

Tidal inundation (“Rob”) investigation using time series of high resolution satellite image data and from insitu measurements along northern coast of Java (Pantura)

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Abstract. Tidal inundation (in Javanese they call it “Rob”) is now becoming a well known phenomenon along northern coast of Java Indonesia (Pantura). The occurrence of tidal inundation was recognized at least in the early 2000 and even earlier. In the recent years the tidal inundation comes not only at a high tide but even at the regular tide in some area across Pantura. In fact in location such as Pondok Bali, north of Blanakan, north of Pekalongan, north of Semarang and north west of Demak, seems those areas are sinking to the sea through times. Sea level rise and land subsidence are considered as main factors deriving the occurrence of this tidal inundation. We were using time series of high resolution satellite image data and insitu data measurements to mapping the tidal inundation along northern coast of Java. All available data from google data satellite archives (year 2000- recent years) and any available sources being analyze together with field surveys tagging and also from media information. As a result we can see the tidal inundation are taking place in Tangerang, Jakarta, Bekasi, Cilamaya, Pondok Bali, Blanakan, Indramayu, Cirebon, Brebes, Tegal, Pemalang, Pekalongan, Kendal, Semarang, Demak, Gresik, Surabaya, Sidoarjo and Pasuruan.

Keywords: tidal inundation; time series satellite image data; insitu measurements

1. Introduction

Pantura is a local common name for northern coast of Java Indonesia. It started from Merak in northern part of west of Java province crossed to Banyuwangi in east Java Province. Pantura existed along with the Java Sea. Despite of any features can be found along Pantura, one of them is Picture in figure 1 showing an example where tidal inundation occurs in many places there in the regular times. Tidal inundation (in Javanese they call it “Rob”) is now becoming a well known phenomenon along Pantura. The occurrence of tidal inundation was recognized at least in the early 2000 and even earlier. In the recent years the tidal inundation comes not only at a high tide but even at the regular tide in some area along Pantura. In fact in location such as Pondok Bali, north of Blanakan, north of Pekalongan, north of Semarang and north west of Demak, seems those areas are sinking to the sea through times.

Investigating this phenomenon is considered necessary because what is happening in the areas indeed formed a disaster. People in the village of Pondok Bali or Worosari Demak are example of victims that already evacuated since their homes now are permanently inundated by sea water. Soon many would follows. The investigation should include finding the causes. Sea level rise, land subsidence and abrasion are some factors to be considered as the causes [1, 2]. This paper will use time series of high resolution satellite image data, insitu and others data for investigation.





Figure 1. Tidal Inundation located at Pondok Bali Pamanukan Pantura West Java part.

2. Data and methods

We were using time series of high resolution satellite image from all available google data archives (year 2000- recent years) together with any others similar available sources. In this case we identify all of coast and nearby areas along Pantura. We analyzed the newest until the oldest satellite image available data one by one. The changing of coast line and the colors or tones of inundation areas can be identified from all these data. Bellow we give two example from Pondok Bali and Demak.

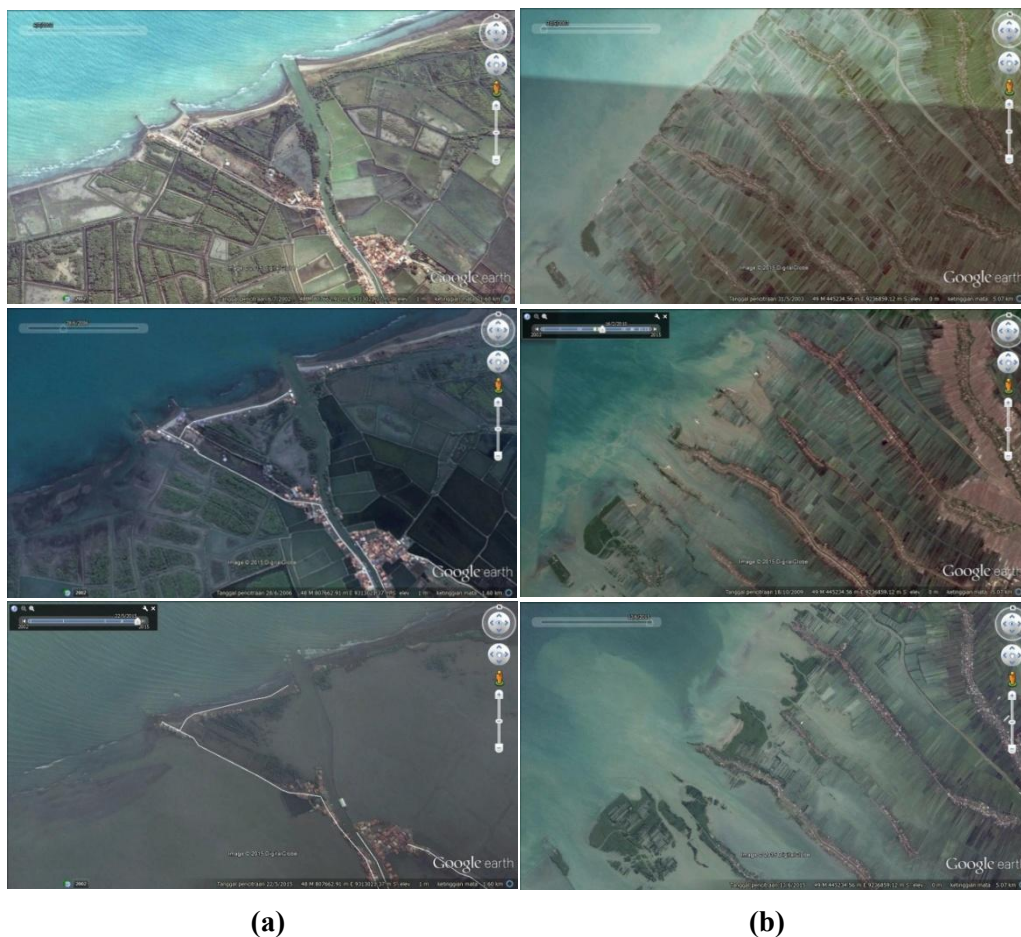


Figure 2. (a) Series in rows of satellite image data of Pondok Bali Blanakan area, (b) Series in rows of satellite image data of northern Demak area. First picture belong to data acquisition in 2002, second belong to 2006 and the third one belong to 2015. We can see the changing of coast line and the colors of inundation (grey water colors and tones).

From the images, we delineate the old predicted coast line with new probable coast line (far inland of tidal inundation), and then we made polygon area to represent the area that at least being inundated (see figure 3 for examples). To delineate the exact line we have limitations on the image colors and tones interpretation since in the dense housing area or images timing being taken in the low tide, etc. in this case tones or a color of inundation was unclear. In order to make sure the true existence of tidal inundation area, in several places we did insitu measurements. Place that we visited included Tangerang, Jakarta, Bekasi, Pondok Bali, Pekalongan, Semarang, and Demak. We found the fact that the area being inundated especially the temporary one is much larger compared to what we delineated from image analysis.



Figure 3. (a) Example delineates the old predicted coast line with far inland of tidal inundation represent new coast line or furthest inundation, (b) example of polygon area represented tidal inundation area taken from delineation the old coast line with far inland or furthest inundation.

Since for some reason we cannot visited all areas of Pantura that expected suffering tidal inundation, we did internet surfed to collect as many information including photo documentations that were reporting tidal inundation around Pantura. Once we found the place we determined the position (coordinates) by using POI (Point Of Interest) of Google map. We noted at least 15 website and we collected more than thirty photo documents. Figure 4 to 5 are example of tidal inundation documentations from internet, each in Salembaran Tangerang, Muara Bekasi, Tegal and Demak. Here are listed of collected internet site; republika.co.id [7, 8], antarafoto.com [9], regional.kompas.com [10], poskotanews.com [11], menlh.go.id [12], panturanews.com [13], kompasiana.com [14], suaramerdeka.com [15], nasional.news.viva.co.id [16], kabar24.bisnis.com [17], suarasurabaya.net [18], nasional.tempo.co [19], wartabromo.com [20], portalkbr.com [21].

Time series of high resolution satellite image from all available google data archives together with any others similar available source have been mixed up with insitu measurements and internet surfed to create comprehensive spatial information on tidal inundation along Pantura. Each data can be complementary or cross checked each others. Result will be discuss at chapter result and discussion.

For investigation the causes, we processed some data and also refered to some publications e.g. Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction by Chaussard et al [5], Land subsidence in Jakarta and Semarang by Abidin et al [1-4]. From these information's we can see well land subsidence and sea level rise along Northern Coast of Java or Pantura. For the next research we begin to install new GPS (Global Positioning System) network along Pantura.



Figure 4. Tidal inundation located at Selembaran Tangerang West Java part of Pantura (left), tidal inundation located at Muara Bekasi West Java part of Pantura (right) [9, 18].



Figure 5. Tidal Inundation located at Northern Tegal Center Java part of Pantura (left), tidal inundation located at Demak Center Java part of Pantura (right) [13, 17].

3. Result and Discussion

From all high resolution satellite image data that we have been collected, processed, and analyzed, we can see the tidal inundation are taking place in Tangerang, Jakarta, Bekasi, Pondok Bali, Blanakan, Indramayu, Cirebon, Brebes, Tegal, Pemalang, Pekalongan, Batang, Kendal, Semarang, Demak, Gresik, Surabaya, and Sidoarjo. Figure 6 shows map of tidal inundation in most locations along Pantura as result of above works. We calculate the area being inundated from the polygon. In Tangerang at least 94.6 hectares are suffering inundation. In Jakarta at least 7.2 hectares are suffering inundation. In Bekasi at least 279.0 hectares are suffering inundation. In Karawang at least 82.0 hectares are suffering inundation. In Subang (Pondok Bali and Blanakan) at least 943.0 hectares are suffering inundation. In Indramayu at least 261.0 hectares are suffering inundation. In Cirebon at least 99.0 hectares are suffering inundation. In Pemalang and Pekalongan at least 21.0 and 13.8 hectares are suffering inundation. In Semarang at least 1157.8 hectares are suffering inundation. In Demak at least 3221.0 hectares are suffering inundation. Table 1 shows complete summary location and each total area being inundate along Pantura. We can see that Demak area is suffering the largest tidal inundation followed by Semarang.

As mentioned earlier, to delineate the exact line from the satellite images, we would have limitation on the image colours and tones interpretation since in the dense housing area or images timing being taken in the low tide, in this case tones or colours of inundation was unclear. It means that the area suffering tidal inundation along Pantura can be much larger. Amplitude analysis on the satellite images, surfing the internet or insitu measurement is a way that might answer larger area being inundated. Indeed we have tried to answer this matter by summarized all places that are informed being inundated from internet site and from insitu measurements. Figure 7 shows map of tidal inundation at most locations along Pantura as result of these works. Table 2 summarize most of the districts and the name of villages being inundated (e.g. in Jakarta, Tangerang, Bekasi, Subang, Indramayu, Cirebon, Tegal, Pemalang, Semarang, Demak, Gresik, Surabaya, Sidoarjo, and Pasuruan).

In a total, number of village almost reach 100 and can be more in the real measurements. Figures 8 to 10 shows comparison among satellite image analysis, insitu measurement, and internet info. It is interesting to see in some part are well match, others shows inundation taking place that none can be seen from the satellite image.

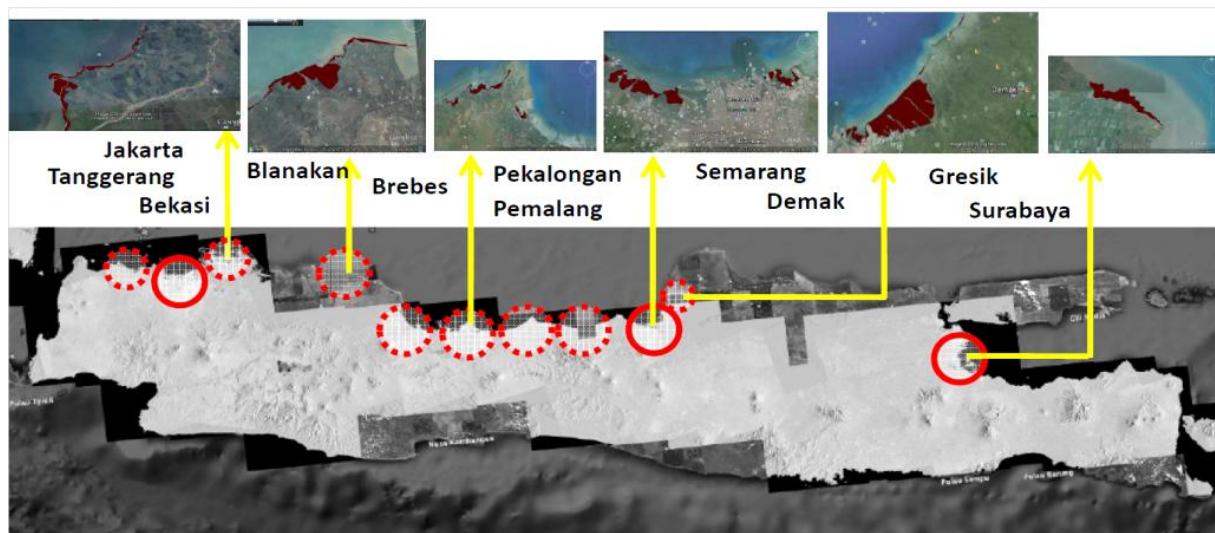


Figure 6. Tidal Inundation in most locations along Pantura from all high resolution satellite images data being collected and analyzed.

Table 1. Summary location and each total area being inundated in Pantura from satellite image analysis.

No	District	Area calculated suffering inundation (in Hectare)
1	Tangerang	94.6
2	Jakarta	7.2
3	Bekasi	279.0
4	Karawang	82.0
5	Subang	943.0
6	Indramayu	261.0
7	Cirebon	99.0
8	Brebes	299.0
9	Pemalang	21.0
10	Pekalongan	13.8
11	Kendal	258.9
13	Semarang	1157.8
13	Demak	3221.0



Figure 7. Tidal Inundation in most location along Pantura from insitu measurements and collections of internet information [7-21].

Table 2. Table Summarize most of the districts and the name of villages being inundated from insitu measurements and internet informations [7-21].

No	District	List of villages reported suffering tidal inundation
1	Tangerang and Jakarta	Dadap Muara baru, Sunter agung, Pademangan barat, Muara Angke, Cilincing
2	Bekasi	Hurip jaya, Donggala, Muara angke, Pantai mekar,
3	Subang	Desa Mayangan, Desa Legon wetan, Desa Legon kulon
4	Indramayu and Cirebon	Desa Eretan, Kelurahan Lemahwungkuk
5	Tegal	Desa Tegal sari dan Desa Muarareja, Desa Mintaragen dan Desa Panggung
6	Pemalang	Desa Pedangung, Desa Sususkan, Desa Kebojongan dan Desa Klegen, Desa Jatirejo, Desa Sidokare, Desa Ujung gede dan Desa Losari, Desa Kendal doyong, Desa Kendal rejo, Desa Tebuireng, Desa Widodaren, Desa Pasucen, Desa Panjunan, Desa Sirangkang, Desa Limbangan mojo, Desa Tasik rejo dan Desa Pesantren, Desa Pendowo dan Desa Kelang depok
7	Semarang and Demak	Marina, Tanjung Mas, Kaligawe, Terboyo, Desa Sriwulan, Desa Bendono, Desa Purwasari, Desa Sidogemah, Desa Gemulak, Desa Tugu, Desa Timbulsloko, Desa Suradadi, Desa Sidorejo, dan Desa Banjarsari
8	Gresik and Surabaya	Kelurahan Lumpur, Desa Kalianak, Desa Margomulyo, dan Desa Greges
9	Sidoarjo and Pasuruan	Desa Weru, Desa Kupang, Desa Sedati, Desa Buduran, Desa Sidoarjo, Desa Jabon, Desa Candi, dan Kelurahan Ngemplakrejo



Figure 8. Tidal Inundation location that quite match among satellite image analysis, insitu measurement, and internet informations [14, 17].



Figure 9. Tidal Inundation location informing larger area base on internet informations [13] compared with satellite image analysis.



Figure 10. Tidal Inundation location informed only from internet informations [15] and none can seen from satellite image analysis.

Indeed the area suffering tidal inundation along Pantura is something that we cannot neglect. It is already a disaster and maybe sometime in the future it will be worsening and becoming very serious

disaster if we do nothing. No doubt we should take an action and started with understands the causes. As mentioned earlier we suspect sea level rise, land subsidence, and abrasion are factors that causes the tidal inundation.

InSAR and GPS results have shown many places along Pantura (e.g. Jakarta, Pondok Bali, Pemalang, Semarang, and Demak) is experiencing land subsidence with yearly rate varying between 1-20 centimeters/years. Figure 11 shows map of land subsidence along Pantura. Figure 12 shows linear trend graphic of land subsidence in Jakarta and Semarang (sample place).

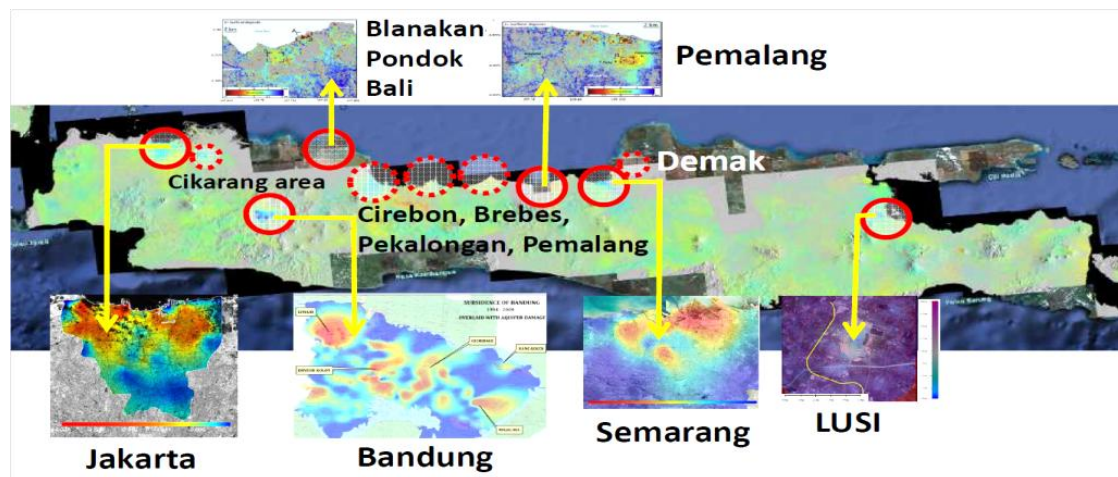


Figure 11. Map of subsidence along Pantura (modified from Chaussard et al [5], Abidin et al [1-4]).

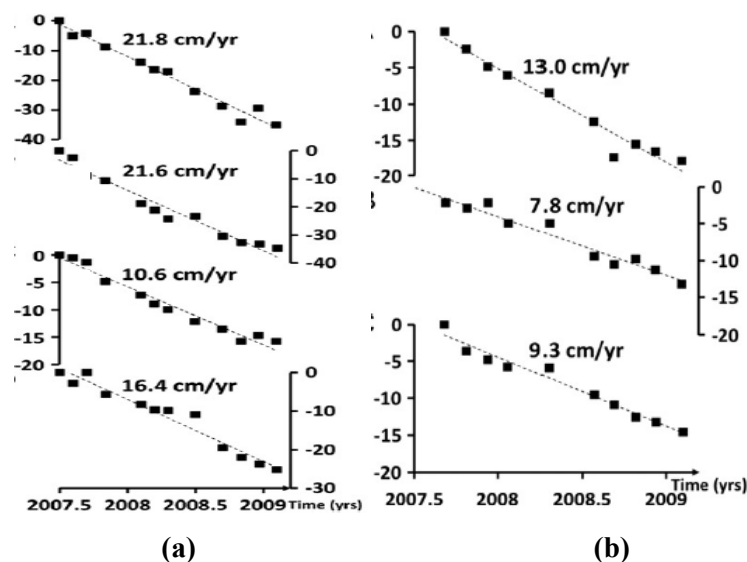


Figure 12. (a) examples of linear trend graphic of land subsidence in Jakarta (b) examples of linear trend graphic of land subsidence in Semarang (modified from Chaussard et al [5]).

Sea level rise along Pantura base on satellite altimetry measurements shows value between 0.1 to 0.6 centimeters/years [6]. This value is less significant compare to subsidence. In this paper we do not yet investigate the abrasion. Nevertheless the tidal inundation considered to be influenced mostly by the land subsidence.

Since the land subsidence is continuing in linier trend, in this case if the linier trend is continuing for many years in the future, then what would happened in future relating tidal inundation is indeed

worrying. We make simulation in Jakarta area on how the topography would respond to land subsidence, sea level rise, and the tidal. We used LIDAR data to generate the topography. Result can be seen on figure 13. Around 26.86% of Jakarta maybe inundated by tidal in year 2025, and around 35.61% of Jakarta maybe inundated by the tidal in year 2050.

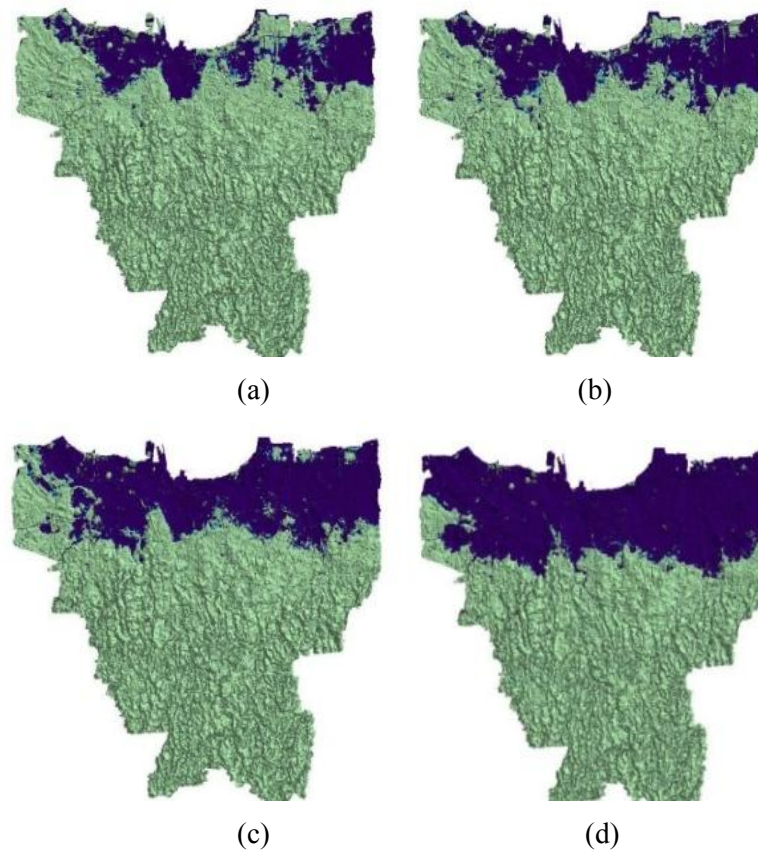


Figure 13. (a) Around 15.58% of Jakarta area prone to inundated by tidal in year 2007 (b) Around 18.78% of Jakarta prone to inundated by tidal in year 2012 (c) Around 26.86% of Jakarta maybe inundated by tidal in year 2025 (d) Around 35.61% of Jakarta maybe inundated by the tidal in year 2050.

We can make simulation for whole Pantura if accurate topography data is available. If the model can created, then we can see the future disaster in Pantura from land subsidence, sea level rise, tidal inundation, and any related coastal hazards. Unfortunately not so many people including the government are truly aware of these matters until now. Hopefully awarnes comes sometimes in the future. We are not expecting many others people need to be evacuate as what had happened in Pondok Bali Blanakan and Worosari Demak, and in few unnoticed places.

We already began to install new GPS network along Pantura and working on more for the next research. Until now there are around 10 GPS subsidence points in Tangerang, 150 GPS in Jakarta, 6 points in Bekasi, 4 points in Karawang, 8 points in Pondok Bali, 7 points in Pekalongan, 40 points in Semarang, and 9 points in Demak (see figure 14).

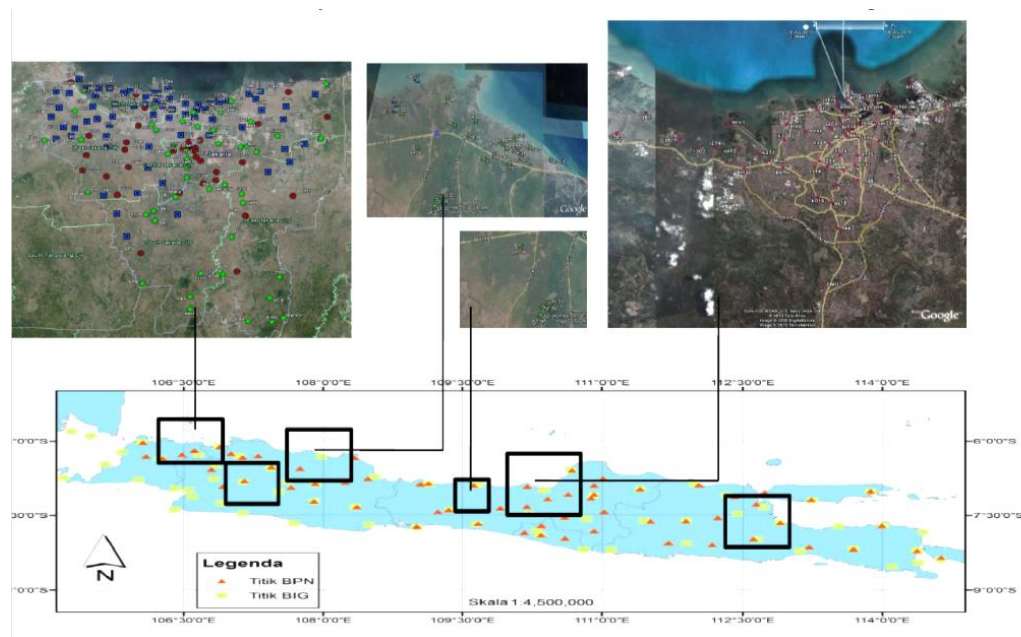


Figure 14. GPS Network along Pantura for monitoring land subsidence in these area.

Since the land subsidence is continuing in linear trend, in this case we should understand why this fact is happening and what the causes are. Our strong hypothesis said that the land subsidence is happening mostly because of effects from overexploitation of ground water, oil and gas. Load from the building, land setting/reclamation, natural compaction and tectonic are complementary or minor causes. Our next research will focus also to prove the strong correlation between land subsidence and ground water, oil and gas exploitation.

4. Conclusions

Investigating tidal inundation phenomenon is considered necessary because what is happening with the tidal inundation indeed formed a disaster in some places along Pantura. People in Pondok Bali or Worosari Demak villages, and probably in others village unnoticed are example of today victim's disaster. They already evacuated to others places since their homes now are permanently inundated by sea water. Soon many would follow we believed.

Tidal inundation considered to be influenced mostly by the land subsidence. In other hand our strong hypothesis said that the land subsidence is happening mostly because of effects from overexploitation ground water, oil and gas. From our investigation we can see the future potential disaster in Pantura from land subsidence, sea level rise, tidal inundation, and any related coastal hazards. Unfortunately not so many people including the government are truly aware of these matters until now. Hopefully awarnes comes sometimes in the future. We are not expecting many people being victims and need to be evacuate.

5. Acknowledgements

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