Determination of Land Subsidence Caused by Land-Use Changing in Palembang City using Remote Sensing Data

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***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 progressive settlement or as a result of the sudden sinking of the ground surface [2]. The ground subsidence can be a localised collapse or regional scale sinking [3]. Study on correlation of land development, urban settlement growth to land subsidence was conducted in several cities around the world (i.e. Rafjahan, Iran; Tuscani, Italy; highly populated Cities in Indonesia; Yangon, Myanmar; Coastal Cities in Africa; over Germany; Bursa, Turkey; Quetta valley, Pakistan) [4 - 8]. It was shown that the increase of population in a highly populated urban area was not only reshaping the surface but also exploit the natural resources (i.e. gas and groundwater) elevating the land subsidence. Study on land subsidence due to groundwater and gas extraction using remote sensing (RS) radar data for major cities in Indonesia have been conducted [1, 9, 10]. The imbalance and unsustainable groundwater utilisation pushed by the increasing of population extended the land subsidence. Urban development contributes to the change in land use and possibly causing inundation during heavy rain. In Jakarta City, the study of land subsidence has been conducted since 1997 by using several geodetic techniques from levelling survey to remote sensing. From the studies, the spatial and temporal variation of land subsidence rates were about 3 cm to 10 cm/years [10].

Pumping groundwater excessively causing imbalance input and output in an aquifer system is one of the significant land subsidence problems in Italy and Mexico [2, 11, 12]. The same issue of land subsidence occurred in major cities in Indonesia, which are Jakarta, Bandung and Semarang [9, 13, 14]. The land subsidence caused defects to buildings and other infrastructures. The impact was categorised into infrastructural, environmental, economic and social [15]. The effect on infrastructural was direct, showing the defect to the horizontal and vertical structure and infrastructure. 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 km^2 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.

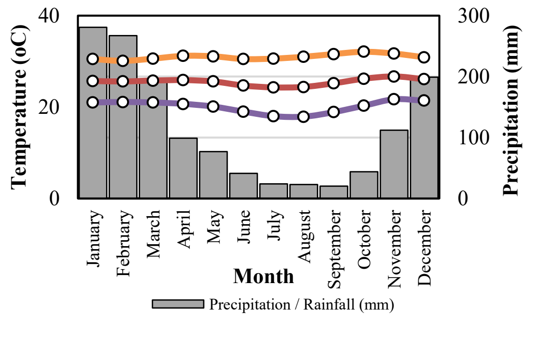

Fig. 1. Average monthly precipitation

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]. In the Palembang City’s spatial pattern which is published in Geoportal Sumatera Selatan, 2018, the conservation swamp area was 23.57 km^2, which is 6% of the total area of Palembang City. The conservation swamp area laid on an average elevation of 1.71 ± 1.98 m above MSL.

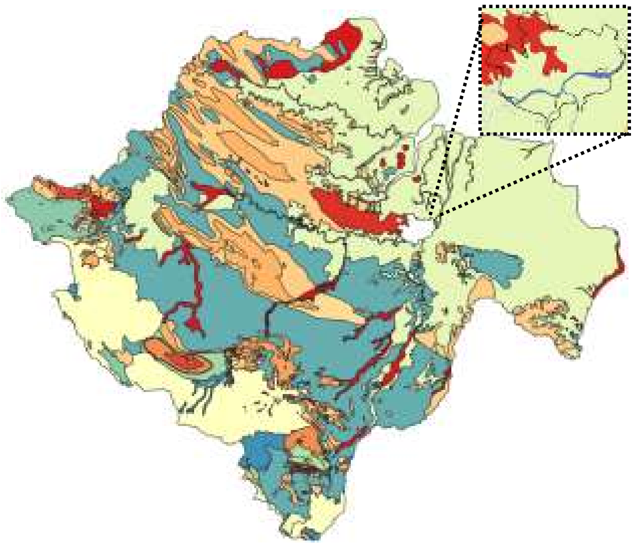

Fig. 2. Geological map of South Sumatra and Palembang City [21]

Fig. 3 shows area within Palembang City, which were occupied as a built-up area in 1990, 2001 and 2013 [22]. The built-up areas are inclusive the urban area with urbanised open space in an urban and suburban area. There is a massive expansion of urban area on the northern Palembang City between 1990 to 2001. The total new urbanised and built-up area from 1990 to 2001 increased about 186.9%. There was approximately 27.5% of increment of the urbanised and built-up area from 2001 to 2013. The Northern area relatively drier and have more stable soil strata.

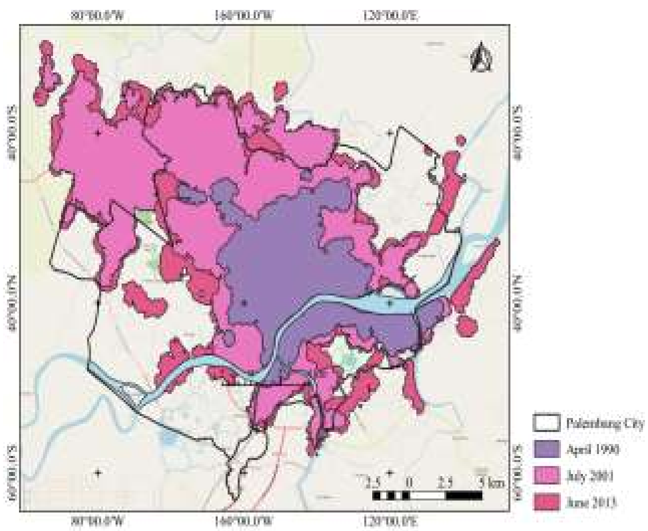

Fig. 3. Urban expansion in Palembang City from 1990 – 2013 [22]

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 sports events (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.

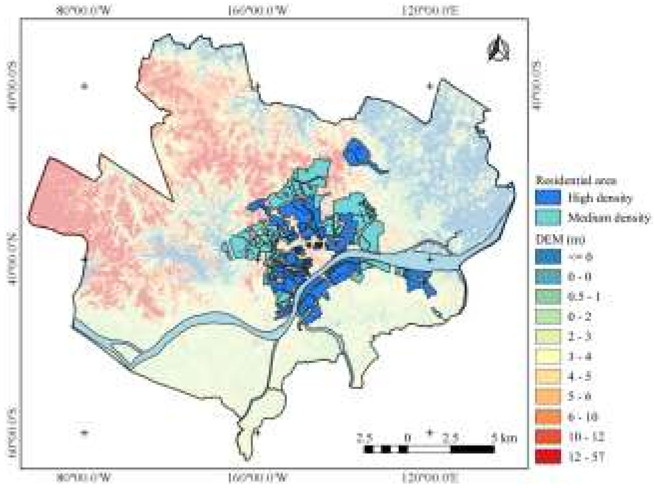

Fig. 4. High and medium density residential area overlaid on DEM

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 RSS 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.

TABLE I. THE BASIC PROPERTIES OF A PAIR OF SLC SAR DATA FOR LAND SUBSIDENCE ANALYSIS

Spatial resolution	5 m (ground range) x 20 m (azimuth)	
Pixel spacing	2.3 m (slant range) x 14.1 m (azimuth)	
Incidence angle	29° – 46°	
Polarization	VH, VV	
Total swath width	250 km	
Product class	SAR Standard L1 Product	
Product composition	Slice	
Product-level	L1	
Product type	SLC	
Slice number	3	
Instrument	Synthetic Aperture Radar (C-band)	
Instrument mode	Interferometric Wide	
Instrument swath	IW1 IW2 IW3	
Data	***Master***	***Slave***
Data size	7.25 GB	7.25 GB
Relative orbit	171	171
Ingestion date	2018-0307 T03:31:27.072Z	2018-0307 T03:31:27.072Z
Mission data take id	146813	146813
Orbit number (start and stop)	20893	20893

Source: The Copernicus Open Access Hub [26]

TABLE II. THE DATA SET AND ITS ACQUISITION DATE

Data set type	Acquisition Date	Time difference (day)
SLC	16 March 2016	1080
SLC	11 March 2017	720
SLC	8 March 2018	357
SLC	29 May 2018	276
SLC	21 August 2018	192
SLC	7 December 2018	84
SLC	1 March 2019	0

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 Geoportal 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 III. GEOSPATIAL DATA SET

Geospatial Map	Date	Source
Spatial pattern map	2012	Regional body for planning and development
Daily flood-prone area map	14 May 2013	South Sumatera Province's Ministry of Energy and Mineral resources
Geological map	12 November 2012	Atlas of Urban Expansion, New York University

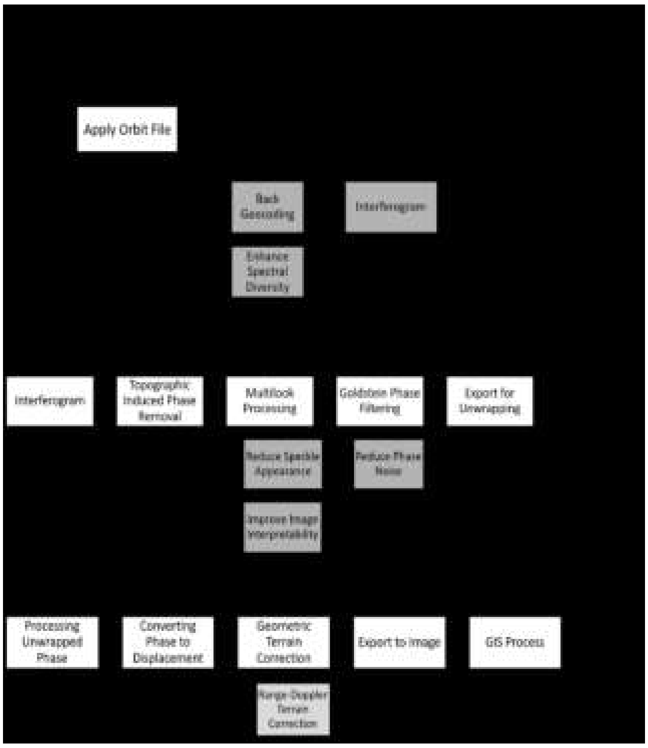

Fig. 5. Steps in processing SLC data for land subsidence using SNAP.

V. DISCUSSION

Land subsidence is found existence in Palembang City. The DInSAR processes on masked high coherence more than 0.2 produced phase and subsidence velocity for one year and two years of data set. The mean subsidence velocity for 1-year is 38 mm/year, and for two years, the mean subsidence velocity is 47.5 mm/year with the highest frequency of subsidence is 85 mm. Shorter time series data set were analyzed as well. Fig. 6 shows a set of processed SAR data from coherence, DInSAR phase, unwrapped phase and displacement sequentially for different acquisition data set. The analysis on coherence giving a prudent understanding of the high coherence and low scattered features on the surface, which will affect directly to the quality of interferogram. Fig. 6 shows a graph on coherence analysis masked within the urban extension of 2013. The urban extension boundary was used to present the area with less vegetation and less water body. It is shown as well that the area within the built-up area still having low coherence value less than 0.4.

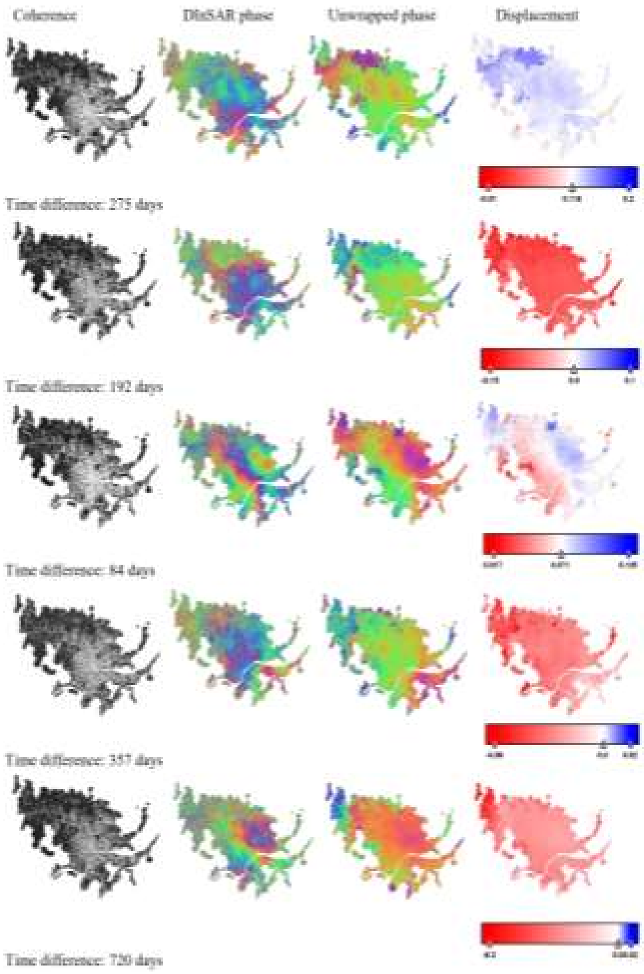

Fig. 6. Processed SAR data for land subsidence

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].

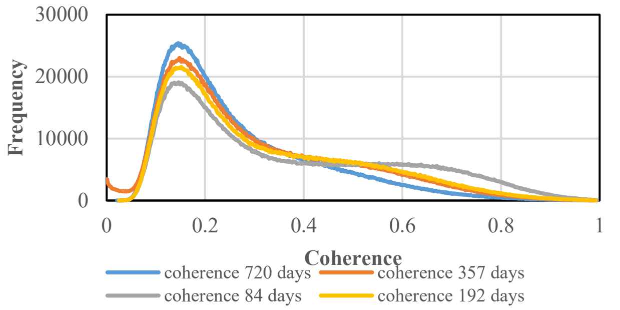

Fig. 7. Comparative data for coherence resulted from the different time data set

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.

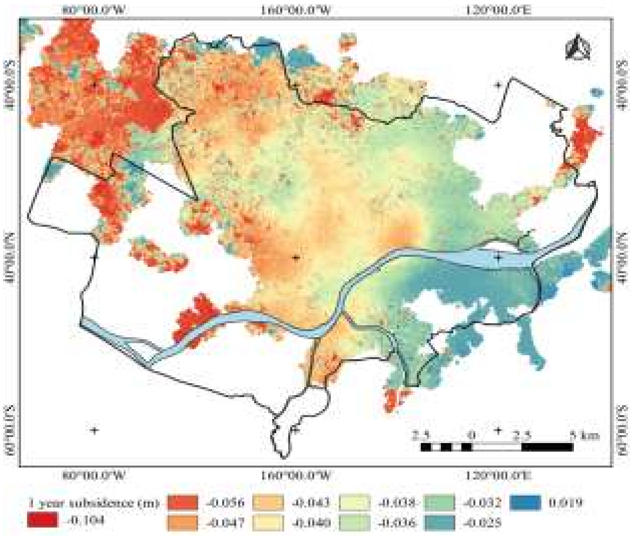

Fig. 8. 1-year land subsidence (m)

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.

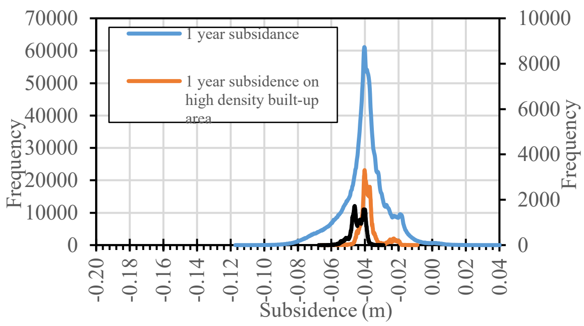

Fig. 9. Histogram of overall subsidence velocity

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.

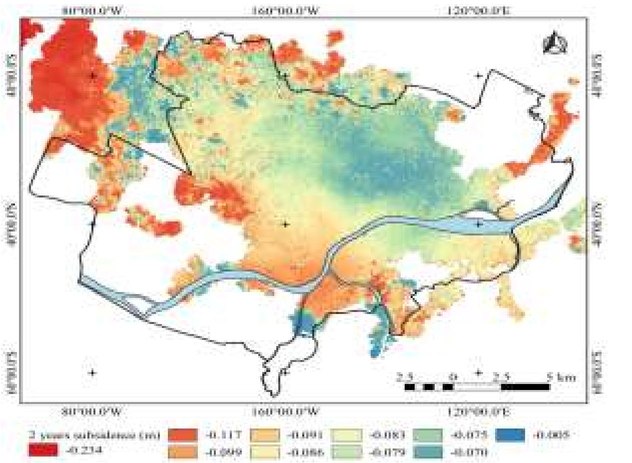

Fig. 10. 2 years subsidence map (m)

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 km^2 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.

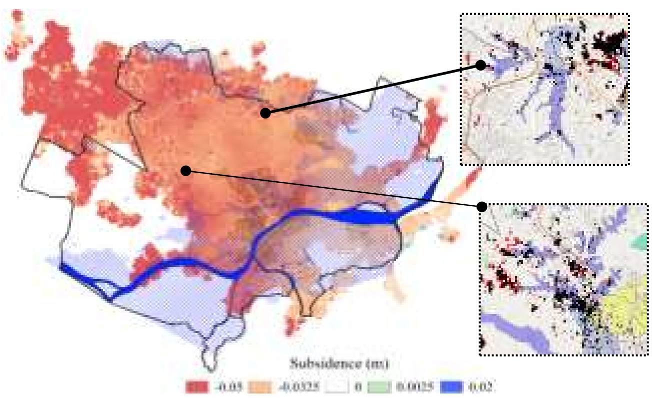

Fig. 11. Land subsidence near swamp conversion area in Palembang City.

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 km^2 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.

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