Insight look the subsidence impact to infrastructures in Jakarta and Semarang area; Key for adaptation and mitigation

Heri Andreas[1,*], *Hasanuddin* Zainal Abidin[1], *Dhota* Pradipta[1], *Dina* Anggreni Sarsito[1]and *Irwan* Gumilar[1]

[1]Geodesy Research Division, Faculty of Earth Science and Technology, Institute of Technology Bandung, Indonesia

Abstract. Land subsidence is not a new phenomenon for Jakarta and Semarang areas. According to some publications, the value of Jakarta's subsidence may reach 2-4 meter in certain place. Meanwhile, more than 2 meter of subsidence is taking place in northern part of Semarang. Some techniques are being used to derive land subsidence information in these areas such as repeated leveling measurements, GPS surveys, and InSAR measurements. The impact of land subsidence in Jakarta and Semarang could be seen in several ways, such as sea inundation ("Rob" in Javanese), problem on infrastructures, the wider expansion of flooding areas, etc. Cracking on housing, street, "sinking" on the bridges and dyke, problems on drainage are examples of infrastructures problems due to the land subsidence. Huge costs have already been spent to fixing those infrastructures problems both in Jakarta and Semarang. Since mostly liniear pattern of land subsidence are recognized in both area today and probably in the next years to come, in this case the impact especially on infrastructures are probably will getting worse. Insight look the subsidence impact to the infrastuctures in Jakarta and Semarang area would raisen the concern, and become key for adaptation and mitigation.

1 Introduction

Jakarta is the capital city of Indonesia, inhabiting an area of about 662 km^2 on Java Island with a population of about 12 million people (fig.1). Geographically Jakarta located at 6^0 10' South Latitude and 106^0 49' East Longitude. Geologically Jakarta is a low land flood basin area with ticked sediment to about 400 meter depth. In the last four decades, urban development of Jakarta has grown very rapidly in the sectors of industry, trade, transportation, housing, and many others. In accordingly land subsidence is quite well known phenomenon for Jakarta. The occurrence of land subsidence was recognized at least in the early the development of the city. The evidence for subsidence was based on repeated leveling measurements, GPS (Global Positioning System) surveys, InSAR (Interferometric Synthetic Aperture Radar) measurements, extensometer, etc. According to some publications [1-4] the yearly value of Jakarta's subsidence generally ranging from 1 to10 centimeter per-year and may reach 20-26 centimeter in certain place, especially in northern part of Jakarta for the recent years.

Semarang is the capital city of Central Java province, located in the northern coast of Java island, Indonesia (fig.1). It is centered at the coordinates of about 6º 58' South Latitude and 110º 25' East Longitude, and covers an area of about 37,367 hectares or 374 km2, with the population of about 1.55 million people in 2010. Topographically, Semarang consists of two major landscapes, namely lowlands and coastal areas in the north and hilly regions in the south. Geologically, Semarang has three main lithologies, namely, volcanic rock, sedimentary rock, and quite ticked alluvial deposits. Land subsidence is also quite well known phenomenon for Semarang. Increases in the population and urban development in the area have accelerated land subsidence through excessive groundwater extraction, and load from buildings and structures. Based on the leveling surveys conducted by the Centre of Environmental Geology from 1999 to 2003 it was found that relatively large subsidence was detected around Semarang Harbor, Pondok Hasanuddin, Bandar Harjo and around Semarang Tawang Railway station, with the rates ranging from 1 to 17 cm/year. Results derived from GPS show that land subsidence in Semarang has spatial and temporal variations. In general, subsidence rates in Semarang have an average rate of about 6 to 7 cm/year, with maximum rates that can go up to 14-19 cm/year at certain locations. The estimation based on the PS (Permanent Scattered) InSAR technique also revealed that the areas close to the shoreline have subsidence rates of more than 8 cm/year [5]. The result is based on the PS InSAR based velocity data derived from 28 ERS-2 and ENVISAT-ASAR radar scenes recorded between 27 November 2002 and 23 August 2006. In another study [6], after processing 22 ascending ALOS-SAR images during January 2007 to January 2009 plus 2 descending SAR images acquired on 6 June 2006 and 17 June 2007, it found maximum subsidence rates of about 8 cm/year in the northern region of Semarang. They are high magnitude of subsidence rate. Surprisingly for the recent

* Corresponding author: heri@gd.itb.ac.id

years it reported that the trend of subsidence is acceleration of instead of linier trend in the nortern eastern area of Semarang City. The area is coinsize with factory areas.

Fig. 1. Geographically location of Jakarta and Semarang city in the Island of Java Indonesia

The impact of land subsidence in Jakarta and Semarang can be seen in several forms, such as sea inundation ("Rob" in Javanese), problem on infrastructures, the wider expansion of flooding areas, etc. Cracking on the housing, building, street, "sinking" on the bridges and dyke, problem on the drainage are examples of infrastructures problem due to the land subsidence. The subsidence it also badly influences the quality and amenity of the living environment and life (e.g. health and sanitation condition) in the affected areas. The economic losses caused by land subsidence in Jakarta and Semarang are enormous; since many buildings and infrastructure severely affected by land subsidence and its collateral coastal flooding disasters are located in the dense housing, industrial zone, and vital infrastructures.

Since mostly liniear pattern of land subsidence are recognized with quite significant rate per year in both area today and probably in the next years to come, in this case the impact especially on infrastructures are probably will getting worse a head too. Certainly, it would lead to more disaster and costs in the near future and absolutely need to be concern. Insight look the subsidence impact to the infrastuctures in Jakarta and Semarang area would raisen the concern, and it is also become key for adaptation and mitigation.

2 Methods

The places with the largest subsidence value, and the boundary condition between the largest and the less (location of differential subsidence), the depth variation on pile foundation, either in Jakarta or Semarang city is prone to the impacts. Cracking on the housing, building, street, "sinking" on the bridges and dyke, problem on the drainage, etc. likely can be seen in these areas. In this case, as a method, investigating the impact to infrastructures in both areas would be focused within these areas. Figure 2 shows map of land subsidence in Jakarta where we can see the largest magnitude to the smallest subsidence in the area over periode 1925 to 1915, while figure 3 shows map of land subsidence for Semarang area for around 8 years measurement (2008-2016). Table 1 and 2 notes the rate and the magnitude of land subsidence each in Jakarta and Semarang area, to give the illustration how large and how fast the subsidence exists. The value of Jakarta's subsidence reached 2-4 meter in certain place from 1925 to 2015, while around 1 meter is taking place in northern part of Semarang from 2008 to 2016. Both of these subsidence will probaly continuing in the quite some times.

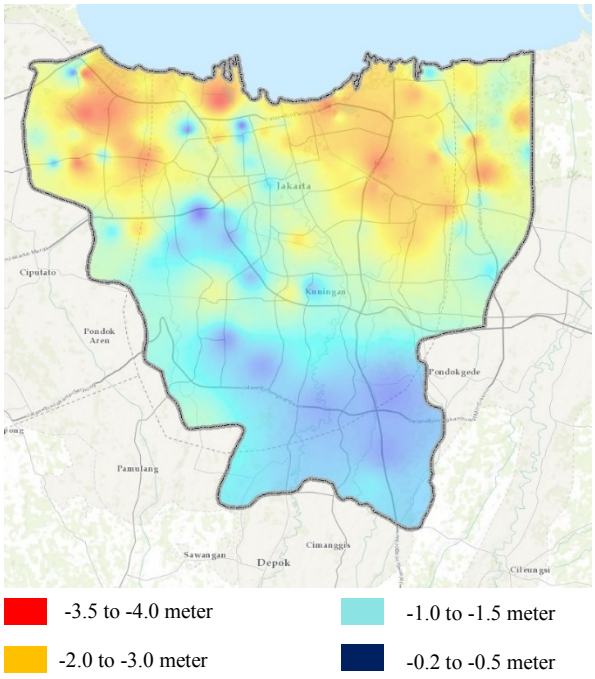

Fig. 2. Map of land subsidence in Jakarta from 1925 to 2015 base on integration of leveling measurements data, GPS surveys, and InSAR.

Table 1. Summary of rate and magnitude of land subsidence in Jakarta area.

No	Segment	Avg. Rate from 1925-1975 (m/years)	Avg. Rate from 1975-2015 (m/years)	Max. Magnitude 1925-2015 (meter)
1	Northern Part	-0.003	-0.10	-4.75
2	Western Part	-0.003	-0.08	-4.36
3	Eastern Part	-0.003	-0.07	-3.12
4	Central Part	-0.002	-0.02	-0.98
5	Southern part	-0.001	-0.01	-0.58

Table 2. Summary of rate and magnitude of land subsidence in Semarang area

No	Segment	Avg. Rate from 2008-2016 (m/years)	Max. Magnitude 2008-2016 (meter)
1	Northern Part	-0.10	-1.00
2	Western Part	-0.05	-0.45

No	Segment	Avg. Rate from 2008-2016 (m/years)	Max. Magnitude 2008-2016 (meter)
3	Eastern Part	-0.06	-0.48
4	Southern Part	-0.01	-0.10

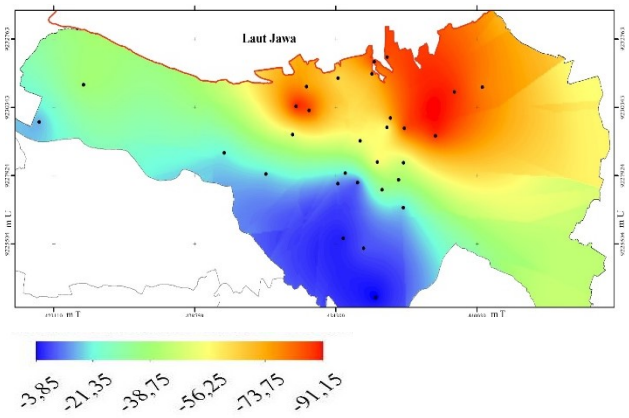

Fig. 3. GPS derived subsidence in Semarang in the periods of 8 year measurement (2008-2016) in centimeter

Since both Jakarta and Semarang area located in the coastal area, in this case chance of inundated infrastructures is big. So, as another method, investigating the impact to infrastructures in Jakarta and Semarang would be focused also within these areas. The inundation comes from the impact of land sinking due subsidence and the sea level rise. Result from satellite altimetry and the tide gauge observations shows the sea level rise at the Java Sea (including north of Jakarta bay and Semarang bay) is around 6 to 10 millimeter per years [7]

3 Results

Below we can see the result from insight look the subsidence impact to infrastructures in Jakarta and Semarang area. We divided the result into several sub chapter each explain about insight look of inundated infrastructures, cracks on building and houses, insight look on the bridges and drainage, on the roads, on dykes, and insight look on the others affected infrastructures. These all results can become important keys for adaptation and mitigation [8]

3.1 Insight looks the inundated infrastructures

Areas at northern part of Jakarta such as Kamal Muara, Pantai Indah Kapuk, Muara Angke, Muara Karang, Muara Baru, Ancol, Tanjung Priok and Marunda are prone to sea inundation or “Rob”. On the high tide some area can be flooded up to one meter. Some places even now have permanently inundated. In northern of Semarang, place likes Pantai Marina, Tanjung Mas, Tambak Loro, Kaligawe, etc., the “Rob” situation are even worse than Jakarta. The inundation is literally destroying the infrastructures. Slowly but sure the inundation it’s like a silent killer to the infrastructures.

Figure 4 shows pictures of inundated infrastructure in Jakarta, while figure 5 shows pictures in Semarang. Figure 6 shows abandon houses due to the most effect that already existed.

Fig. 4. Some pictures of inundated infrastructures in Jakarta (taken in year 2010). The inundation is slowly damaging the infrastructures if no action of adaptation or mitigation

Fig. 5. Some pictures of inundated infrastructures in Semarang (taken in year 2016). The inundation is slowly damaging the infrastructures if no action of adaptation or mitigation

Fig. 6. The silent killer has already given most of the effect. Some houses and buildings in Semarang have already been abandoned (pictures taken in year 2016)

3.2 Insight looks the cracks on buildings and houses

In the northern part of Jakarta and Semarang, especially around boundary area of the larger and the less subsidence value, and the shallow and the deep infrastructures where they meet, the cracks on building and housing are appearing. Figure 7 shows pictures of cracks on the building and houses in Jakarta, while figure 8 shows pictures in Semarang. Many have suffering and fixing the buildings and the houses due to the impact.

Fig. 7. Cracks on the buildings and houses around northern part of Jakarta (pictures taken in 2009). Many have suffering and fixing from the subsidence impact

Fig. 8. Cracks on the buildings and houses around northern part of Semarang (pictures taken in 2012). Many have suffering and fixing from the subsidence impact

3.3 Insight looks on bridges and drainage

In the first initiation, the bridge level is design around 1 to 1.5 meter or even more above the water level so the water would easily pass through and flowing. Nevertheless, the subsidence with rates for about 10-20 centimeter per year has made bridge is slowly "touching" the water. In the end, the flow will be disturbed, and even the water will pass the bridge's floor. Figure 9 shows the "sinking" bridge in Jakarta, while figure 10 shows similar situation in Semarang. Many have suffering and fixing the bridges due to the subsidence impact and the costs are quite expensive.

In Jakarta area at least there are ten bridges which in the near future might be slowly destroying by the water underneath. Even some of them will pass by the water regularly on the high tide. Two bridges are located in Kamal Muara, one in Muara Baru, several bridges around Ancol and Martadinata, several bridges located around Gunung Sahari. We have seen also bridges that newly elevated which are one located in Muara Angke, and one in Muara Karang. Base on the news, cost for elevated the bridges is around 1 million US dollar each. We can imagine if in the future more bridges need to be elevated, in this case many dollar should spent.

In Semarang area at least there are five bridges which in the near future might be slowly destroying by the water underneath. Even some of them are passed by the water permanently now (fig. 10). This situation is very danger for the people whom use the bridge, especially during the rainy season when the water level even

higher. Two bridges are located in Raden Patah, one in Tanjung Mas, several bridges around Kaligawe. We expected around five years from now the government should spend at least 5 million US dollar for fixing the bridges.

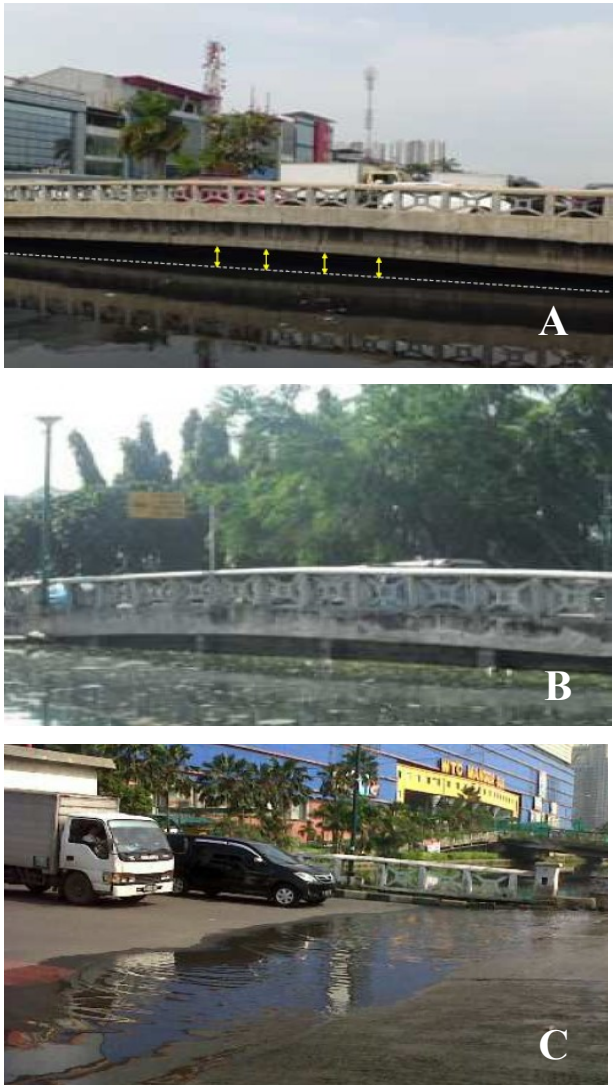

Fig. 9. Illustration of "sinking" bridge in Jakarta. Figure A, B, C shows the bridge is slowly touching the water, and finally the water can pass the bridge

Fig. 10. Illustration of "sinking" bridge in Semarang area. We can see the bridge is passed by the water. The bridge can be flooded even permanently.

Land subsidence can be disturbed the drainage system as well. Due to differential subsidence, water can stop flowing or reverse or even has to pump out to the higher level of others drainage or canal and river. Figure 11 shows pictures of dysfunction of drainage system in Jakarta and Semarang. The situation is problem for water management, it can be increase the flood potential, etc.

Fig. 11. Dysfunction of drainage system in Jakarta and Semarang. Water is stop flowing or reverse or even has to pump out to higher level of other drainage or canal and river

3.4 Insight looks on roads

Due to the impact from subsidence, many roads have been damage both in Jakarta and Semarang. The differential subsidence might wrinkle the flatter of the road. Figure 12 shows picture of wrinkle road in Jakarta and Semarang. The roads maybe also destroy by heavy weight from the load, and frequently inundated by the water. Many have suffering and fixing the road in Jakarta and Semarang due to the subsidence impact. Some even need to elevate for even a meters thickness to avoid flooding. The costs are remarkably expensive. These situations will continue if the subsidence is continuing through times.

In Jakarta area at least we identify more than 20 kilometer of road are suffering the impact from subsidence, while in Semarang area also more than 20 kilometer as well. Both mostly located near the coastal area. Base on the news, cost for fixing the road is around 1 million US dollar for ten kilometer. We can calculate the length of road need to be repair and how many dollars should spend.

Fig. 12. Impact of subsidence to the road in Jakarta and Semarang. The road is wrinkling and damaging. Many have suffering and fixing. The costs are remarkably expensive.

3.5 Insight looks on dykes

Dykes are supposed to be protecting the land from "Rob", but they are sinking. Figure 13 shows picture of 1 meter of dyke which was failed to protect Jakarta from "Rob" in 2007, and after raised 1 meter more in 2008, it is slowly sinking and about to failed again to protect Jakarta after 2013. For the recent years indeed it has been elevated again for more than 1 meter. Figure 14 shows situation in Semarang where dyke is failed to protect the land from inundation. So, there are interesting fact that dyke is considered not a final solution for subsidence mitigation.

Fig. 13. Illustration of dyke "sinking" in northern part of Jakarta. In 2007, around 1 meter of dyke failed to protect the land, while 2008 another 1 meter elevated dyke would soon after 2013 would probably failed again.

Fig. 14. Situations where "sinking" dykes failed to protect northern area of Semarang from inundation or "Rob"

In table 3 below, we try to calculate the sinking dyke around Jakarta and Semarang. We can see the rate and the future magnitude of sinking within 10 to 20 years. In this case, we can see the longevity of dyke protection in both areas. For the information, Jakarta now has a "giant sea wall" program on protecting the city from the subsidence and inundation. But, if the sea wall is subsiding and sinking, then how effective the program is an important question to be answered.

Table 3. Rate and future magnitude of dykes sinking in Jakarta and Semarang

No	Segment	Rate Sinking (m/years)	Magnitude after 10 year (meter)	Magnitude after 20 year (meter)
1	Pantai Mutiara Jakarta	0.10	1.0	2.0
2	Muara Baru Jakarta	0.12	1.2	2.4
3	Ancol Jakarta	0.05	0.5	1.0
4	Tanjung Mas Semarang	0.08	0.8	1.6
5	Tambak Loro Semarang	0.10	1.0	2.0
6	Kaligawe Semarang	0.12	1.2	2.4

3.6 Insight looks on others affected infrastructures

There are still many infrastructures type that can be impacted or affected by the subsidence instead of some that have already explained above. The piping for instance can be impacted by the subsidence, and even the breakwater that is supposed to protect beach from abrasion can be also impacted. Figure 15 shows Google and pictures of sinking breakwaters in Pantai Ancol north of Jakarta. In 2004 around 1 meter height of breakwaters are manage to protect the beach from abrasion, while in 2010 and recent years the breakwaters are drowning to the sea.

Fig. 15. The sinking of breakwater in Pantai Ancol Jakarta. In 2004 around 1 meter height of breakwaters manage to protect the beach from abrasion, while in 2010 and the recent years they are suffering drowning to the sea.

3.7 Map of the impacts

We have plotted on map many of the impacts of the land subsidence to the infrastructures in Jakarta and Semarang (see figure 16 and 17). We can see that areas at northern part of Jakarta such as Kamal Muara, Pantai Indah Kapuk, Muara Angke, Muara Baru, Ancol, etc. are prone to the impacts, while area in northern of Semarang, place likes Tanjung Mas, Kaligawe, etc., are experiencing the same situation.

As mentioned earlier in Jakarta at least there are ten bridges which are affected by the subsidence, more than 20 kilometer of roads are suffering the impact from subsidence. We surveyed all around northern part of Jakarta each in 2009 and in 2012, and we found more than five hundreds houses are suffering cracks due to subsidence impacts. We found more than 200 hectare areas are suffering tidal inundation even there are already dykes. If dyke is not established, it surely more hectares would be suffering.

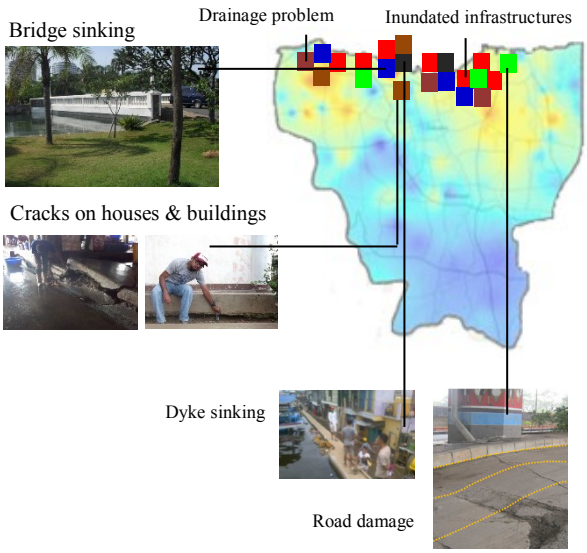

Fig. 16. Map plotted the impacts of land subsidence to the infrastructures in Jakarta area

Also mentioned earlier in Semarang at least there are five bridges which are affected by the subsidence, more than 20 kilometer of roads are suffering the impact from subsidence. We surveyed all around northern part of Semarang area each in 2009 and in 2016, and we found more than five hundreds houses are suffering cracks due to subsidence impacts. We also found many houses are being elevated in every five year for about 1 meter to avoid inundation. We found more than 800 hectare areas are suffering tidal inundation so far.

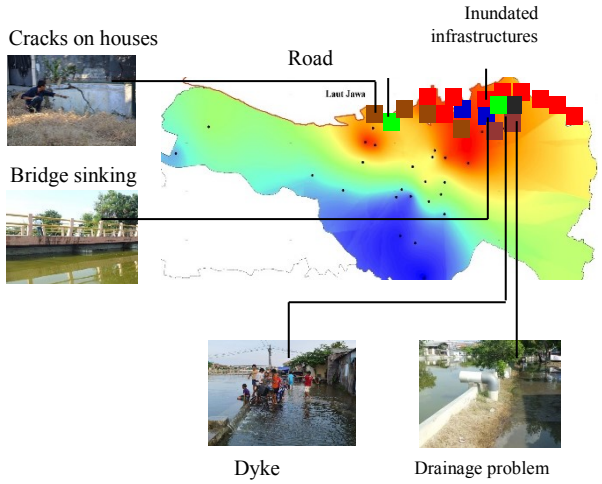

Fig. 17. Map plotted the impacts of land subsidence to the infrastructures in Semarang area

4 Discussions

From insight look the subsidence impact to infrastructures in Jakarta and Semarang area, we considered the impact is already a disaster. Some adaptation and mitigation have been carried out (e.g. build the dyke, fixing the infrastructures, etc), but it seem still not quite sufficient. We can see clear example

from the dyke sinking and failed to protect land from inundation. This situation is because land subsidence in still continuing in to the future. Indeed on figure 18 we can see the linier trend of land subsidence in Jakarta and Semarang for recent years and most probably for sometimes in the future. Considered strongly we need to stop the land subsidence in both areas for best mitigation.

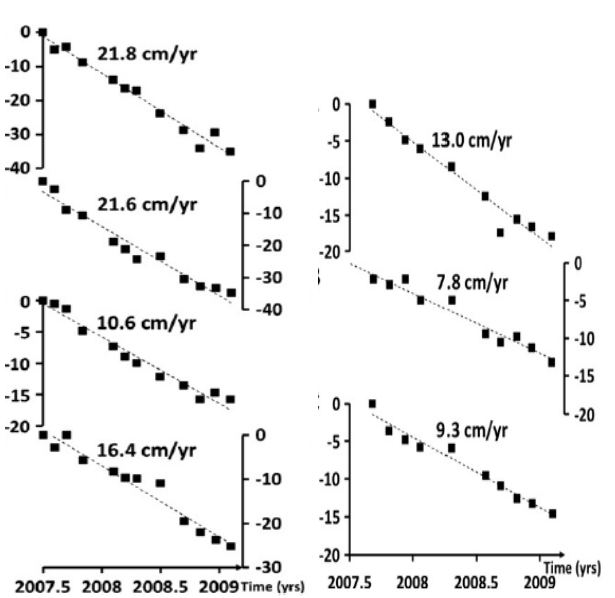

Fig. 18. Linier trend of land subsidence in Jakarta and Semarang areas which are probably still continuing for the future

If only we built the dykes and fixing the infrastructures, with the fact of linier trend of subsidence, in this case we always wait for silent disaster to slowly returned given a disaster. There are several example on others city around the world who manage to stop the land subsidence (e.g. Tokyo and Osaka Japan, Venice Italy, San Joaquin USA, etc.). By stopping the groundwater abstraction, mostly the land subsidence is stopped. Nevertheless stopping groundwater abstraction in Jakarta and Semarang is stillJ., Arnaud a big homework.

5 Conclusions

Cracking on housing, building, street, “sinking” on the bridges and dyke, problems on drainage, etc. are infrastructures problems due to the land subsidence in Jakarta and Semarang area. Huge costs have already been spent to fixing those infrastructures problems in both areas. Base on the news, cost for elevated the bridges is around 1 million US dollar each. We can imagine if ten or even more bridges need to be elevated, in this case many dollars absolutely should be spend. Base on the news, cost for fixing the road is around 1 million US dollar for ten kilometer. We can calculate the length of road need to be repair and how many dollars should spend. For Jakarta and Semarang, in each area at least there is already more than 20 kilometer of road being affected by the land subsidence impact.A.

Since mostly liniear pattern of land subsidence are recognized continously in both area, in this case the impact especially on infrastructures are probably will getting worse. Certainly, it would lead to more costs in the near future and absolutely need to be concern. Insight look the subsidence impact to the infrastuctures in these areas would raisen the concern, and it is also become key for adaptation and mitigation. We cannot wait for any five years from now for silent disaster of land subsidence given finally the significant disaster to Jakarta and Semarang. We need better adaptation and mitigation immediately. There are plan for giant sea wall in Jakarta, and sea wall in Semarang. Nevertheless until now we found it still in visibilities studies and master plan. Considered strongly we need to stop the land subsidence in both areas for best mitigation.

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