Land Subsidence Prone Areas Identification in Yogyakarta City using Sentinel-1 Imagery

F M Zein, I P A Shidiq and Rokhmatuloh

1Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia
farhan.makarim@ui.ac.id

Abstract. Yogyakarta is the city with the raising in population growth every year. Population growth demands more land and water consumption. Land-use changes from natural to a built-up area like residential or commercial areas will increase the load of the land and decrease the water infiltration area. The intensively land-use changes have been lowering the ground-water surface with an average rate of 30 centimeters per year. The increase of land load and the lowering of the ground-water surface are implications of land subsidence. This study aims to map and to estimate the rate of land subsidence in Yogyakarta City. This study used remote sensing technology, especially an active remote sensing system. An Interferometric Synthetic Aperture Radar (InSAR) technique applied form Sentinel-1 radar satellite imageries can show the location and pattern of land subsidence. This study shows that there is subsidence in the city of Yogyakarta. The total subsidence that occurred in 2015 to 2017 did not show any specific pattern, whereas in 2019 & 2019 there was an increase in the intensity of subsidence in the southeast.

1. Introduction

Yogyakarta City is a city located in the Special Region of Yogyakarta (DIY). The city of Yogyakarta has an area of 32.5 km2 consisting of 14 districts and 45 villages and in 2017 has a population density of 13,000 people per km2 [1]. Yogyakarta City population growth continues to increase every year [1]. In 2010 the population in the city of Yogyakarta was 388,627 people. With projections by the Central Statistics Agency (BPS) in 2017 there will be a population of 422,372 people. Population growth in the city of Yogyakarta makes a change in land use from non-built up area to built area. The percentage ratio of land use in Yogyakarta City changed from 47.65% of built up area and 52.3% of non-built up area in 2011 to 62.19% of built up area and 37.81% of non-built up area in 2017[2].

Changes in land use from non-built to built (residential dwellings or buildings) make the land load increases and decreases the water catchment area. Increasing population growth also makes an increase in the use of ground water which makes the city of Yogyakarta experience a 30 cm per year decrease in groundwater level. The increase in the burden of land due to the construction of residential or building dwellings and the decline in groundwater levels due to groundwater use are implications of the occurrence of land subsidence in urban areas [3].

Interferometric Synthetic Aperture Radar (InSAR) techniques have been widely used in research to detect the presence of land subsidence, such as in Surabaya [4], Jakarta [5], Bandung [6], and
Semarang [7]. In this study, InSAR time series analysis was used with a time span from 2015 to 2019 to detect land subsidence that occurred in the Yogyakarta City area. SLC Sentinel-1 imagery from 2015 to 2019 is used with a time span between images (temporal baseline) of 3-4 months. This study also seeks to determine the annual subsidence pattern in the city of Yogyakarta.

2. Data and methods

The image used in this study is the Sentinel-1 image. Sentinel-1 is a radar satellite that consists of a constellation of two satellites, namely Sentinel-1A and Sentinel-1B. Sentinel-1 has a C-band SAR instrument with a wavelength of 5.6 cm and has a temporal resolution of 12 days. The radar instrument on Sentinel-1 that emits its own electromagnetic waves (active remote sensing), allows it to capture image regardless of the weather and time (day or night).

In this study the SLC Sentinel-1 image was used with the acquisition mode Interferometric Wide Swath (IW), VV polarization and flight direction descending. As many as 21 images used from 2015 to 2019 with a time span between images (temporal baseline) of 3-4 months. Each of these images will be paired into a master and slave to make the interferogram. Processing is done using the SNAP (Sentinel Application Platform) and QGIS.

The image used in the Interferometric Wide Swath (IW) mode acquisition has 3 sub-swaths with each sub-swath consisting of several bursts. To reduce processing time, a split is performed on sub-swath and burst where the location of Yogyakarta City is located. Split each image to produce 3 bursts. The second step is processing to make an interferogram. The stages include: correction of the orbit file, coregistration, interferogram generation, and deburst. The third stage is topographic phase removal, multilooking, and filtering phase. The fourth stage is the unwrapping phase to get the absolute phase and convert the phase into a vertical displacement value. After the vertical displacement value is obtained, coherence filtering, geocoding, stacking and adding to the image in the same year is done to determine the annual subsidence pattern.

![Interferogram generation processing flow](image1)

**Figure 1.** Interferogram generation processing flow

![Data processing flow for topographic phase removal, multilooking, phase filtering, and phase unwrapping](image2)

**Figure 2.** Data processing flow for topographic phase removal, multilooking, phase filtering, and phase unwrapping
3. Result and discussion

The results of interferograms that have been unwrapped and converted into vertical displacement phases are displayed and analyzed to determine the occurrence of subsidence. The vertical displacement per interferogram is then added up annually to find out the annual subsidence pattern.

3.1. Vertical displacement per interferogram

Interferogram that has been processed into vertical displacement is shown in the following figure.

![Figure 3. Vertical displacement per interferogram in 2015-2016](image-url)
Figure 4. Vertical displacement per interferogram in 2017-2018

Figure 5. Vertical displacement per interferogram in 2019
From the results of making vertical displacement, subsidence was detected in 2015 to 2019. In 2015 there were subsidence between January and July. In 2016 there were subsidence in January to April and July to October. In 2017 there are subsidence in January to July. In 2018 subsidence occur in April to July and October to December. In 2019 subsidence were detected throughout the year, January to October.

3.2. *Total vertical displacement per year*

Each Vertical Displacement in each year is added up to get the total subsidence that occurs annually. Interferograms which did not show any subsidence were not included in the calculation because of the possibility of the interferogram data being affected by atmospheric noise effects, which in this study did not remove atmospheric noise effects methods such as PSI/SBAS.

![Image of vertical displacement maps for 2015, 2016, and 2017](image-url)

**Figure 6.** Total vertical displacement in 2015-2017
Figure 7. Total vertical displacement in 2018 & 2019

The total subsidence that occurred in 2015-2017 did not show a certain pattern. In 2015 the subsidence occurred in the northeast region, while in 2016 it occurred in the west to northwest region, and in 2017 it occurred in almost all regions of Yogyakarta City, with high subsidence intensity in the western region. In 2018 and 2019, the subsidence that occurred showed a pattern of increasing intensity, i.e. subsidence occurred in the southeast region, where in those regions the intensity increased in 2019.

4. Conclusions
This study shows that there is subsidence in the city of Yogyakarta. The total subsidence that occurred in 2015 to 2017 did not show any specific pattern, whereas in 2019 & 2019 there was an increase in the intensity of subsidence in the southeast.

References
[1] BPS 2018 Kota Yogyakarta Dalam Angka 2018 (Yogyakarta)
[2] Rozano B and Yan W 2018 Monitoring the transformation of Yogyakarta’s urban form using remote sensing and Geographic Information System in IOP Conference Series: Earth and Environmental Science.
[3] Abidin H Z, Andreas H, Gumilar I, Fukuda Y, Pohan Y and Deguchi T 2011 Land subsidence of Jakarta (Indonesia) and its relation with urban development Nat. Hazards vol 59
[4] Anjasmara I, Yulyta S, Cahyadi M N, Khomsin K, Taufik M and Jaelani L 2018 Land subsidence analysis in Surabaya urban area using time series InSAR method vol 1987
[5] Abidin H Z et al 2005 Monitoring Land Subsidence of Jakarta (Indonesia) Using Leveling, GPS Survey and InSAR Techniques BT - A Window on the Future of Geodesy pp 561–566.
[6] Gumilar I, Abidin H Z, Hutasoit L M, Hakim D M, Sidiq T P and Andreas H 2015 Land Subsidence in Bandung Basin and its Possible Caused Factors Procedia Earth Planet.
Abidin H Z, Andreas H, Gumilar I, Sidiq T P and Fukuda Y 2013 Land subsidence in coastal city of Semarang (Indonesia): Characteristics, impacts and causes Geomatics, Nat. Hazards Risk