STUDY ON FLOOD INUNDATION IN PEKALONGAN, CENTRAL JAVA

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Abstract. Tidal flood or 'rob' is a serious problem in many coastal areas in Indonesia, including Pekalongan in the northern coast of Java island. This study aimed to simulate the flood inundation area for different scenarios of sea level rise, also to investigate the possibility of land subsidence that may further aggravate the problem of flooding in Pekalongan. In this study, the MIKE-21 model was used to simulate and predict the flood inundation area. Tidal data were generated from the Tide Model Drive (TMD). The tidal flood simulations were carried out for three different scenarios of sea level rise: 1) current situation, 2) next 50 years, assuming no sea level rise, and 3) next 50 years, assuming 50 cm of sea level rise. Based on the results, the ranges of water level rise in Pekalongan for each scenario were 0.23-1.27 m, 0.36-1.38 m, and 0.65-1.53 m, respectively. Meanwhile, ground displacement maps were derived from the ALOS/PALSAR data using Differential Interferometric Synthetic Aperture Radar (D-InSAR) technique. Twelve level 1.0 images of ALOS/PALSAR data acquired in ascending mode during 2008 to 2009 were collected and processed in time-series analyses. In total, 11 pairs of interferogram were produced by taking the first image in 2008 as the master image. The results showed that the average of land subsidence rate in Pekalongan city was 3 cm/year, and the subsidence mainly occurred in the western part of the city.

Keywords: *Tidal flood, MIKE-21, InSAR, Pekalongan, ALOS/PALSAR*

1 INTRODUCTION

Located on the northern coast of the island of Java, Pekalongan often experiences coastal erosion and tidal flooding or 'rob'. The floods inundate settlement areas near the coastal zone and the extent of the affected area increases from year to year. Coastal area of Pekalongan becomes subject to flooding as a combined result of high rainfall, land use changes, changes in river cross-section, and unusually high tides (Rahmawati and Ardhiani, 2008). In addition, long term processes such as subsidence and sea level rise due to global warming can lead to encroachment of sea water to the land. According to the survey conducted by the Ministry of Marine Affairs and Fisheries (DKP) in 2010, the mean sea level rise in the north coast of Java reached up to 6-10 millimeters per year. Subsidence in the coastal area of major cities in Indonesia clearly evident as shown by a number of studies (Chaussard *et al.*, 2013; Hay-Man Ng, 2012; Lubis, 2011; Marfai, 2007), and for Pekalongan (Chaussard *et al.*, 2013).

As reported by the media, floods happened almost every year in Pekalongan. Most recent flood in May 2013 affected at least three villages (Mulyorejo, Tegaldewo, and Jeruksari) in the sub-district of Tirto, inundated thousands of houses with an average height of 30-50 cm (Radar Pekalongan Online, 2013). On December 2010, floods with height up to 1 m affected nine villages in three sub-districts of North Pekalongan, West Pekalongan and East Pekalongan; that was a quarter of the city area. The floods also resulted in a shift of shoreline of about 100 meters from initial conditions with a length of up to five kilometers (Media Indonesia, 2010). If this situation continues, it is not impossible that Pekalongan will be completely sunk in the next few decades.

The objectives of this study were to simulate flood inundation area for different scenarios of sea level rise using a numerical modeling MIKE-21, and to investigate the land subsidence in the study area using Differential Interferometric Synthetic Aperture Radar (D-InSAR) technique.

2 MATERIALS AND METHOD

2.1 Study area

Coastal zone of Pekalongan is located on the lowland plain of the northern coast of central Java, and the area has an average elevation of 1 m above mean sea level. It has huge potential in fisheries and agriculture sectors, and it has been traditionally known as one of the largest fishing port town in Southeast Asia (Priyanto, 2010). Pekalongan, Banger, and Bulan rivers are passing through the city and influences the development of urban built-up area along the river and coastline. Therefore, they make this area vulnerable to flooding. Changes in land use due to residential growth, agricultural expansion and recent industrial development in the lowland area contribute to the degradation of coastal areas of Pekalongan. Figure 1 shows the location and geographic coordinates of the study area.

2.2 Datasets

Datasets used for this study consisting of several datasets to perform flood modeling and satellite images for interferometry processing. Data for flood modeling were: (1) Topographic map of Pekalongan 1:25,000 scale, (2) Digital Elevation Model (DEM) from SRTM with 30 m resolution, (3) Bathymetry data from GEBCO with 30 arc second resolution, (4) River streamflow (Q), (5) Tidal data from field observation conducted on 30 October-13 November 2011, and (6) Triplet images of ALOS/PRISM data to generate high resolution DEM. Multi-temporal data of level 1.0 of ALOS/PALSAR data from 2008 to 2009 (12 images) were used for interferometry processing. ALOS/AVNIR-2 data was also used as background for presenting the results.

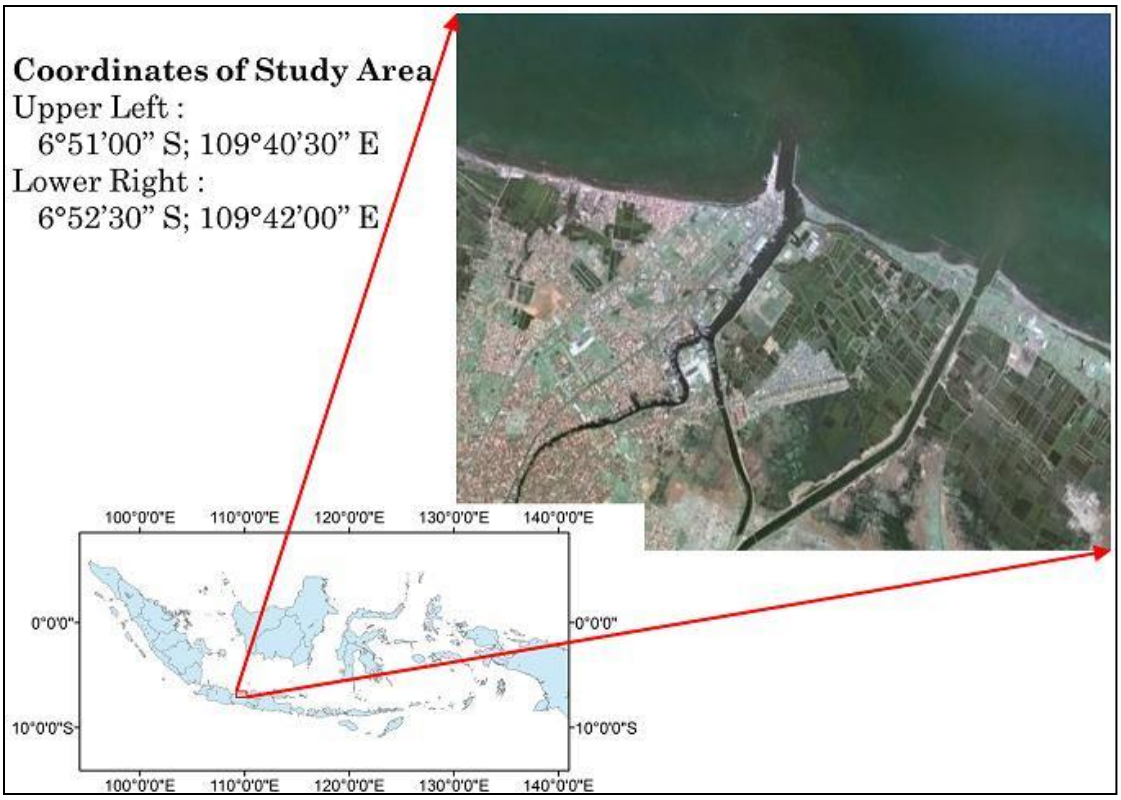


Figure 1. Location of the study area.

2.3 Data porcessing and analyses

The schematic flowchart of methodology used in this study is shown in Figure 2. Tidal data were generated from the Tide Model Drive (TMD). TMD is a Matlab package from Oregon State University that can be used to run all global and regional models for making predictions of tide height and currents (Padman and Erofeeva, 2005). A numerical modeling tool MIKE-21 of DHI was used to simulate and predict the flood inundation area. Given the complexity of the problem and non-availability of some data needed for the simulations, the boundary conditions were restricted to a limited area where most of the population and infrastructures exist. To evaluate the influence of sea level rise, the model simulations were carried out for three different scenarios: (1) current situation, (2) next 50 years, assuming no sea level rise, and (3) next 50 years, assuming 50 cm of sea level rise.

An attempt to extract Digital Elevation Model (DEM) as one of the inputs for the flood model was performed using ALOS/PRISM triplet images. Leica Photogrammetry Suite (LPS) from ERDAS software was used for this purpose. GCPs were collected from height points of topographic maps. DEM was generated using different combination of stereoscopic images, Nadir-Forward, Backward-Nadir, Backward-Forward, and Backward-Nadir-Forward. The accuracy of ALOS/PRISM-derived DEM was evaluated and compared to topographic map and the SRTM DEM.

To measure the spatial extent and magnitude of ground deformation in the study area, ALOS/PALSAR data were used to derive a series of land subsidence maps using Differential Interferometric Synthetic Aperture Radar (D-InSAR) technique. Time series analyses of interferometry were performed for 11 pairs of interferograms relative to the first image in 2008 (master image) using SARScape of ENVI software. The D-InSAR technique measured ground displacement in the radar line-of-sight (LOS) direction by computing the phase difference of two SAR images at different time of acquisition. SRTM DEM with 90 m resolution was used to simulate a synthetic topographic phase and remove topographic noise. Goldstein adaptive filter generated output interferogram with reduced phase noise. The phase of the interferogram can only be 2π, thus phase unwrapping was performed to resolve this 2π ambiguity. After orbital refinement, unwrapped phase was converted to displacement value and geocoded into a map projection.

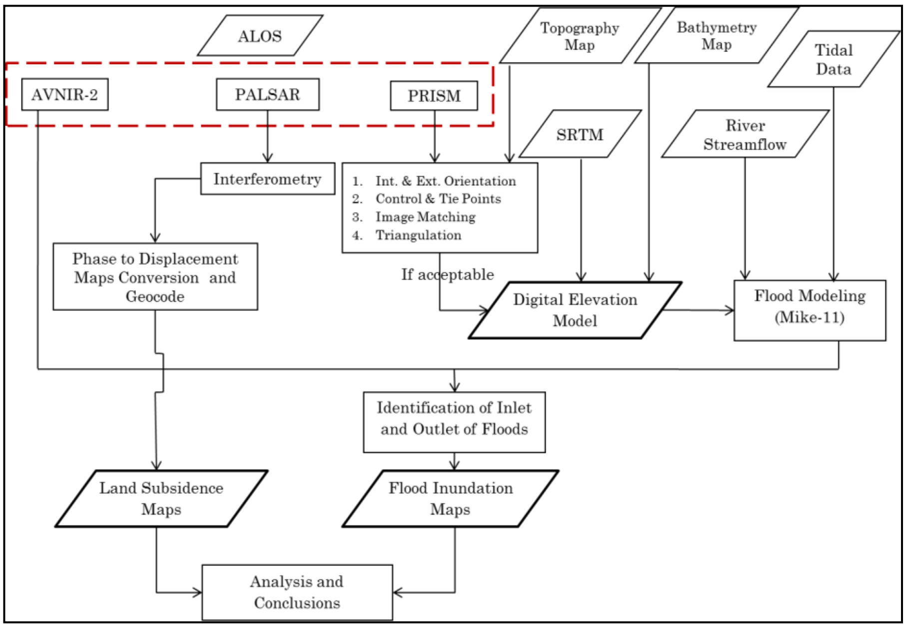


Figure 2. Flowchart of research method.

3 RESULTS AND DISCUSSION

3.1 Tidal data

Flood modeling in coastal area required tidal data as an input to simulate changes in water level with time. Field observation of tidal data in the study area was only available for a short 1 month duration (24 October to 23 November 2011. Therefore, the Tide Model Drive (TMD) was used to generate tidal data. Figure 3 shows the simulated tidal data of whole region.

To validate the results, TMD-derived tidal data were compared with data from the field observation in Pekalongan station. Tidal data generated from the TMD showed an average accuracy of 7 cm with reference to the observation data. Figure 4 shows a time series comparison between tidal data of TMD and field observation from 24 October to 1 November 2011. In general, the tidal data from TMD closely match with the field observation, though less accuracy found in high tide compare to the lower one.

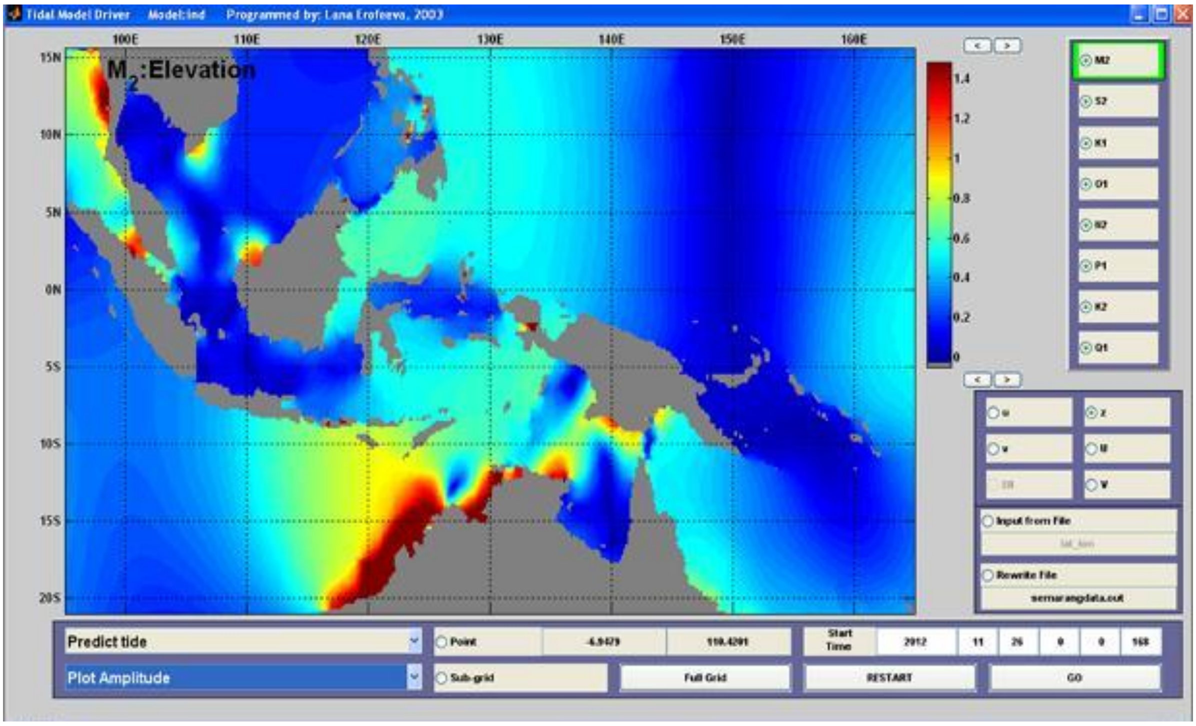


Figure 3. Tidal data generated from TMD

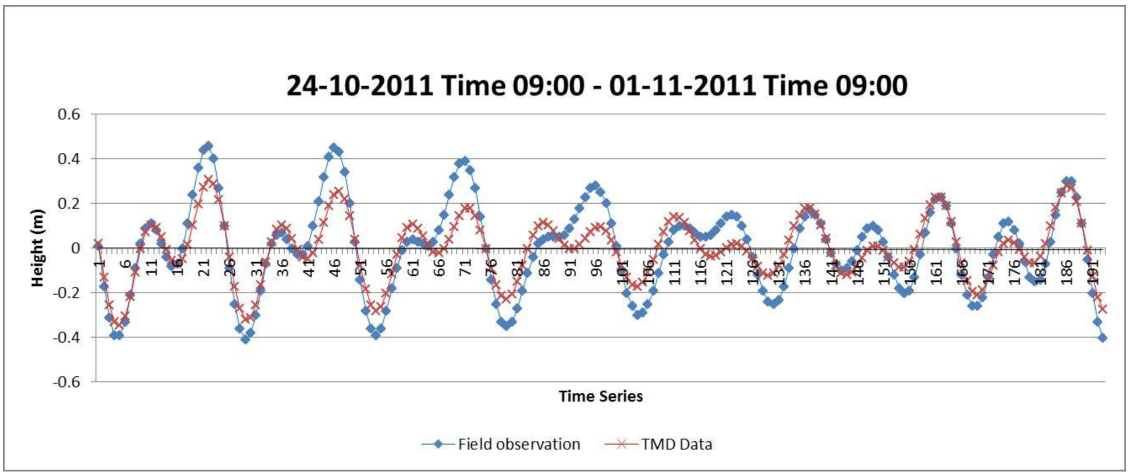
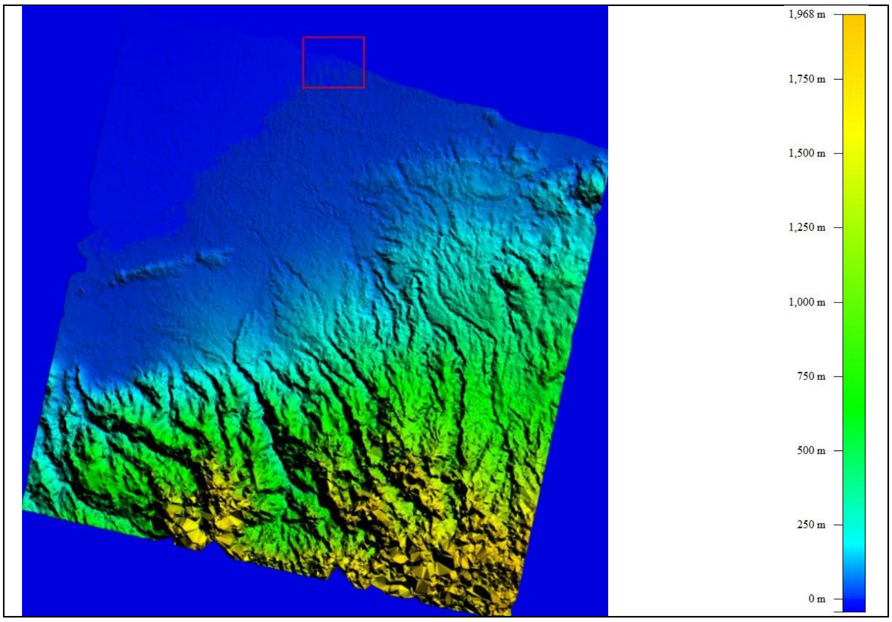


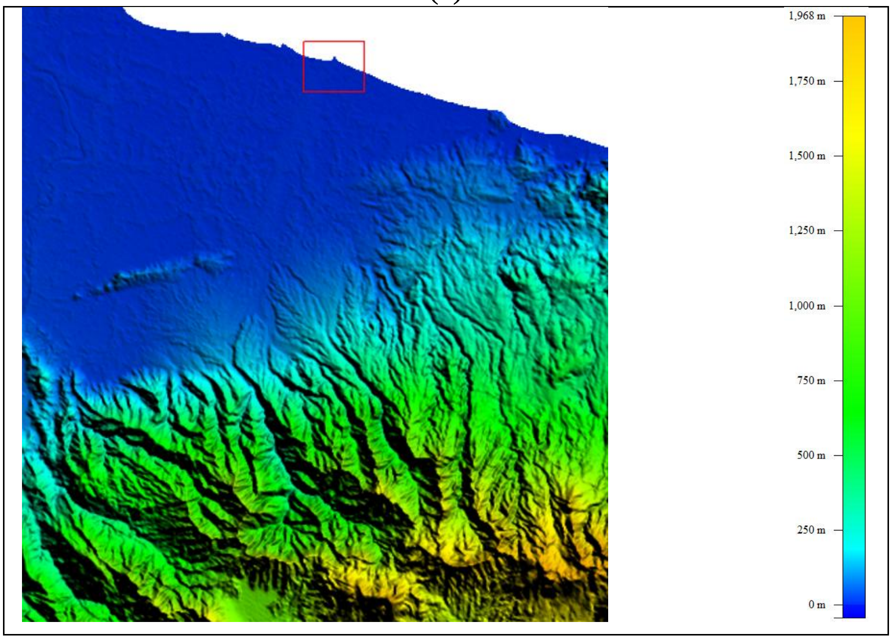
Figure 4. Tidal data generated from TMD

3.2 Digital elevation model (DEM)

Figure 5(a) and 5(b) shows DEM generated using stereo pairs of ALOS/PRISM and SRTM data, respectively. The accuracy was evaluated by calculating Root Mean Square Error (RMSE) from 10 control points collected from a topographic map. These points were evenly distributed in the study area. The RMSE of SRTM DEM was also calculated to compare the results. It was found that the average accuracy of ALOS/PRISM DEM was 2.55 m and RMSE was 3.26 m. It was slightly better than the accuracy of DEM generated from SRTM, which had an average accuracy of 4.13 m and RMSE of 5.52 m. However, the DEM of ALOS/PRISM indicated negative value in some pixels especially in the western part of the study area (Figure 5(a)), that become a problem if it will be used as an input for flood modeling. Based to the reason, DEM from SRTM was used as input for the flood inundation modeling.



(a)



(b)

Figure 5. DEM generated from (a) ALOS/PRISM, (b) SRTM. A red box in both figures

indicates the extent of the study area.

3.3 Flood inundation from MIKE-21

The results of flood inundation model calculated from MIKE-21 can be seen in Figure 6. Different scenarios of sea level rise were considered in this study: (1) current situation, (2) next 50 years, assuming no sea level rise, and (3) next 50 years, assuming 50 cm of sea level rise. The third scenario was taken by considering the data from DKP showing an increase of mean sea level in the north coast of Java up to 6-10 milimeters per year, which indicated a sea level rise of 30-50 centimeters in the next 50 years. Based on the results, the ranges of water level for each scenario were 0.23-1.27 m, 0.36-1.38 m, and 0.65-1.53 m, respectively. Considering a sea level rise of 1 cm/year, the inundation level in the mainland area in the next 50 years will almost be double in comparison to no sea level rise scenario.

3.4 Land subsidence

Figure 7 shows time series of land subsidence in Pekalongan from 2008 to 2009. Positive values (yellow to red colors) represent uplift, while negative values (green to blue colors) represent downlift or subsidence. Horizontal displacement assumes to be negligible since only ascending acquisition images were available and ground observa- tion in major cities in Indonesia showed displacement mainly occurred vertically

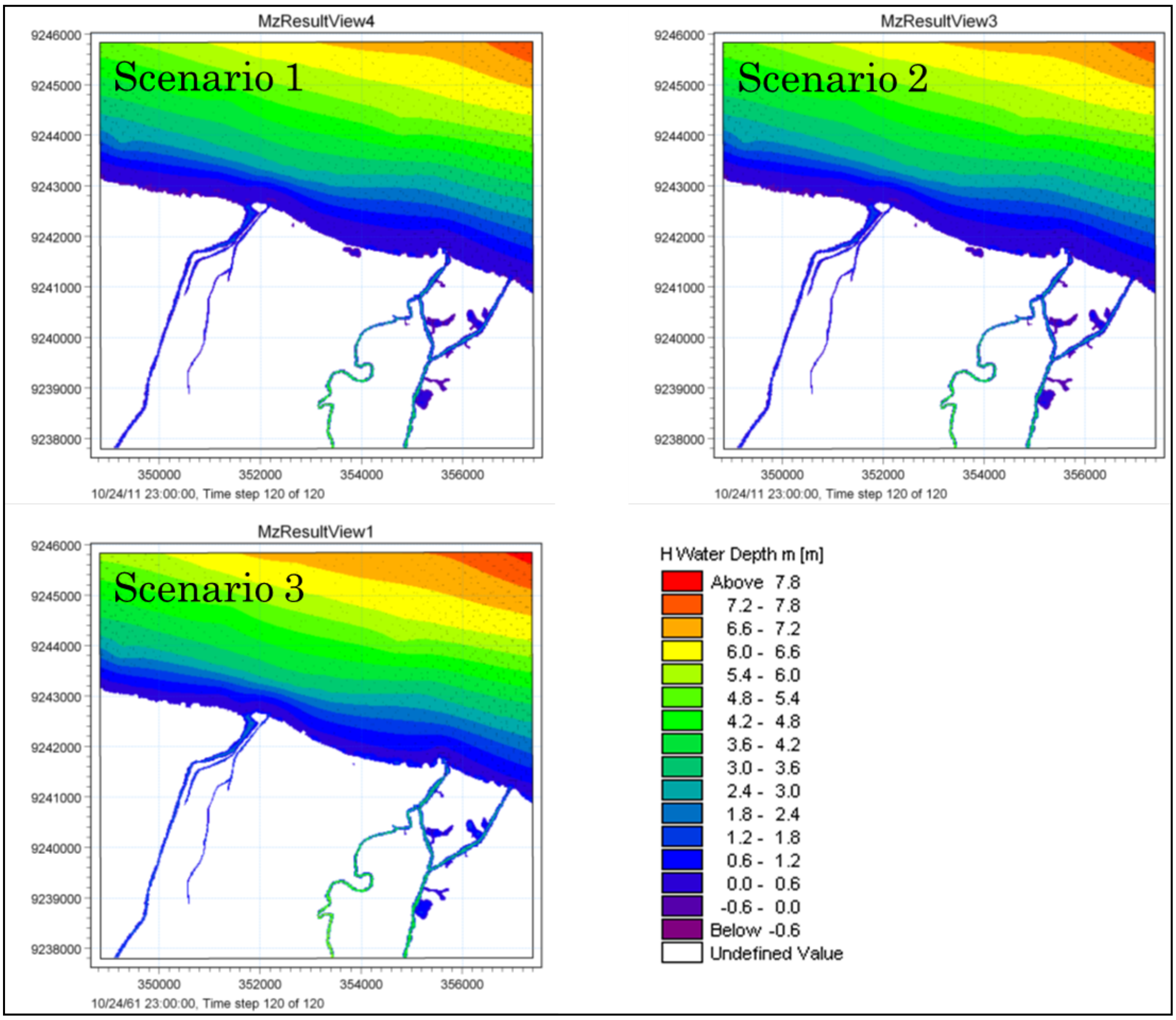


Figure 6. Flood inundation for different scenarios.

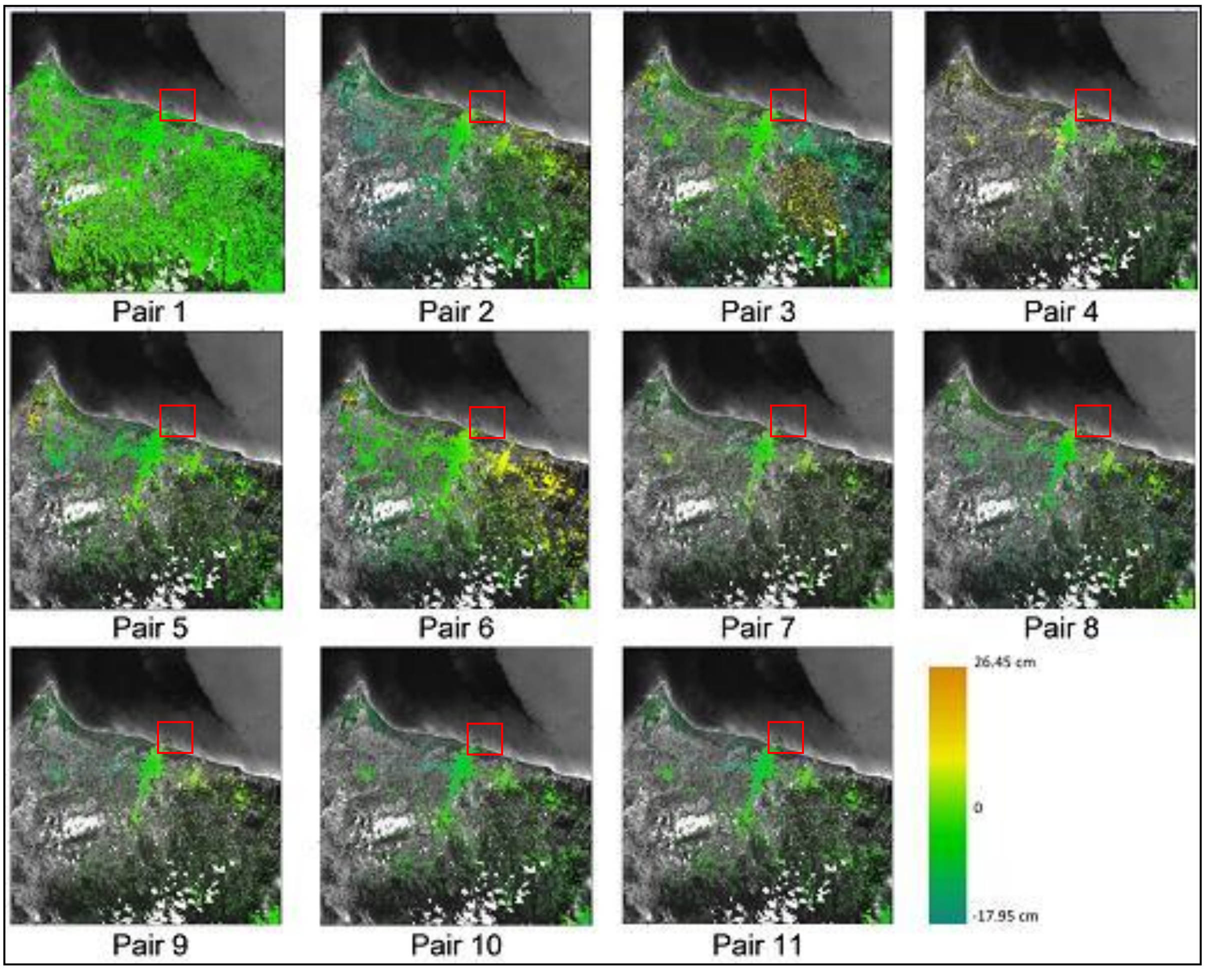


Figure 7. Land subsidence maps generated from D-InSAR. A red box in the figures indicates the extent of the study area

(Chaussard *et al.*, 2013). LOS converted into vertical displacement and the results showed that the average value of land subsidence rate in Pekalongan city was 3 cm/year. The subsidence rate showed here was lower than the study conducted by Chaussard *et al.* (2013), which was 4.8 cm/year. Ground water extraction from agriculture area was considered to be the main cause of subsidence, combined with increased urbanization and settlements development.

In general, land subsidence increased the risk of coastal flooding in the study area. Based on the visual observation, there was a correlation between land subsidence and the results of flood modelling. A relatively high rate of subsidence occured almost in whole area of the study area, while the flood maps (see Figure 6) also showed inundation especially along the Banger and Bulan rivers.

A field verification was needed to confirm the results that could be important for flood mitigation and management by considering the on-going land subsidence processes.

4 CONCLUSION

Sea level rise due to global warming and land subsidence were likely to intensify the extent and severity of coastal erosion and tidal floods in Pekalongan. The flood water level increased almost double if the scenario of sea level rise was considered. It was estimated that the land subsidence rate observed in Pekalongan reached 3 cm/year. Ground water extraction from agriculture area was considered to be the main cause of subsidence, combined with increased urbanization and settlements development.

Availability of information on flood inundation and land subsidence can help local government to plan for disaster risk reduction in Pekalongan, Central Java. In future work, ground data should be integrated to provide a better understanding of coastal floods or rob in Pekalongan.

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