Abstract— Palembang City locates at lowland where 70% of the city has an elevation from 0 to 5 m above mean sea level. With tremendous development and land-use change, Palembang City has faced more problems with a flash flood and a larger inundated area. This paper presents a study on the subsidence on Palembang City using remote sensing data. The Synthetic Aperture Radar (SAR) data set, which ranged from within one year, two years and three years were used in this study. The terrain corrected interferogram phase, and the displacement maps were analysed and generated using Differential Interferometric Synthetic Aperture Radar (DInSAR) technique in Sentinel’s Application Platform (SNAP) toolbox. From the study, it is discovered that the land subsidence in Palembang City occurred with an average velocity of 38 mm/year. The land subsidence causes the further problem of an inundated area worsens the existing runoff water discharge which controlled by the tide of Musi River. There are 1.8 km² of a possible extension of a daily flood-prone area within the administrative boundary of Palembang City.

Keywords—remote sensing, DInSAR, land subsidence, flood

I. INTRODUCTION

Natural subsidence happened due to an isostatic load of Holocene deposits from sediments and natural compactions or as a consequence of tectonic and volcanic operations [1]. The land subsidence is also determined by gentle and or as a consequence of tectonic and volcanic operations [1]. The land subsidence caused defects to buildings and other infrastructures. The other impacts were mostly indirect, such as widening the flood-prone area due to the sinking of land.

Traditionally, monitoring land subsidence was conducted by using an optical levelling survey and Global Positioning System (GPS) survey [2, 3, 10]. The techniques measure the elevation of benchmark point (TBM) within local and regional networks. The traditional GPS survey relative costly regards to instrumentation and installation cost. The use of image data taken from satellite using active sensors for decision making is increasingly practised. The coverage area and adequate revisiting time made the data become an alternative in earth observation tasks [16-18].

This paper presents the analysis of land subsidence velocity for Palembang City within three years with comparative numerical data taken during the dry season and rainy season. The aim is to determine land subsidence rate in a year, locate the area subject to land subsidence and evaluate with the flood event for possible determination of inundated area. Remote sensing data from Sentinel satellite is used for this study. Palembang historically was known as a city with hundreds of rivers and a wetland city since the colonial period in the early 20’s century. Palembang City converted its wetland up to 55% in 2010. The city has lost around 220 tributaries and remaining only 95 tributaries flowing to the Musi River. The loss of natural drainage increased the trend of flooding from 18 events in 2007 to 46 events in 2012 [19].

II. REMOTE SENSING APPLICATION FOR EARTH OBSERVATION

Application of Earth Observation (EO) by using remote sensing data from satellite have shown over the past two decades. It is due to the advancement of performance of satellite system and improvement in temporal and spatial
resolution of the data which cover a wider area. Other than that, the computational power of the computer was increased, reducing time to process the data with a sophisticated system to reduce atmospheric disturbance in radar data [17].

Sentinel-1 (S1) is the first of the Copernicus Programme of the satellite constellation. The mission of the S1 compound of two satellites performing C-band synthetic aperture radar imaging. The S1-A was launched in 2014 and the second satellite in the constellation, the S1-B was launched in 2016. This satellite constellation conducted by the European Space Agency. The satellite constellation has six days repeat cycle observing the earth from 632 km altitude at 20 m ground resolution covering an area of 250 by 170 km.

III. STUDY AREA

The study area presented in this paper is Palembang City. Palembang is the capital of the South Sumatra. It lies between 2°52’ to 3°5’ South latitude and from 104°37’ to 104°52’ East longitude. The terrain condition of Palembang City is almost flat on low land with elevation less than 5 m above mean sea level. The city of Palembang has an area of 401 km² divided into 18 districts. It is surrounded by three regencies (i.e., Banyuasin Regency on its north; Muara Enim Regency and Ogan Ilir Regency on the south). Palembang City is a major hub for industry in Indonesia. The textile, paper, wood, chemicals, pharmaceuticals, rubber and plastic product. The industrial and plantation products are transported through the Musi River.

Palembang is in tropical climate conditions with two seasons predominantly dictated by monsoon from the Northwest. Average temperatures vary between 26°C and 29°C. Due to the northwest monsoon blowing, the rainy season takes place from December to March. The average peak precipitation in the rainy season is 77 mm with 18 –19 days of rain per month. During the rainy season, there is a prevalent issue; some regions in Palembang City are flooded. The quantity of rainfall received reduced gradually between April and September and became known as the transitional season followed by the dry season. In August and September, the minimum precipitation happened. The average evaporation is between 85 and 124 mm per month. Fig. 1 displays monthly precipitation and temperature quantity in Palembang City.

![Average monthly precipitation](image1)

Geologically Palembang City is laid on top of the swamp deposit layer from the Holocene era. The Northwest part of Palembang City, the geological formation from the Miocene era, as shown in Fig. 2. The soil layer in Palembang City is predominantly clay, sandy clay, marlstone and sandy marlstone [20, 21].

There were new urbanised open spaces on South and South-East of Palembang City. It is aligned with the development sports facilities from 2006 to 2018 for National
and international games (i.e. SEA Games in 2014 and preparation of ASIAN Games in 2018). The expansion of urbanised open space in Palembang City was following the increase of the population. From 1990 to 2013 there were increasing by about 1.7% of the population from 1.19 million to 1.72 million. Within Palembang City, the high-density area and medium density area are scattered on an average elevation of 4.2 ± 2.6 m and 4.8 ± 3.4 m respectively.

Flooding in Palembang City happens typically during the rainy season from October to March where the amount of received rainfall more than 150 mm/h. Many other factors caused the flooding and inundation, which were directly and indirectly, contributed to the flood. The main elements are due to uncontrolled land-use change, high rainfall intensity and insufficient drainage capacity of the urban drainage water management system. There are areas considered having high vulnerability to inundation. The vulnerability is mainly dictated due to the area was developed for urban purposes larger than 60%. One case was in sub-river system (SRS) of Lambidaro River, where the drainage capacity is insufficient [23, 24]. Fluctuation tide on Musi River plays a significant role in contributing the flood as well. The water level of Musi River is varying from the highest of +3.7 m above MSL during the rainy season and the lowest of +1.8 m above MSL during the dry season [25].

In the last recent years, five drainage systems from 19 drainage systems, which are integrated within SRS in Palembang City, are still facing flooding and inundation problems. Those five drainage systems are SRS of Lambidaro River, SRS of Sekanak River, SRS of Bendung River, SRS of Buah River and the SRS of Sriguna River located at an altitude about 3 m above MSL [20]. Last year on November 13, 2018, the city was poured with 6 hours rainfall. The existing retention ponds have insufficient storage capacity causing some SRS were inundated in-depth ranged from 60 – 100 cm in Pahlawan District, which is in SRS of Bendung River. At Poligon settlement, which is in SRS of Lambidaro River, the height of inundation was from 20 – 60 cm.

IV. STUDY METHOD

In this study, the Sentinel 1-A (S1-A) of Interferometric Wide Swath (IW) level 1 processed Single Look Complex (SLC) data Complex images for three consecutive years were used to generate one-year interferogram and displacement map of Palembang City. The data acquisition date was 16th March 2016 to 1st March 2019 using C-band Synthetic Aperture Radar (SAR) sensor in 3 separated sub-swaths, and each sub-swath consist of a series of bursts. Each burst is a processed SLC image. The basic properties of the S1 IW SLC product are shown in Table I. The SAR data set used in this study are listed in Table II.

![Fig. 4. High and medium density residential area overlaid on DEM](https://example.com/fig4.jpg)

### Table I. The Basic Properties of a Pair of SLC SAR Data for Land Subsidence Analysis

<table>
<thead>
<tr>
<th>Property</th>
<th>Master</th>
<th>Slave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data size</td>
<td>7.25 GB</td>
<td>7.25 GB</td>
</tr>
<tr>
<td>Relative orbit</td>
<td>171</td>
<td>171</td>
</tr>
<tr>
<td>Ingestion date</td>
<td>2018-0307</td>
<td>2018-0307</td>
</tr>
<tr>
<td>Orbit number (start and stop)</td>
<td>20893</td>
<td>20893</td>
</tr>
</tbody>
</table>

Source: The Copernicus Open Access Hub [26]

<table>
<thead>
<tr>
<th>Data set type</th>
<th>Acquisition Date</th>
<th>Time difference (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>16 March 2016</td>
<td>1080</td>
</tr>
<tr>
<td>SLC</td>
<td>11 March 2017</td>
<td>720</td>
</tr>
<tr>
<td>SLC</td>
<td>8 March 2018</td>
<td>357</td>
</tr>
<tr>
<td>SLC</td>
<td>29 May 2018</td>
<td>276</td>
</tr>
<tr>
<td>SLC</td>
<td>21 August 2018</td>
<td>192</td>
</tr>
<tr>
<td>SLC</td>
<td>7 December 2018</td>
<td>84</td>
</tr>
<tr>
<td>SLC</td>
<td>1 March 2019</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: The Copernicus Open Access Hub [26]

The steps to generate the terrain corrected interferogram phase and the displacement using Differential Interferometric Synthetic Aperture Radar (DInSAR) technique in Sentinel’s Application Platform (SNAP) toolbox version 6.0.1. are shown in Fig. 5. The SNAP is a common open-source architecture for toolboxes software which is developed to process remote sensing data published by European Space Agency (ESA). In step 1, the raw SAR image cropped into selected four bursts in IW3 sub swath with VV polarisation. Orbit file was then applied to the selected bursts. The process was followed by coregistration using back geocoding and enhance spectral diversity for interferogram generation. The deburst operation will merge the interferogram. Step 2 was conducted to prepare the unwrapped phase of interferogram by removing the topographic induced phase using Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) at 30 m data and apply multilook processing from the Debursted
Interferogram using Lee filter. The multilook processing is aimed to reduce speckle appearance and improve image interpretability. The processes were conducted in SNAP and the wrapping process was performed in the Snaphu software. The next processes in step 3 were started with importing the wrapped phase of the interferogram and continued with converting the phase into displacement. At this stage, the phase and displacement maps were completed.

The next process was preparing the phase and displacement data for further processed in GIS by conducting the terrain correction assigning the correct projection of the data. Masking of the DInSAR of phase, displacement and coherence were conducted using vector data of Palembang City’s extension of built-up urban and sub-urban for June 2013 data. Geospatial data from government bodies were used for this study. The geospatial data were published openly in Geportal Sumatera Selatan which is established in supporting the Presidential Regulation of the Republic of Indonesia No. 9 of 2016 on geospatial information for development. The geospatial data which was used in this study are listed in Table III.

<table>
<thead>
<tr>
<th>Geospatial Map</th>
<th>Date</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial pattern map</td>
<td>2012</td>
<td>Regional body for planning and development</td>
</tr>
<tr>
<td>Daily flood-prone area map</td>
<td>14 May 2013</td>
<td>South Sumatera Province’s Ministry of Energy and Mineral resources</td>
</tr>
</tbody>
</table>

TABLE III. GEOSPATIAL DATA SET

The coherence value from processed C-band SAR data will subject to have low coherence interferometry and low backscatter value when it was reflected from vegetation and water body. The coherence value is measured from the decorrelation of two co-registered acquisitions, which has a range of values of 0.0 to 1.0. The vegetation is not a stationary object, and for a water body, it reflects the radar
signal away from the antenna in the specular direction. Both caused low coherence and low back-scattered value. Other than that, the C-band SAR data affected by the atmospheric noise [27-29].

Fig. 7. Comparative data for coherence resulted from the different time data set

The subsidence velocity that was masked by the urban extension map is shown in Fig. 8 for time difference 357 days data set. It is shown in Fig. 8; the mean subsidence velocity is 38 cm/year.

Fig. 8. 1-year land subsidence (m)

By using data from Palembang City’s spatial pattern, the land subsidence velocity on high-density housing area was calculated. It gives the subsidence velocity value in a range from 5 mm/year to 55 mm/year. The range of average subsidence velocity for time difference of 3 years data set is shown in Fig. 9.

Fig. 9. Histogram of overall subsidence velocity

Fig. 10 shows subsidence for two years (i.e., 720 days of time difference data set). It is found that there is propagative subsidence velocity that was occurred compared to 1-year time difference data set. The average subsidence velocity is 45 mm/year. The subsidence is ranged from 5.4 mm to 23.4 cm. Within the high-density housing area, the mean subsidence is 82.6 mm ± 7.5 mm.

Fig. 10. 2 years subsidence map (m)

The 1-year subsidence velocity is shown in Fig. 11. The daily flood-prone area within Palembang City will extend to a more significant area if the subsidence velocity rate of 38 mm/year is propagated. The area which is inundated by the flood will be expanded and become deeper by the existence of land subsidence. Fig. 11 shows a set of images consist of a daily flood-prone area in Palembang City overlaid on 1-year subsidence velocity map and high-density residential area as in A. The two inset images which show area with subsidence velocity more than 5 cm/year, are shown in B and C respectively. Those areas have an elevation of 3 m and 5 m. It shows that there is a possible extension of flood-prone area due to land subsidence. The area is located close to swamp conservation area (i.e. the blue area in insert B and C). Extension of flood-prone area will be about 1.8 km² within the administrative boundary of Palembang City based on the area that is subjected to 5 cm subsidence on 5 m surface elevation above MSL.

Fig. 11. Land subsidence near swamp conversion area in Palembang City.
VI. CONCLUSION

Palembang City subjected with average 1-year subsidence velocity of 38 cm/year and average subsidence velocity of 45 cm/year from 2 years data set analysis. The land subsidence has mostly occurred in the area, which is close to the swamp conservation area. From this study, it is found that there are 1.8 km² of a possible extension of a daily flood-prone area within the administrative boundary of Palembang City. Validation of the finding from the study was based on flood event occurred. The use of radar data which is available for the public provided by ESA will be able to serve the need of reliable information on earth observation especially for land development, disaster prevention, disaster mitigation and monitoring. This effort is aligned with the initiative of the Government of Indonesia in utilizing geospatial data since 2010 and was regulated in the Presidential Regulation No. 9 in 2016.

ACKNOWLEDGMENT

The authors would like to thank Universiti Tenaga Nasional, Malaysia for the opportunity to publish this paper under the MOU with Universitas Indo Global Mandiri, Indonesia.

REFERENCES


