The Change in Elevation, Land Subsidence and Local Sea Level Rise Using Coastal Response Model in Jakarta

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Abstract. The rapid urban development activities on the coast of Jakarta has a major impact on the risk of land subsidence. This land subsidence causes significant changes in land elevation. Especially, the coastal areas of Jakarta receive the risk of inundation. The primary purpose of this research was to examine the responses of Jakarta coastal areas based on land subsidence rates of a 24-day baseline data of SAR Sentinel 1A, and local sea-level rise prediction from MOTIWALI data. The methods used in this research were an interferometric SAR (InSAR) and Coastal Response Models. The results of this study indicate that the coastal model response using adjusted elevation based on interferogram elevation and land subsidence rates of SAR Sentinel A1 in a relatively short time (monthly) escalates the evaluation of areas with potential undergoing inundation impacts. Jakarta coastal area receives a greater response with changes in the elevation adjustment based on the local sea-level rise of 0.54 m and land subsidence rates of 0.02. The model demonstrates that the coastal landscape of Jakarta was not possessing the capacity to respond to sea-level rise. Coastal dikes are quite effective as an initial defense in the event of extreme sea waves. The coastal response model using SAR Sentinel 1A data can respond to resource management decisions in coastal areas, and improve assessments quickly that consider the impacts of future land subsidence and local sea-level rise.

1. Introduction

Coastal areas of Jakarta as one of ten big cities in Southeast Asia, is vulnerable to environmental pressures including global climate change [1]. Jakarta becomes one of the most vulnerable coastal city not only in Indonesia but also being recorded as the most susceptible city for flooding in the world [2]. For more than three decades, various studies such as [3] and [4] indicate that the land subsidence gets worst in this city, principally in the coastal areas comparing with its local sea-level rise. Of course, this is a potential condition that aggravates the coastal inundation, if it is not anticipated further. For instance, by building the coastal dikes [5]. Some aspects have been taking into account to anticipate these threats since five years ago, like establishing dikes along this coastline [6] to withstand sea waves and revitalizing areas with potential inundation [7] by building more significant coastal defences.

The increasing urban development of various infrastructure establishment and skyscrapers have altered the geomorphological features of Jakarta. This development does not stress the remaining open
space areas, 10%, in the last few years. Infrastructure loads bring about pressure on the land subsidence. In the long-term, Jakarta responds adaptively to sundry environmental condition changes in the coastal areas, including impacts of land subsidence and sea level rise. The increasing local mean of sea-level rise is approximately 0.71 cm per year [8]. Followed by the land subsidence, for instance in studies [3], [4] based on the vertical profile of Jakarta Metropolitan [9], [10] which indicate that the coastal area of Jakarta is currently below sea level.

The input data from SAR Sentinel 1A is very potential to provide a spatial model which can respond to changes in the urban elevation in only a relatively short period (less than a month). The spatial model uses this type of SAR, primarily to respond to relatively brief changes in land subsidence rates and local mean of sea level rise, which is the purpose of this paper. Various studies regarding coastal response [11, 12, 13], one of them had referred to being improved in this research.

2. Research Method

2.1. Area Study

The study was located in the territory of Jakarta, Indonesia. It has significant land subsidence rate, especially in the areas with vulnerable inundation [13], locating in the coastal areas of Jakarta. The study area is geographically situated at 6°7′ S - 6°22′ S and 106°40′ E - 106°55′ E. Several inundation spots (red) and non-inundation (blue) are still found in the study area, which are presented in Figure 1. The map of the location of this study shows that the coastal area is still quite responsive to the impact of inundation throughout the year.

![Figure 1](image)

Figure 1. The vulnerable and invulnerable inundation in the research location.

2.2. Materials and Tools

Materials used in this study were products of multi-data Single Look Complex (SLC) SAR Sentinel 1A belong to the European Space Agency (ESA) downloaded from https://scihub.copernicus.eu/dhus/#/home. The acquired data were 24-day baseline data. All of them were gathering in the format of SAFE (Standard Archive Format Europe) [14] and listed in Table 1 below.

The in-situ data of local sea level rise recorded using a tide gauge instrument MOTIWALI (http://teknologi-kelautan.com). It measured tides real-time and continuously in November 2016. For the average user, an appropriate series consists of hourly measurements covering the synodic month of approximately 29 days. The instrument was set in the Kolinlamil station, Jakarta. The data was analyzed using Harmonic Analysis, Method of Least Squares (HAMELS). HAMELS in this study was available in the toolbox Water level: Analysis 2010 version1.0 and Tide level: Prediction 2010 version 1 through
GUI MATLAB [15]. The tidal data analysis generated harmonic constituents. It was then applied to analyze the local sea level rise.

**Table 1.** SAR Sentinel 1A multi-data used.

| Acquisition  | Single Look Complex data with a 24-day baseline                  |
|--------------|-----------------------------------------------------------------|
| 22/5/2016    | S1A_IW_SLC__1SSV_20160522T111451_20160522T111519_011370_01146  |
| 15/6/2016    | S1A_IW_SLC__1SSV_20160615T111452_20160615T111520_011720_011F8  |

The survey data were collected using GPS, camera, and others. Furthermore, the software used in the data processing was QGIS Las Palmas version 2.18.15 (https://qgis.org/en/site/) and SNAP version 6.0 (https://earth.esa.int/). Both software allows interfaces with many free-open-source plugins.

2.3. **Processing Data of SAR Sentinel 1A**

In general, the processing SAR data utilized InSAR method, which was aimed at (i) synchronizing SLC; (ii) calculating different phases to generate interferograms; (iii) eliminating phase ambiguity (*unwrapping phase*); (iv) converting the phase to be higher. A diagram of data processing is presented in Fig. 2 as follows.

![Diagram of data processing](image)

**Figure 2.** Data processing diagram of land subsidence deformation utilized InSAR Sentinel 1A during a period of May to June 2016 in Jakarta.

The process of data processing based on Figure 2 above utilized two multi-temporal data starting from a selection of the study area using *SI TOPS Split, Sub-Swath*, and *Burst*. This process did not involve a tool subset to determine the study area due to its ability to omit supporting information for interferometry. The *SI TOPS Split* was able to segregate polarization because of interferometry applying a single VV polarization only. *Apply Orbit File* was conducted to acquire satellite-geometrics in calculating interferograms. ESA SNAP only supported the ORBIT for the launched satellites such as Sentinel. The next process was *Back Geocoding* to registry image pairs (*stack*) in the same orbit frame. The process of Interferogram Formation was taken to get an interferogram from image pairs, and information of coherence distribution. *Deburst* was intended to remove gaps of *Sub-Swath* data, then the *Burst* before the interferometric process proceeded. The Filtering Phase diploid a Goldstein Filtering. This filtering process was designated to reduce fringe/artifact and noise of interferograms causing by either atmospheric noise or phase incoherence. The results of filtering were then exported into SNAPHU format to gain an Unwrapping Phase utilized a SNAPHU (*Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping*) version 1.4.2 software [17] operating in a Cygwin window system. The *Phase Unwrapping* was converted into DEM through a *Phase to Height or Phase to Elevation* operation. An absolute estimate for calculating the value of vertical displacement (VD), i.e.
\[ VD = \frac{UP \times 0.56}{-4 \times PI \times \cos(\text{rad}(\text{Incidence angle}))} \]  

(1)

where UP represents Unwrapping Phase, PI = Phase Interferogram, wavelength C-band SAR Sentinel 1A of 0.56, and local incidence angle 36.28°.

2.4. Coastal Response Model

Coastal Response prediction model considers adjusted land elevation (AE) adapted from Lentz et al. (2016):

\[ AE = E - SL + VD \]  

(2)

where AE represents the adjusted elevation with respect to projected local sea levels; E denotes the initial land elevation from Sentinel 1A; SL is a projected local sea level in the 2016s from data tide gauge measurement of instrument MOTIWALI; and VD gives the vertical displacement rates of a 24-day baseline from data series Sentinel 1A in Table 1.

3. Results and Discussion

3.1. Adjusted Elevation, Land Subsidence Rates and Local Sea Level Rise

This research indicates that adjusted elevation during the acquisition period (24-day baseline) is not changed rapidly. The calculation results show the maximum land subsidence rates of 0.02 m. The spatial change in land subsidence rates shown in Figure 3. This result also exhibits that most of the lands in Jakarta do not experience vertical displacement. It was relevant with the other case location in North Java The study area undergoes land-consolidated and unconsolidated. During the baseline period, we found the areas with and without land subsidence. However, the hitting down of sea waves on some coastal dikes make the seawater moves to the land quickly. Within less than a month baseline, the land subsidence still occurs in some coastal areas of Jakarta. For example, Kalibaru, Cilincing, and Marunda sub-districts. Some areas that are directly adjacent to the coastline of Jakarta also undergo land subsidence like Makassar and Cakung subdistricts in Eastern and Western Jakarta. Some areas without land subsidence are Penjaringan and Tanjung Priok.

Figure 3. Land subsidence rate (m) in Jakarta with a 24-days baseline of SAR Sentinel 1A data in the acquisition period of 22/5/2016 - 15/6/2016.

The study results during a relative short-term acquisition period indicate that there is still a risk of surface inundation due to sea level rise in coastal areas. This result refers to the inundation monitoring results spatially based on the multi-satellites and multi-temporal data analysis denoted the inundations occurred from last May to early June 2016 [7]. The study results show that the value of land subsidence
is relatively small during the acquisition period, which is only 3.80% of the local mean of sea level rise of 0.54 m based on monthly tide height prediction charts in May and June 2016 (Figure 4) according to HAMELS calculations [16] from data tide of MOTIWALI [13]. Although land subsidence is relatively small, it has the potential to exacerbate the risk of inundation. It is consistent with the study of Takagi et al. [5] predicts a small dike of 1 m that can describe the risk of coastal inundation if land subsidence can be stopped.

![Figure 4](image-url). Monthly tide height prediction charts: (a) May 2016, and (b) June 2016 in Jakarta waters which is shown by local mean sea level of 0.54 m (red line).

### 3.2. Coastal Response Change Adjusted Elevation Based on Spatial Model

The results showed that the elevation in the study area mostly has low elevation, especially in spots prone to inundation in Pademangan, Koja, Tanjung Priok and Cilincing, as shown in virtual red and orange based on the SAR Sentinel 1A elevation interferogram (Figure 5). The results of computation using the equation model (2) obtained a model of spatial change in the coastal area of Jakarta in Figure 6. Based on this figure shows an elevation adjustment to the initial elevation conditions to respond to land subsidence rates and mean of sea level rise. The Jakarta coastal area responds to these two factors based on (1) the extended land area which is below sea level as shown in the red and orange radar images; (2) Jakarta's coastal landscape can respond adaptively to changes in land subsidence and sea-level rise mean; and (3) inundation risk analysis is not only intended for coastal areas but can extend to areas close to the inundated prone areas, such as parts of West Jakarta, East Jakarta and Central Jakarta in the future. This condition will indeed keep taking place if there are no anticipating actions like establishing coastal dikes for un-protected areas as seen in the seashore around Kali Adem Port and revitalizing the existing dikes becoming higher along the coastlines. Some studies expressed that the coastal areas of Jakarta frequently experience inundation along the year, even though the local sea level rise is relatively low [8], [3]. Furthermore, seawater has engulfed the coastal dikes and flooded vulnerable locations along with the coastal areas of Jakarta [5]. The monitoring results using multi-temporal data of SAR Sentinel 1A confirm the inundation spatial dynamics that happened last May to early June 2016 in the coastal areas of Jakarta [7]. One of the causes is several coastal dikes falling in that period as the results of sea waves, and inducing surface water inundation in some coastal areas of Jakarta. This condition influences the ecological and environmental aspects [8, 13].

The results of studies denote that the the impact of a relatively small local sea level rise average should be considered, as surface water inundation is expected to continue, especially in inundation-prone areas without permanent embankments along the coastline. For example, Fishermen Villages around Kali Adem port, Kali Baru and Marunda beaches. In addition, land subsidence is still occurring, although the value is relatively low, the baseline is short and not all areas of North Jakarta experienced it in this study (Figure 3). Land subsidence in Jakarta has average of 19 cm per year for more than 30 years from 1982 to 2015 based on various studies [3, 4, 19] indicating that this problem has not been
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The study results show that the Jakarta coastal area receives a greater response with changes in the elevation adjustment according to the model (Figure 6) based on the elevation interferogram (Figure 5). The impact of 0.54 m local sea level rise and land subsidence (Figure 3) still shows significant pressure on the Jakarta coast based on this model. Coastal dikes are quite effective as an initial defense in the event of extreme sea wave, as happened in late May and early June 2016 [1]. This relevant to Indonesian Government which is currently completing coastal dikes along 120 km of the coastlines of Jakarta [6]. The maximum height of the established dikes is approximately 4-m high. This height is higher than the estimating model based on the study results of Takagi et al. [5] applying dikes height of 3-m high. The Takagi’s Model is expected to be quite tall and will lose its capability to stop coastal flooding by 2040.

Figure 5. Interferogram elevation baseline 24 days during the data acquisition period of 22/5/2016 and 15/6/2016 of SAR Sentinel 1A

Figure 6. Interferogram coastal response model through elevation adjustment as the results of the land subsidence during the data acquisition period of 22/5/2016 and 15/6/2016 as well as the local sea level rise of 0.54 m.

4. Conclusion
The coastal response model using adjusted elevation based on interferogram elevation and land subsidence rates of SAR Sentinel A1 in a relatively short time (monthly) escalates the evaluation of areas with potential undergoing inundation and local sea-level rise impacts. The Jakarta coastal area
receives a greater response with changes in the elevation adjustment based on the local sea-level rise of 0.54 m and land subsidence rates of 0.02. A model demonstrates that the coastal landscape of Jakarta was not possessing the capacity to respond to sea-level rise. Coastal dikes are quite effective as an initial defense in the event of extreme sea waves.

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