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Deformation identification using DInSAR multi temporal analysis method in supporting infrastructure development (case study of the area around the nation's new capital)

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Deformation identification using DInSAR multi temporal analysis method in supporting infrastructure development (case study of the area around the nation's new capital)

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Abstract. The relocation of nation's capital is one of the government's flagship programs at this time. The lack of information on soil structures that are prone to deformation can bring an impact on the failure of infrastructure development in the areas of New State Capital (known as Ibu Kota Negara/IKN). Therefore, a significant study is important to find out the deformations that may occur in the region as an initial information in determining the location for safer infrastructure development based on the soil structure conditions in the research area. This research used the Differential Interferometry Synthetic Aperture Radar (DInSAR) method with a multi-temporal approach to identify the deformations in the research area. The data included SAR images of Sentinel 1A type SLC with C band (5.405 GHz) for the period 2015-2019. The results confirmed that deformation had been identified in several areas, both those experiencing subsidence and uplifting. The maximum subsidence was 12.97 cm at Sepaku district on period 2018-2019 and the maximum uplift was 10.01 cm on period 2017-2018. The identified areas with deformation generally take place in areas with a high density of buildings, construction areas, road infrastructure, and river alluvial deposits.

1. Introduction

One of the considerations for choosing the North Penajam Paser and Kutai Kertanegara, East Kalimantan Province as candidates for the New State Capital (known as Ibu Kota Negara/IKN) is that they are the safest areas from disasters, especially geological disasters such as earthquakes and tsunamis [11]. However, based on its geological conditions, the IKN areas do not escape from potential geological disasters caused by ground deformation in the area. Based on the lithology, the research areas are dominated by a fairly thick sedimentary structure, which is part of the Kutai basin. The thick sedimentation is very prone to deformation since it has a relatively weak soil structure.

Based on the geological map, the North Penajam Paser area, which is the site of point 0 of the new IKN development, takes place is included in Balikpapan area. Almost all the rocks in this area had experienced deformation which forms anticlines, synclines, and faults [13]. In the southern area, there is a Holocene age (quarter layer) alluvial deposits with unconformity structure. Based on these geological conditions, the new IKN area has the potential to experience deformation that can trigger geological disasters, such as landslides, subsidence, earthquakes, sink holes, and soil liquefaction. Therefore, it may have a direct impact on the conditions of the infrastructure. Based on the data obtained from the Cent of Volcanology and Geological Hazard Mitigation in the research area, a landslide occurred in the Sepaku district in April 2018, which caused damage to dozens of houses [5].

Therefore, this research used a method to identify and to map the areas that are prone to deformation. This step is one of the attempts to mitigate geological disasters, as well as to provide initial information for planning infrastructure development in the research area. The method used in this research is the Differential Interferometry Synthetic Aperture Radar (DInSAR) multitemporal analysis using SAR Sentinel 1A radar image type Single Look Complex (SLC) with C band to identify the deformation [1][2][4][6][7][10]. The output parameters of the processing results using the DInSAR method was mapped using QGIS software to produce a thematic map of land deformation in the new IKN area.

2. Data And Methods

2.1 Research Area

This research was conducted in the Sepaku and Penajam subdistricts of the Penajam Paser Utara district, East Kalimantan Province. The coordinates of 0.9ºS - 1.38ºS and 116.48ºE - 116.82ºE are presented in figure 1. The location of the deformation observation points in this research is shown in the rectangular location with a red dot (figure 1) as presented in Table 2.

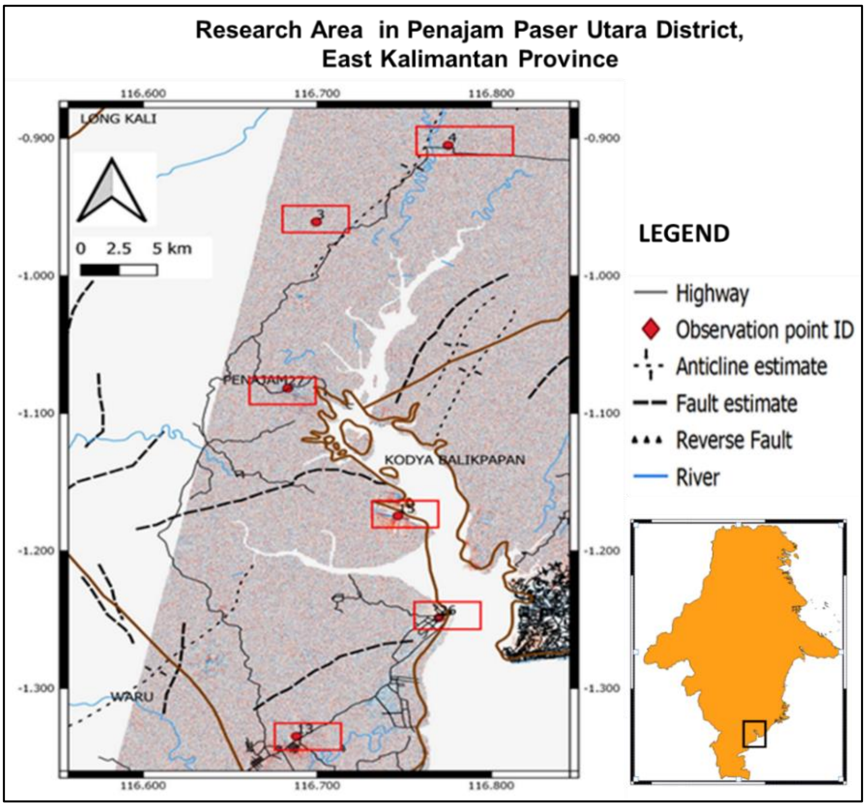

Figure 1. Research area at Penajam Paser Utara District.

IOP Conf. Series: Earth and Environmental Science **851** (2021) 012017 doi:10.1088/1755-1315/851/1/012017

2.2 Data
The data used in this study are secondary data obtained from the following sources:
- Sentinel satellite image data set 1-A with C band (working at a frequency of 5.405GHz and a wavelength of 5.6 cm), Single Look Complex (SLC) type 1st level, period 2015-2019. The data can be downloaded from ASF Alaska via https://vertex.daac.asf.alaska.edu (see Table 1).
- Digital Elevation Model Nasional (DEMNAS) data used to validate the DEM model generated from DInSAR processing. The DEMNAS data has a spatial resolution of 0.27-arcsecond. It can be downloaded via http://tides.big.go.id/DEMNAS/.

The software used in this research includes SNAP (Sentinel Application Platform) version 7.0, and QGIS version 3 software.

Table 1. Sentinel 1A Acquisition Data[a].

Processing Year	Mst/Slv	ID Scene	Acquisition	Polarization	Orbit	Abs Orbit
2015-2016	Mst	S1A_IW_SLC__1SDV_20151213T215045_20151213T215112_009029_00CF3C_47F1	13 Des 2015	VV+VH	Descending	9029
	Slv	S1A_IW_SLC__1SDV_20161207T215052_20161207T215119_014279_0171A9_E4E2	7 Des 2016	VV +VH	Descending	14279
2016-2017	Mst	S1A_IW_SLC__1SDV_20161207T215052_20161207T215119_014279_0171A9_E4E2	7 Des 2016	VV +VH	Descending	14279
	Slv	S1A_IW_SLC__1SDV_20171202T215051_20171202T215118_019529_021262_E608	2 Des 2017	VV+VH	Descending	19529
2017-2018	Mst	S1A_IW_SLC__1SDV_20171202T215051_20171202T215118_019529_021262_E608	2 Des 2017	VV+VH	Descending	19529
	Slv	S1A_IW_SLC__1SDV_20181221T215057_20181221T215124_025129_02C65E_2C74	21 Des 2018	VV+VH	Descending	25129
2018-2019	Mst	S1A_IW_SLC__1SDV_20181221T215057_20181221T215124_025129_02C65E_2C74	21 Des 2018	VV+VH	Descending	25129
	Slv	S1A_IW_SLC__1SDV_20191204T215104_20191204T215131_030204_0373CD_857E	4 Des 2019	VV+VH	Descending	30204

[a]Source: initial inventory of Sentinel 1A data availability

2.3 Processing Method
The processing method used in this research includes the acquisition stage, pre-processing stage, data processing stage, and postprocessing stage. The acquisition process was carried out by downloading secondary data in the form of Sentinel 1A satellite images and DEMNAS data in the research area with the links listed previously. The further details are presented in figure 2, showing the research data processing method. The data processing and analysis techniques of this research were divided into three stages: the data processing technique using the DInSAR method using Snaphu software and the GIS processing using QGIS software.

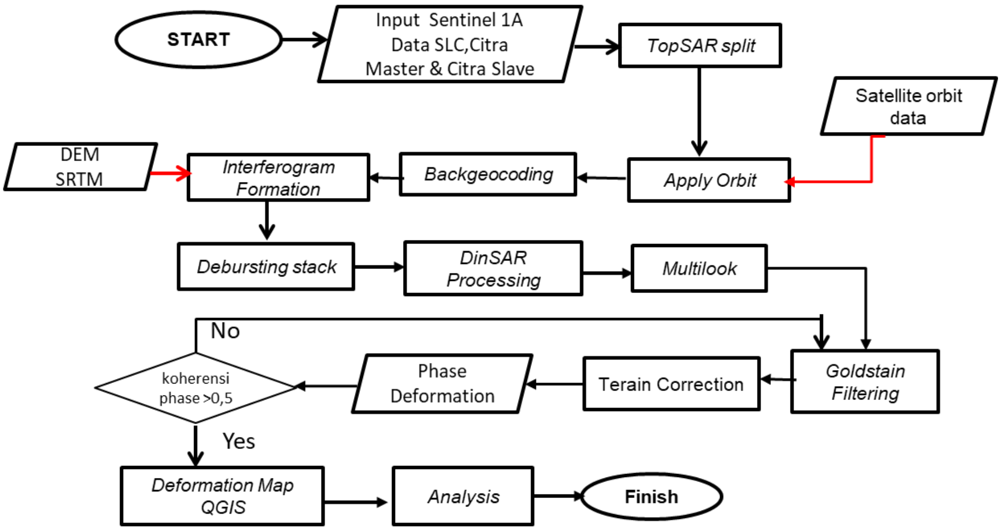

Figure 2. Data processing flow chart on SNAP software.

Data processing using DInSAR method in the initial stages, the TopSar Split process is carried out to divide one satellite image scene into three subwadths (IW) and burst mode (1-9) which covers the research area. This research, the researchers used subwadth IW3 with burst 6 to 9. After the TopSar split process is carried out, the researchers then input the satellite orbit value data. The next process is the formation of an interferogram and input the DEM value, i.e., the SRTM 30 meters 3 seconds [6]. To reduce the noise and to sharpen the fringer on the interferogram, a filtering process was performed, i.e., enhanced spectral diversity. The next step was carried out using TopSar Deburst followed by the process of eliminating the topography phase (Thopo phase removal) and reducing the error phase with the multilooking process. The next process is Goldstain phase filtering to remove noise and increase the coherence value. The final stage is to perform terrain correction. The post processing stage was performed with GIS using QGIS version 3 software to display deformation maps in the research area.

3. Result and Discussion

3.1. Results of Data Processing Using DInSAR Method

Figure 3 shows the phase coherence value resulting from DInSAR processing using SNAP software after the Goldstein filter was carried out. Most of the pixels still have a low coherence value <0.4. The low coherence value indicates that the research area still has a fairly high vegetation density and high noise even though it has gone through the filtering stage. It indicates that the frequency C band (wavelength of 5.6 cm) is not capable enough to penetrate the dense vegetation canopy, so there is considerable noise in the backscatter phase received by the satellite. Therefore, this research only analysed areas that have a coherence value > 0.5 to get the interferogram phase with the best accuracy [4][8].

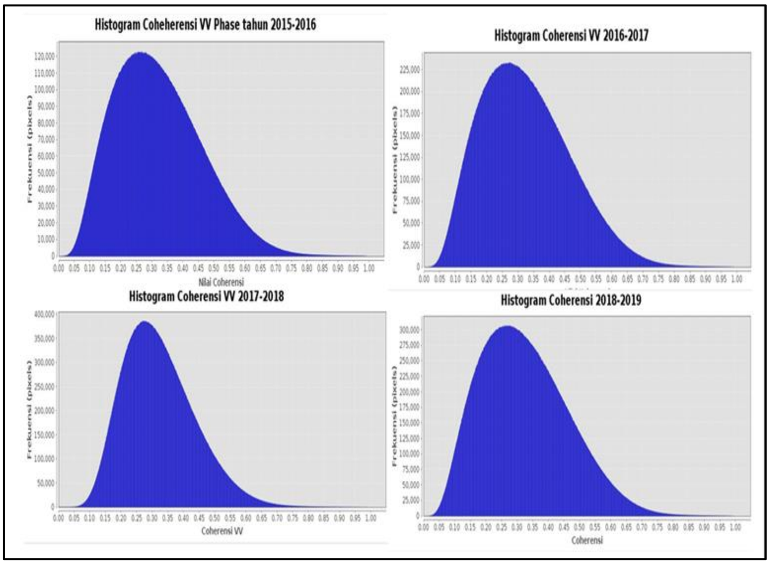

Figure 3. Graph of the coherence value of DInSAR processing result.

In the analysis process, the map of the observation point location is presented in figure 1. The research location, Sepaku district, is shown by point IDs 3,4 and 27. Otherwise, the point samples in Penajam subdistrict are shown by point IDs 13,15 and 26. This research used 6 sample points which became the identified locations where vertical deformation occurred and had a phase coherence value > 0,5. The results of data processing using the DInSAR method at the observation location points are shown in Table 2. On the deformation map (figure 5, 6, 7), the deformation area of the Sentinel 1A image data processing used the DInSAR method with SNAP software. The identified areas getting vertically deformed are indicated by red blocks, showing that the subsidence and the deformation phase is negative, while blue blocks are areas that had experienced an uplift and showed positive phase values. The white areas are generally areas that are relatively stable and do not experience change or deformation. The results of the DInSAR multitemporal processing for the 2015-2019 period showed a maximum subsidence of 12.97 cm and a maximum land increase (uplift) of 10.01 cm (figure 4). The deformation process that occurred in the research area was quite complex. The area where deformation was identified changes every year, whether in the deformation area, the area, or the amount of deformation (cm).

Table 2. Value of data processing results at observation points.

No. ID Point	Subdistrict Name	Coordinate		Magnitude of Deformation (cm)				Deformation Average (cm/year)	Elev. DEMNAS (meter)
		Latitude (°)	Longitude (°)	2015-2016	2016-2017	2017-2018	2018-2019		
3	Sepaku	-0,957	116,693	-2,85	-3,17	-5,06	-5,01	-4,02	55,15
4	Sepaku	-0,905	116,775	-12,42	-5,69	10,01	-12,97	-10,36	9,82
13	Penajam	-1,335	116,688	-7,40	-5,20	-7,40	-5,62	-6,41	26,48
15	Penajam	-1,175	116,746	-9,19	-4,36	-9,19	-7,13	-7,47	8,00
26	Penajam	-1,249	116,770	3,06	2,57	-5,53	-7,48	-6,51	5,27
27	Sepaku	-1,079	116,677	5,80	-5,32	-9,15	-12,04	-8,84	47,00

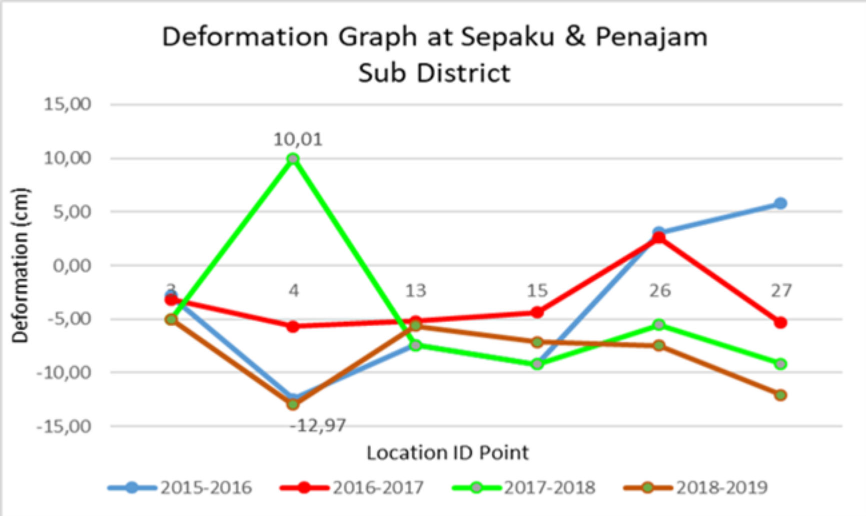

Figure 4. Deformation chart in Penajam and Sepaku district.

3.2. Discussion

The location of point 13 (figure 5) is the terminal area of PT. Pertamina's oil refinery in the Penajam district. In the 2015-2019 period, the location of this point experienced an average land subsidence of 6.41 cm per year. The subsidence occurred at point 13 due to the continuous load from buildings and oil refineries. Meanwhile, the soil structure at the location of that point was not strong enough to withstand the loads of the building above it. The point 26 was a densely populated port city with a fairly high building density. This area was identified as having deformations in the form of subsidence and uplift. The subsidence that occurred at point 26 had a speed of 6.51 cm per year. The subsidence occurred in this area due to the load of buildings with high density and human activities such as groundwater extraction. Based on geomorphology, the uplift that occurred in this area is closely related to alluvial material deposits, because this area is located at the mouth of rivers and the sea.

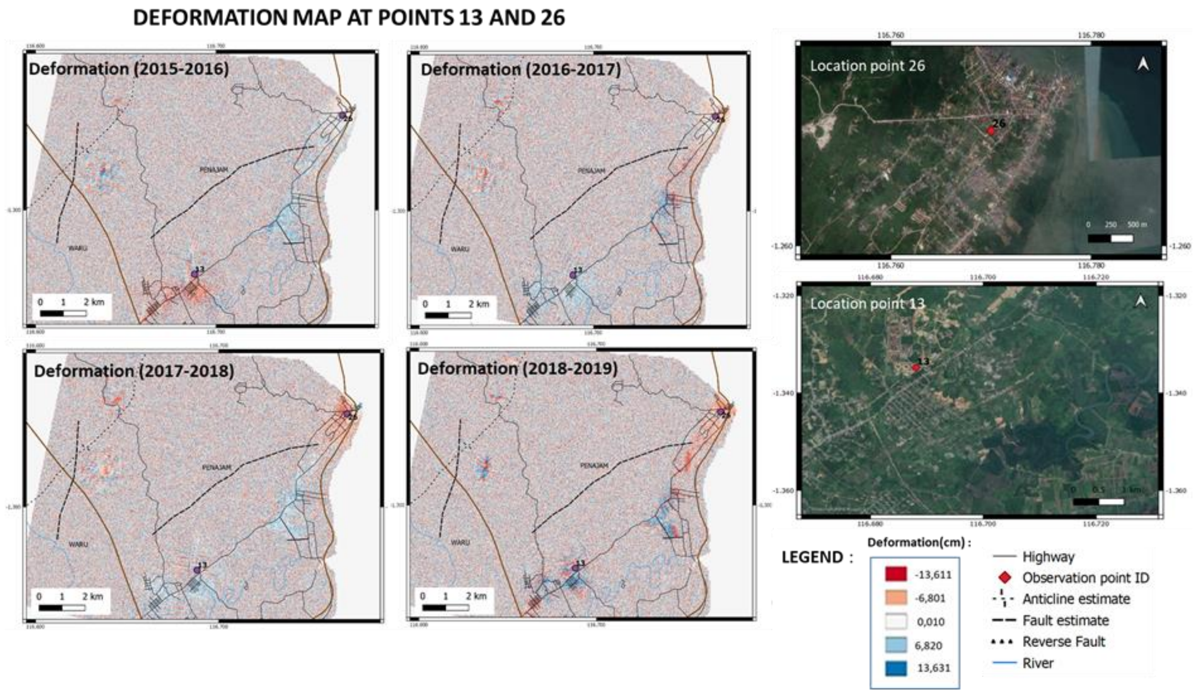

Figure 5. Deformation Map at Point 13 and 26, Sepaku District for Period 2015-2019

IOP Conf. Series: Earth and Environmental Science **851** (2021) 012017 doi:10.1088/1755-1315/851/1/012017

Based on figure 6, the location of point 3 is the location of point 0 IKN, where it is planned to be the centre of government. This location is located at an elevation of 55 meters in a hilly area. The land subsidence that occurred in this area is still classified as the lowest area compared to the location of point 4 and point 27 of about 4.02 cm per year. This could happen since there had been no development of supporting infrastructure for the capital city, while the deformation occurred due to the deforestation activities in the region.

The location of point 4 (figure 6) is the main provincial road in the Sepaku district with an elevation of about 9-10 meters. Based on figure 4, the location of point 4 experienced the highest land subsidence in the period 2018-2019 of 12.97 cm and the average land subsidence per year was 10.36 cm per year. The deformation that occurred in this area is closely related to development activities in the form of road infrastructure and buildings around point 4. The location of point 4 is the main access that connects the regions. The soil structure in the area of point 4 had a weak structure compared to that of point 3, making it more prone to deformation. In 2017-2018, this location was identified as uplift 10 cm increase in land due to development activities, such as elevating the road body at location 4.

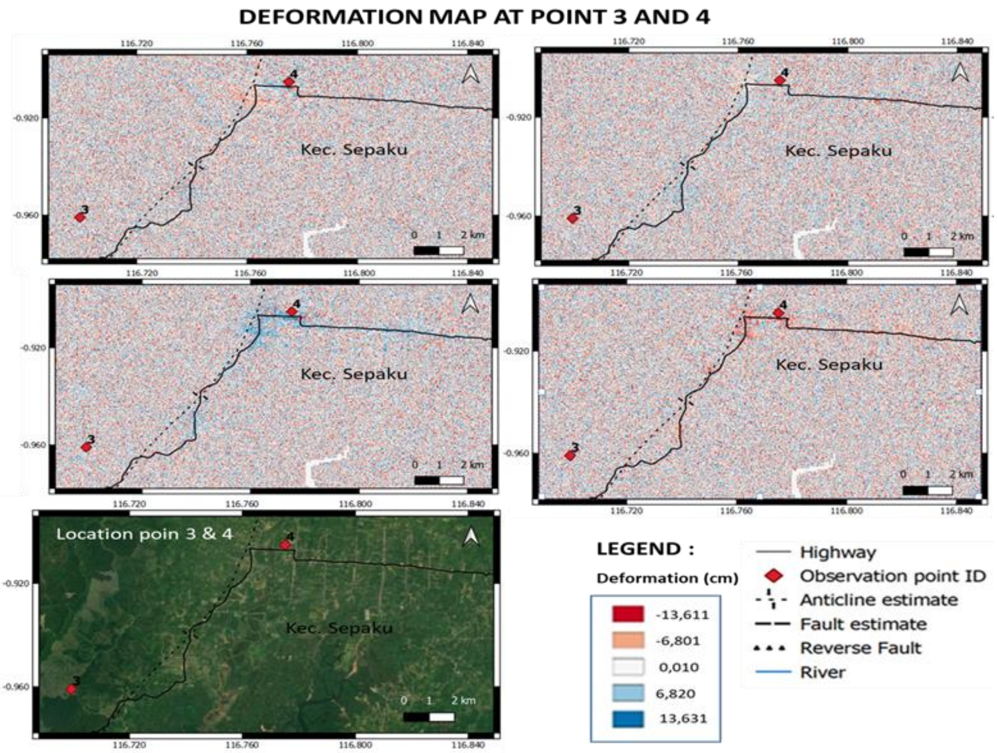

Figure 6. Deformation Map at Point 3 & 4, Sepaku District for Period 2015-2019

Land subsidence at observation point 15 (figure 5) was influenced by building density and alluvial material deposited in the area around Balikpapan Bay. The presence of sedimentary material deposits is a factor in the area around point 15 experiencing an uplift. The location of point 27 is an area that had experienced landslides in Sepaku district in April 2018 [5] as shown in figure 7. This area is a hilly area with steep slopes with a height of 47 meters. The DInSAR multitemporal processing results confirms that this area had been identified as experiencing subsidence in the time span before the landslide disaster of 9.15 cm [4][9]. The average land subsidence value in this area is 8.84 cm per year. Hence, the underlying cause for landslides at point 27 based on this study is deformation in the form of subsidence due to the loading of buildings with a high enough density in the area around the landslide, the topographical conditions, and the presence of high rainfall.

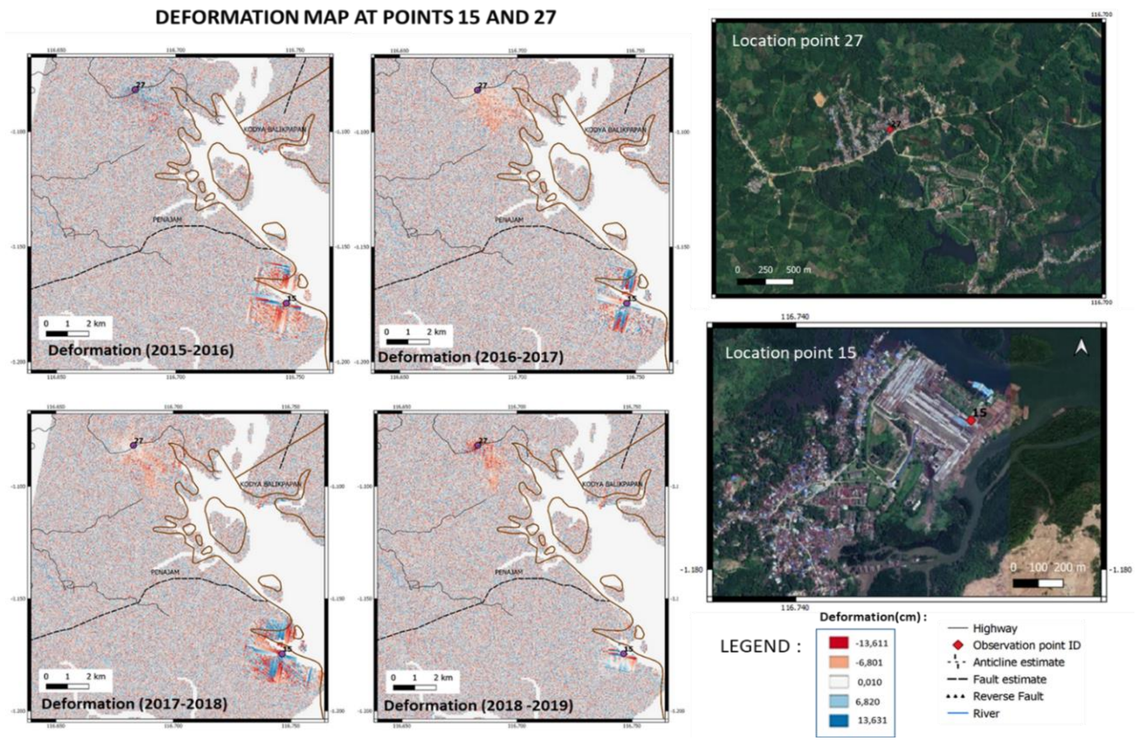

Figure 7. Deformation Map at Point 15 and 27, Penajam and Sepaku District for Period 2015-2019

The observational areas generating a deformation process can be used to monitor the developments in an area. Areas under development can generally be identified from the deformation contrast values that have changed significantly, compared to areas that are not under development [6][12]. This can be seen from areas that experience deformation in the form of subsidence with high building density, and this is closely related to the loading of big building volumes on the soil structure. Land subsidence may also occur due to the extraction of big amount of groundwater, particularly in densely populated urban areas [2].

4. Conclusion

The deformations that occur in the research area can be identified properly using the DInSAR method. Multitemporal analysis using DInSAR on Sentinel 1A images in the research area is able to detect changes of ground deformation, both subsidence and uplift from time to time. This method can identify areas that experience landslides caused by subsidence that have occurred in the research area. Based on the results of data processing, the area with the greatest land subsidence rate is the location of point 4 at Sepaku Distrct, with an average annual subsidence of 10,75 cm per year. This location also experienced a maximum uplift of 10 cm which occurred in the 2017-2018 period. Meanwhile, the area with the lowest land subsidence is the location of point 0 IKN (point 3) at Sepaku subdistrict with a land subsidence rate of 4,02 cm per year. The identified areas with deformation generally take place in areas with a high density of buildings, construction areas, road infrastructure, and river alluvial deposits.

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