Watershed Flood Vulnerability Assessment Based Land Subsidence Analysed from a Long Time Period of Sentinel-1 Radar Data

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Abstract. Identifying flood vulnerability in an area is part of disaster risk management, especially for mitigating flood events. The level of vulnerability can be recognized from many factors. One of the primary sources of flood vulnerability in urban lowland areas is land subsidence. Sentinel Radar data has been proven to be able to produce land subsidence data accurately. This study was conducted using two Sentinel 1A Radar data acquired on 7 December 2014 and 20 August 2021. Determining the level of flood vulnerability, the analysis of land subsidence is operated at the watershed scale. The highest land subsidence recorded in the Kali Sunter watershed area was 81mm in Kayuputih Village, East Jakarta City. The villages classified as “Extremely Vulnerable” are Sunurbatu in Central Jakarta City, Kayuputih in East Jakarta City, Kelapagading Barat in North Jakarta City, and Mekarsari in Depok City.

1. Introduction
Floods are still the source of the most frequent disasters in the world. The increase of precipitation and weather anomalies are the causes of the intensify of floods [1]. The increase in flood events is also triggered by physical environmental conditions and changes in land use, such as loss of vegetation cover and growth of the built-up area [2]. Although environmental conditions continue to change, disaster risks can be mapped and mitigated appropriately as part of disaster risk management [3]. Disaster mitigation activities can be carried out in several ways. One of them is by identifying the level of vulnerability of an area. The level of vulnerability describes the risk of a disaster or possible loss and indicates the locations that require more attention and protection to reduce the impact that may be caused [4]. The level of vulnerability can be determined by analyzing all environmental aspects, including the physical, social, and economic environment in an area. The vulnerability level depends on the type and intensity of exposure, sensitivity, and adaptive capacity of an area. The data scale and availability also affect the accuracy of identifying its level [5].

One of the variables that can be used to measure the level of vulnerability is land subsidence. It has been a significant problem in urban areas. Irresponsible use of groundwater [6] and the construction of high-rise buildings [7] have caused significant land subsidence. Land subsidence can create basins that turn out to trap water flow. Water from upstream cannot be adequately streamed through existing waterways but will cause inundations that can potentially become floods. This risk is exceptionally to occur, especially in lowland areas with gentle and flat slopes. In coastal areas, land subsidence also
affects the possibility of seawater going through the mainland and increases the severity of the flood events [8].

Using Sentinel Radar data has been proven to produce land subsidence data accurately [9]. This image data has a 10-meter spatial resolution to generate the information in a detailed map. Land subsidence research that has been done previously has only been carried out over a short period [6], [9]–[11]. Most of them are only various for a few months or a few years. In this study, the time used was quite long. The Sentinel-1A image utilized is the image acquired in the same year as the satellite launched. It, which was launched on 3 April 2014, provides consistent images till present. This study was conducted using two 7-year different image data, which were acquired in 2014 and 2021. This comparison offered significant land subsidence data on the research area.

Determining the scope or specific boundary is an essential step for analyzing the vulnerability level. In terms of the flood events, the administrative line is proper less for assessing the flood vulnerability. Based on hydrology terms, using a river basin or watershed border will be more relevant. Therefore, this study is applied to the watershed scope. The land subsidence rate can be identified in all upstream and downstream regions using the watershed boundary approach. In previous studies, this analysis was only carried out in lowland, especially in coastal areas related to sea-level rise [7], [10], [11]. However, the level of vulnerability is delivered based on the village area. This paper aims to provide flood vulnerability levels for all villages in the Kali Sunter watershed based on the land subsidence rate. This rate was generated from The Sentinel Radar data using the DInSAR method [12].

2. Method

This research was conducted in the Kali Sunter watershed area on Java Island, Indonesia, which is positioned at 106°50’10” - 106°50’40” E and 6°9’50” - 6°20’70” L (Figure 1). This watershed crosses the provinces of West Java and DKI Jakarta, with most of the area located in the Capital City. Administratively, the Kali Sunter watershed is located in 6 districts, 23 sub-districts, and 89 villages. The Kali Sunter watershed has two main rivers: the Sunter river on the east and the Cipinang river on the west part. The Kali Sunter watershed can be classified as a lowland watershed whose upstream has an altitude of 125 m above sea level.

![Figure 1](https://example.com/Figure1.png)

**Figure 1.** The position of the Kali Sunter Watershed.

Land subsidence analysis was carried out using Radar Sentinel 1A image data of SLC (Single Look Complex) type with VV polarization, which were acquired on 7 December 2014 and 20 August 2021. This data was downloaded from the [https://scihub.copernicus.eu/dhus page](https://scihub.copernicus.eu/dhus page/#/home), which is the official
website of the European Space Agency (ESA) to disseminate of image data. Sentinel image data processing utilized the SNAP and SNAPHU applications, which can also be obtained from the ESA website. Topographic data such as DEM/SRTM are provided online through the application. The image processing stage used DInSAR (Differential Interferometry Synthetic Aperture Radar) method to identify displacement in a specific area using certain steps (Figure 2).

**Figure 2.** Process for generating flood vulnerability map. The work consists of two main stages: a) image processing from Sentinel-1A, b) spatial analysis for producing the flood vulnerability map.

The spatial analysis process for examining the land subsidence data and assessing flood vulnerability operated using the ArcGIS ESRI software (Figure 2). After obtaining land subsidence data, the value is then reclassified into specific classes using the mean land subsidence value (Table 1.). The flood vulnerability level is generated from the mean value calculated from the total number of land subsidence divided by the area.

| Land subsidence average (mm) | Flood vulnerability level |
|-----------------------------|---------------------------|
| 0 to -5                     | Not Vulnerable            |
| -6 to -10                   | Less Vulnerable           |
| -11 to -20                  | Vulnerable                |
| < -20                       | Extremely Vulnerable      |

3. Results and discussion

3.1. Land subsidence

Using Sentinel-1 Radar data with the DInSAR method can identify land displacement, indicating the level of land subsidence. This study shows that the highest land subsidence in the Kali Sunter watershed area is 81mm in Kayuputih Village, East Jakarta City (Figure. 3a). The average land subsidence rate in this village area is recorded at 24mm. The Kayuputih Village could be included in the coastal area of Jakarta, which its distance is ±8km from the northern coast of Jakarta. This displacement value means that this area has had an 11.6mm/year land subsidence rate for seven observed years. This value is lower than the land subsidence between 1989-2007, which reached 22.2-33.3mm/year [13]. This condition is understandable because the pattern of development in Jakarta after 2010 tends to be more stable. After all, almost the entire area has become built-up land. The exciting finding is that the displacement occurs in the coastal areas and in higher areas. A significant shift also occurred in Mekarsari Village, located...
at 80m above sea level. At this location, the maximum subsidence reaches 51mm. This study also recorded the land rises for several locations, but the majority and the average show the reasonable land subsidence rate.

Figure 3. Land subsidence rate in Kali Sunter watershed from 7 December 2014 until 20 August 2021 (unit in mm; a negative value means land subsidence event).

Figure 4. flood Vulnerability map visualized based on village boundary.

3.2. Flood vulnerability
The level of flood vulnerability is generated from the average value of the rate of land subsidence in the entire village area. The study resulted that four villages classified as “Extremely Vulnerable”, 22 villages as “Vulnerable”, 51 villages as “Less Vulnerable,” and 13 villages as “Not Vulnerable” (Table 2.). All the villages classified as “Extremely Vulnerable” are located in different districts; Sumurbatu in Central Jakarta City, Kayuputih in East Jakarta City, Kelapagading Barat in North Jakarta City, and Mekarsari in Depok City. The Mekarsari village is on the floodplain of the Cipinang river and is still segmented as the upstream of Kali Sunter Watershed. The Sumurbatu, Kayuputih, and Kelapagading Barat are nearer to the coastal line of Jakarta. The “Not Vulnerable” villages are mostly located on the watershed's edge (Figure 4). This location is on the top of the gully side that is relatively safer to the flood event.
Table 2. Distribution of villages in Kali Sunter watershed based on their level of vulnerability.

| District / Level | Not Vulnerable | Less Vulnerable | Vulnerable | Extremely Vulnerable |
|------------------|----------------|-----------------|------------|---------------------|
| Central Jakarta City | Rawasari | Galur, Joharbaru, Cempakaputih Barat, Cempakabaru | Cempakaputih Timur, Kampungrawa, Harapanmulia | Sumurbutu |
| East Jakarta City | Utankayu Timur, Ciracas, Kayumanis, Cipinang-cempedak, Utankayu Utara | Cipayung, Jatinegara, Pinanggranti, Setu, Rawaterate, Kelapadua Wetan, Susukan, Pisangan Timur, Pondokranggon, Dukuh, Kramatjati, Pisanganbaru, Lubangbuaya, Halimperdana-kusuma, Kebonpala, Cipinang Besar Utara, Cilangkap, Cipinang Besar Selatan, Cawang, Cipinangmelayu, Rawamangun, Makasar Sungai Bambu, Rawa Badak Selatan, Tugu Utara, Tugu Selatan, Pegangsaan Dua, Koja, Cilincing, Kebonbawang, Lagoa, Semper Timur, Semper Barat, Kalibaru, Rawa Badak Utara, Kelapa Gading Timur | Cibubur, Rawabunga, Jatinegarakaum, Bambuapus, Ceger, Cipinangmuara, Pekaya, Klender, Pulogadung, Jati, Rambutan, Cililitan, Munjul, Pondokbambu, Cipinang | Kayuputih |
| North Jakarta City | | | Sunter Jaya | Kelapagading Barat |
| Depok City | Leuwinanggung, Ciampeun, Cilandak | Curug, Sukamaju Baru, Tapos, Jatijajar, Sukatani | Cisalak Pasar, Harjamukti | Mekarsari |
| Bekasi City | Jatiranggon, Jatimurni, Jatirahayu | Jaticempaka, Jatiwarna, Jatiraden, Jatikarya, Jatisampurna, Jatiwaringin | | Jatimelati |
| Bogor | Ciriung | | | |

4. Conclusion
One of the variables that can reflect the level of flood vulnerability is land subsidence. It can be identified from land displacement generated using Sentinel-1 Radar data with the DInSAR method. The highest land subsidence in the Kali Sunter watershed area is 81mm and found in Kayuputih Village, East Jakarta City. Four villages are classified as “Extremely Vulnerable” and possibly face a severe flood event in the future. Further study could combine multivariable data, including social and economic information, for understanding flood vulnerability in such areas.
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