitoring land subsidence in Semarang has been conducted on July 7 to 13, 2008, June 5 to 11, 2009, July 21 to 24, 2010, and June 21 to 26, 2011. The number of measured points can be seen in Figure 5. SMG1 point is a reference point located in the south of Semarang which assumed stable.

The data were processed using the software Bernese 5.0 [*Beutler et al.,* 2007]. Since we are mostly interested in the relative heights with respect to a stable point, the radial processing mode was used instead of a network adjustment mode. In this case, the relative ellipsoidal heights of all stations are determined relative to SMG1 station. For data processing, a precise ephemeris was used instead of the broadcast ephemeris. The effects of tropospheric and ionospheric biases are mainly reduced by the differencing process and the use of dual-frequency observations. The residual tropospheric bias parameters for individual stations are estimated to further reduce the tropospheric effects. The algorithms for the tropospheric parameter estimation can be found in *Beutler et al.* (2007). In processing baselines, most of the cycle ambiguities of the phase observations were successfully resolved (Abidin et al., 2012).

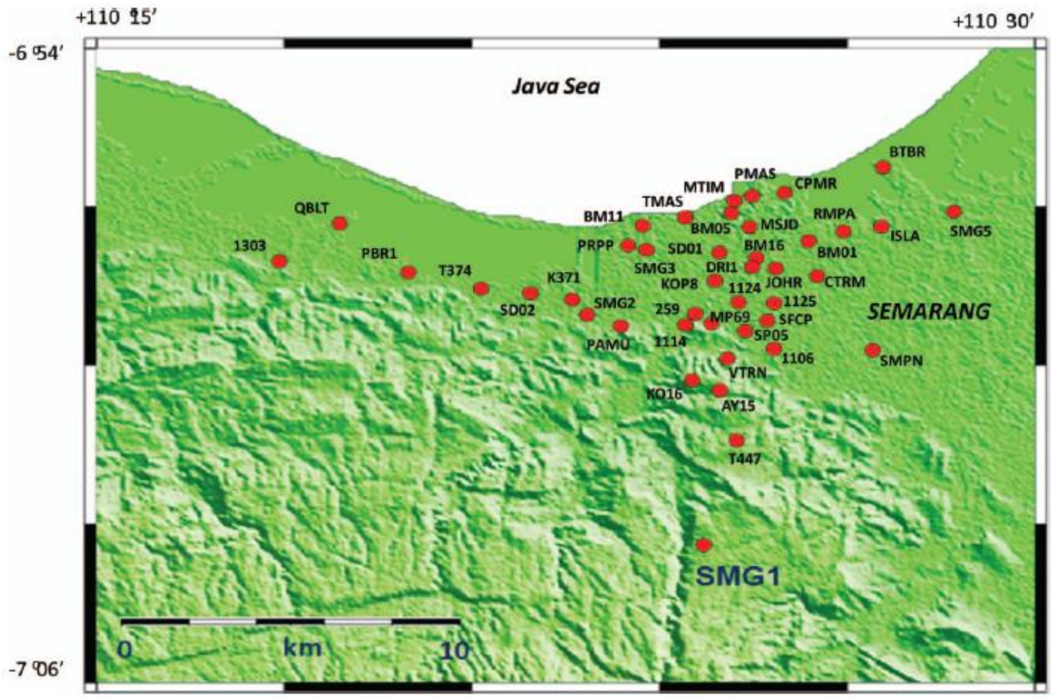


Figure 5. Distribution of GPS observation points for observing land subsidence in Semarang areas

Land subsidence, rate of land subsidence per year , and its standard deviation in the period 2008-2010 in the area of Semarang can be seen in Table 1. Land subsidence and its zoning map in Semarang from 2008-2011 can be seen in Figure 6.

Table 1. GPS-derived subsidence results in Semarang, based on GPS surveys (2008–2011)

POINT	2008-2009				2009-2010				2010-2011			
	□dh12 (cm)	□(□dh12) (mm)	□□dh12 (cm/year)	□(□□dh12) (mm)	□dh12 (cm)	□(□dh12) (mm)	□□dh12 (cm/year	□(□□dh12) (mm)	□dh12 (cm)	□(□dh12) (mm)	□□dh12 (cm/year)	□(□□dh12) (mm)
259	-1	0.1	-1.1	0.1	-1.6	0.1	-1.5	0.1	-2.9	0.1	-2.9	0.1
1106	-6.2	0.2	-6.8	0.2	-2.2	0.2	-2.0	0.2	-2.7	0.1	-2.7	0.1
1114	-4.8	0.2	-5.3	0.2	-0.4	0.2	-0.4	0.2	-0.6	0.1	-0.6	0.1
1124	-3.4	0.2	-3.7	0.2	-5.2	0.2	-4.8	0.2	-8.5	0.1	-8.5	0.1
1125	-4.1	0.1	-4.5	0.1	-5.6	0.1	-5.1	0.1	-4.0	0.1	-4.0	0.1
1303	-0.8	0.1	-0.8	0.1	0.0	0.1	0.0	0.1	-1.1	0.1	-1.1	0.1
AY15	-2	0.1	-2.2	0.1	-1.0	0.1	-0.9	0.1	-1.1	0.1	-1.1	0.1
BM01	-12.4	0.2	-13.5	0.2	-10.5	0.2	-9.6	0.2	-10.5	0.1	-10.5	0.1
BM05	-4.5	0.6	-4.9	0.6	-7.7	0.1	-7.0	0.1	-5.4	0.1	-5.4	0.1
BM11	-3.5	0.1	-3.8	0.1	-10.7	0.1	-9.8	0.1	-3.3	0.1	-3.3	0.1
BM16	-9.4	0.2	-10.3	0.2	-3.5	0.2	-3.2	0.2	-3.5	0.1	-3.5	0.1
BM30	-1.5	0.2	-1.6	0.2	-0.1	0.2	0.0	0.2				
BTBR	-8	0.1	-8.8	0.1	-8.8	0.1	-8.1	0.1	-8.6	0.1	-8.6	0.1
CTRM	-6.1	0.1	-6.7	0.1	-20.4	0.1	-18.7	0.1	-7.0	0.1	-7.0	0.1
ISLA	-11.3	0.1	-12.3	0.1	-10.6	0.1	-9.7	0.1	-5.8	0.1	-5.8	0.1
JOHR	-4.4	0.1	-4.9	0.1	-19.3	0.1	-17.7	0.1	-8.7	0.1	-8.7	0.1
K371	-3	0.3	-3.3	0.3	0.0	0.3	0.0	0.3	0.0	0.2	0.0	0.2
KO16	-1.8	0.2	-2	0.2	-0.9	0.2	-0.8	0.2	0.0	0.1	0.0	0.1
MP69	-4.7	0.2	-5.1	0.2	-1.8	0.2	-1.7	0.2	-0.5	0.1	-0.5	0.1
MSJD	-7.9	0.1	-8.7	0.1	-8.1	0.1	-7.4	0.1	-5.8	0.1	-5.8	0.1
MTIM	-8.6	0.1	-9.4	0.1	-10.5	0.1	-9.7	0.1	-5.9	0.1	-5.9	0.1
PMAS	-4.9	0.1	-5.3	0.1	-12.4	0.1	-11.4	0.1	-7.7	0.1	-7.7	0.1
PRPP	-8.3	0.1	-9.1	0.1	-15.0	0.1	-13.8	0.1	-10.3	0.0	-10.3	0.0
SD01	-7.3	0.2	-8	0.2	-5.8	0.1	-5.3	0.1	-7.8	0.1	-7.8	0.1
SD02	-3.9	0.1	-4.2	0.1	0.7	0.1	0.7	0.1	0.0	0.1	0.0	0.1

Table 1. GPS-derived subsidence results in Semarang, based on GPS surveys (2008–2011) **(continued)**

SFCP	-3.6	0.1	-3.9	0.1	-7.5	0.1	-6.8	0.1	-3.7	0.1	-3.7	0.1
SMG2	-1.2	0.1	-1.3	0.1	0.9	0.1	0.8	0.1	-8.0	0.1	-8.0	0.1
SMG3	-10.1	0.1	-11	0.1	-10.8	0.1	-9.9	0.1	-9.9	0.1	-9.9	0.1
SMG5	-5.2	0.1	-5.7	0.1	-14.8	0.1	-13.6	0.1	-8.8	0.1	-8.8	0.1
SMPN	-4.8	0.1	-5.3	0.1	-8.7	0.1	-7.9	0.1	-5.1	0.1	-5.1	0.1
SP05	-10.4	0.3	-11.3	0.3	-6.1	0.2	-5.6	0.2	-4.8	0.1	-4.8	0.1
T447	-2.8	0.1	-3	0.2	-0.9	0.1	-0.8	0.1	0.0	0.1	0.0	0.1
VTRN	-6.2	0.2	-6.8	0.2	-0.9	0.1	-0.9	0.1	-0.3	0.1	-0.3	0.1
SMKN					-9.0	0.1	-8.2	0.1				
T374					0.2	0.1	0.2	0.1	0.0	0.1	0.0	0.1
CPMR					-9.3	0.0	-8.5	0.0	-3.5	0.1	-3.5	0.1
RMPA					-11.0	0.1	-10.1	0.1	-9.8	0.1	-9.8	0.1
DRI1					-4.9	0.0	-4.5	0.0	-5.3	0.0	-5.3	0.0
K370					-12.7	0.1	-11.6	0.1	-8.2	0.1	-8.2	0.1
KOP8					-7.7	0.1	-7.0	0.1	-10.7	0.1	-10.7	0.1
PAMU					-0.7	0.1	-0.7	0.1	0.0	0.1	0.0	0.1
PBR1					-0.1	0.6	-0.1	0.6	-2.6	0.9	-2.6	0.9
QBLT					-1.5	0.0	-1.4	0.0	-3.4	0.1	-3.4	0.1

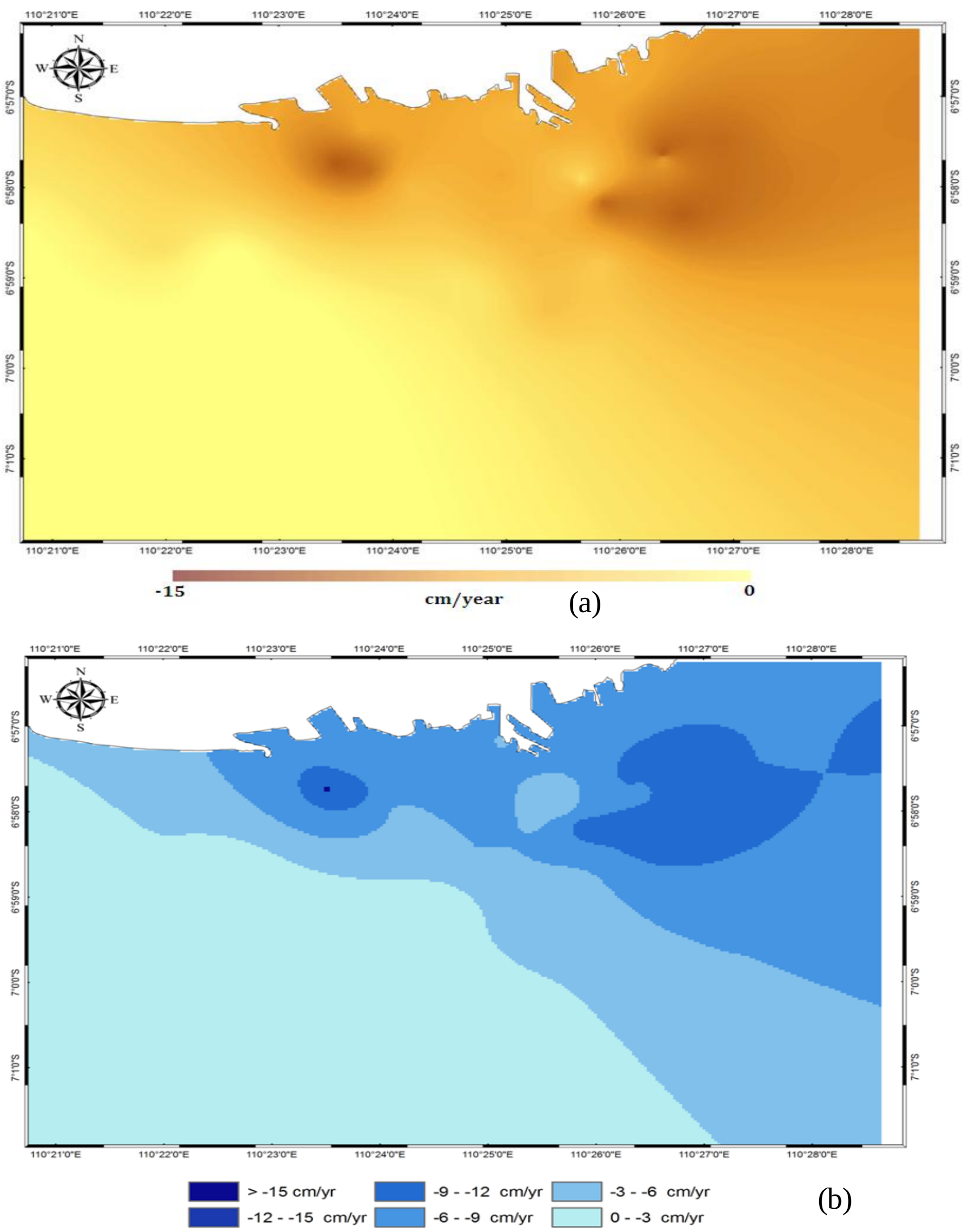


Figure 6. GPS derived subsidence rates in Semarang in the periods of 2008–2011 (a) and its zoning (b)

The result above conveyed that northern Semarang (port, Pasar Johar, Tanjung Mas, Tawang Station,) as well as eastern Semarang (Kaligawe area) has a significance subsidence rate with an average of 6-7 cm per year.

4. THE IMPACT OF LAND SUBSIDENCE IN SEMARANG

As explained earlier, any land subsidence is one of the disasters that cause substantial economic losses through damage to buildings and infrastructure (bridges, pipes, etc.), and tidal flooding *(rob)* in coastal areas (coastal zone), and would lead to reduced quality of life and environmental (sanitary and health conditions). In addition to direct impacts (direct losses), land subsidence also caused economic losses (indirect losses) such as reduced of income, loss of livelihood, business interuption, and declining economic growth.

Semarang's coastal area people which get effects from land subsidence due tidal flooding quickly adapted and have adjustment the building, for instance elevating homes, raised the level of the house or yard, even making a small dam to block the water. Sea water which creep into the ground can cause damage to the foundation, floors, walls, and also the frames (Marfai and King, 2007). Not to mention buildings that almost drowned (under way), damaged bridges, damage pipelines, and other infrastructure.

Field survey has been conducted in order to identify losses due to land subsidence in Semarang. Distribution of the survey and identified damage can be seen in Figure 7.

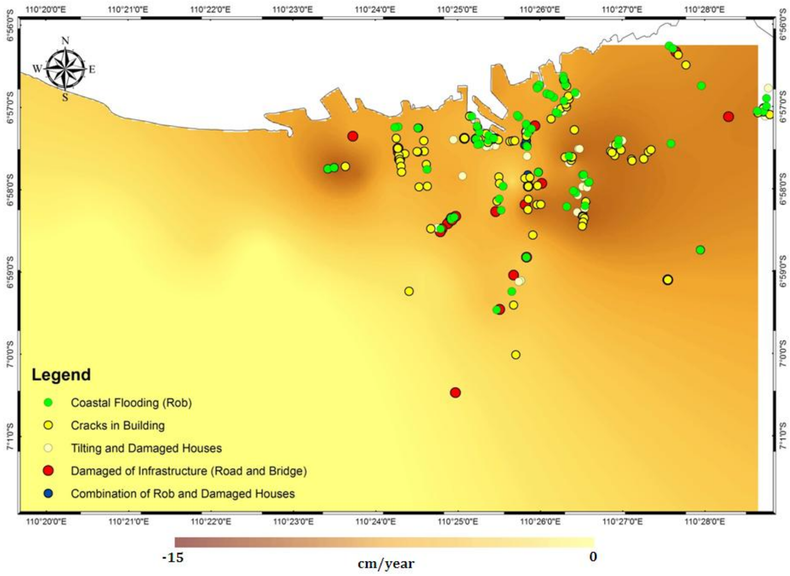
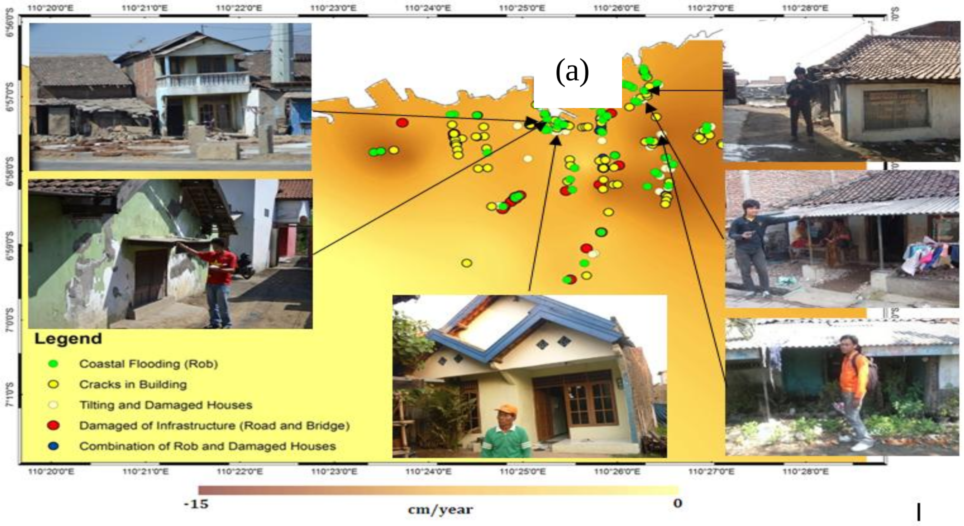


Figure 7. Mapping of land subsidence impact in Semarang

In the impact of land subsidence in Semarang mapping, it showed the northern region experienced a lot of damage sort of damage houses or tilted (Figure 8a) , the amount of cracks in buildings and infrastructure (Figure 8b and 8c), as well as the wider expansion of *rob* which had entered the central region of Semarang (Figure 8d). Cracking on the building and road occurs in the boundary of large subsidence area and the less.



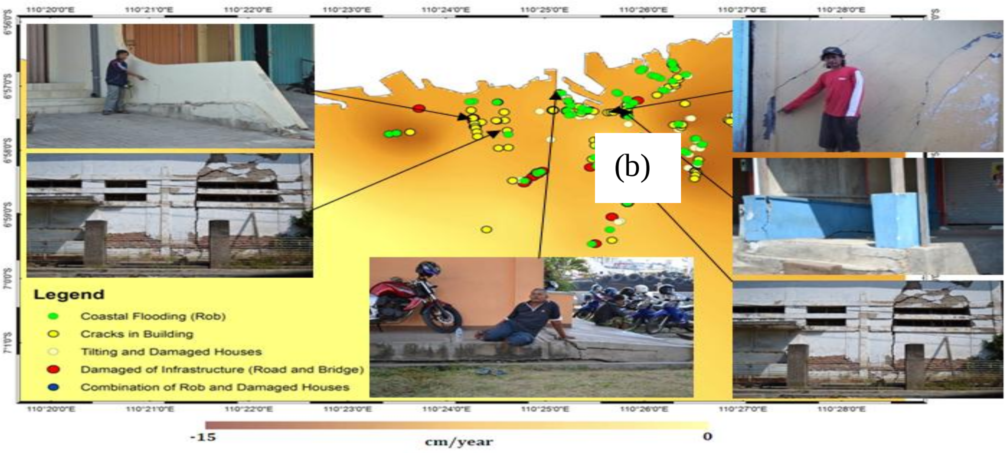


Figure 8. Impact of land subsidence on tilting and damaged houses (a), cracks in building (b), damaged on infrastructure, and *rob* (d)

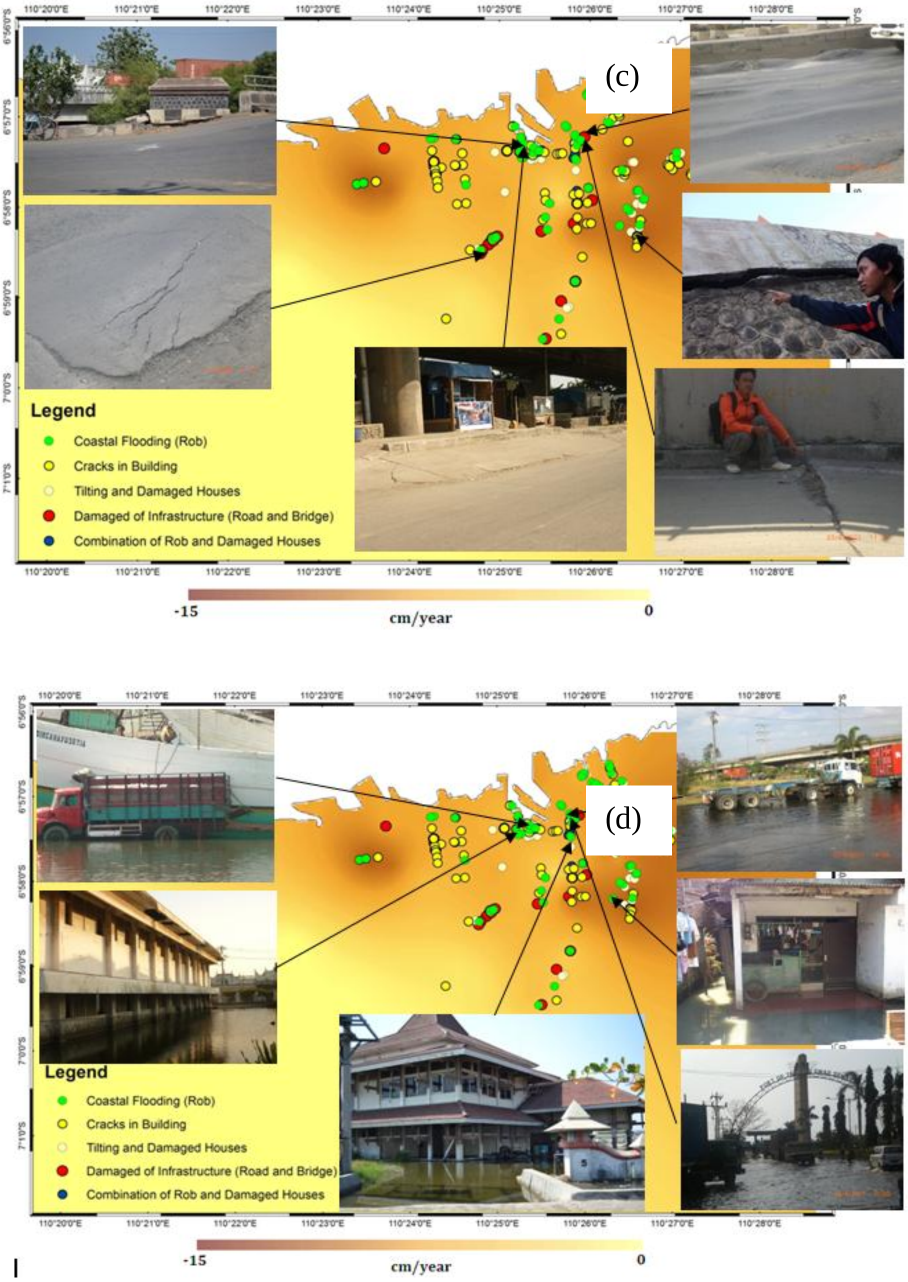


Figure 8. Impact of land subsidence on tilting and damaged houses (a), cracks in building (b), damaged on infrastructure, and *rob* (d) (continued)

Land subsidence in Semarang is believed to be caused the combination of natural consolidation of young alluvium soil, load of buildings and structure, and groundwater abstraction. The last factor expected to be main caused land subsidence in Indonesia's big cities (Jakarta, Bandung and Semarang) or in countries in the world such as Tokyo, Osaka, Bangkok, and Manila.

Excessive groundwater pumping in Semarang causes steadily increased of subsidence to the present, with the development of housing and industry. Utilization of groundwater in (mid aquifer and The Deep aquifer) which is pumped enormously than the recharge will lead to a reduction in the volume of groundwater, which in turn would affect the decrease in groundwater table (MAT). The loss process of pore water pressure due to pumping that increased the pressure on the clay layer as akuitard or aquifer compaction. This is the reason behind land subsidence in Semarang. The number of drilled wells and taking groundwater continues to increase; in year 1990 - 1997 there was a significant increase, and the years 1997 - 2000 the rate of increase is reduced and increased again in 2000 to the present.

In some drilled wells, there is a positive correlation between the decrease in groundwater level and land subsidence in some areas in Semarang (Table 2) .

Tabel 2. Rate of groundwater table level and subsidence in some areas in Semarang

Point	X (meter)	Y (meter)	VMAT (m/year)	point	Subsidence rate (2008-2011) m/year)	Distance between well and GPS point (m)
Well 1	436423	9228486	-0,294	1124	-5,7	372,3681
Well 3	426635	9228354	-0,128	PBR1	-1,3	1135,713
Well 4	433921	9229898	-0,493	SMKN	-9	64,60713
Well 5	427074	9227750	-0,208	PBR1	-1,3	1852,161
Well 8	438275	9227444	-0,416	1106	-3,7	1350,779
Well 12	432447	9229692	-0,597	K370	-10,4	383,7356
Well 13	424254	9231113	-0,26	QBLT	-2,4	65,79514
Well 14	436768	9231961	-0,703	PMAS	-8,3	355,5348
Well 15	439824	9230794	-0,894	ISLA	-9,2	511,809
Well 17	433818	9229492	-0,648	SMKN	-9	470,5422

5. CLOSING REMARK

Land subsidence in Semarang still occurs, especially in the northern region of Semarang. In the length of 2008-2009 speed of subsidence reached 13 cm / year, then increased in 2009-2010 to 19 cm / year and dropped back to 11 cm / year in 2010-1011. Areas that suffered severe damage due to subsidence are the northern and eastern regions Tanah Mas, ports, Kaligawe, Raden Patah, Citarum, Genuk etc.. Interesting point is that western region did not experience a significant subsidence. Various potential damage caused economic loss is cracking (cracking) on buildings and infrastructure (roads and bridges), damaged and tilting houses. In addition to direct losses, subsidence also causes indirect lose which is the increase of *rob* widespread in the northern region of Semarang.

Related with subsidence causes in Semarang; in needs to be studied more about the contribution of causes include: excessive taking of groundwater, load of building and structure in coastal areas, and natural compaction. The data showed that the number of wells and groundwater in Semarang increase more and more. In 1900 there are only 16 wells and continue to increase to 1050 wells in 2000, as well as the taking of groundwater increased from 0.4 million m3 in 1900 to 38 million m3 in 2000. In some areas, there is positive correlation between decrease of groundwater table and land subsidence.

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