Ground deformation analysis on road infrastructure in north buton Indonesia using interferometric synthetic aperture radar (Insar)

L M G Jaya, J Safani, A Okto, M Hasbi and A Kadir

1Faculty of Engineering, Universitas Halu Oleo, Jalan HEA. Mokodompit, Kampus Hijau UHO Bumi Tridharma Anduonohu, Kendari, Indonesia
2Faculty of Earth Science and Technology, Universitas Halu Oleo, Jalan HEA. Mokodompit, Kampus Hijau UHO Bumi Tridharma Anduonohu, Kendari, Indonesia

Email: Laodemgj@uhon.ac.id

Abstract. We investigate ground deformation that occurred on national road infrastructure in North Buton Regency, South East Sulawesi, Indonesia. This research conducted to obtain spatial information about ground deformation occurred. Road infrastructure plays an important role in economic and transportation particularly in North Buton. Road damage will cause losses both economically and security. The method of the research was Interferometric Synthetic Aperture Radar (InSAR). InSAR uses two SAR Images from two different acquisitions to generate interferogram and then ground deformation parameter. We used Sentinel-1 images acquisition years of 2015 and 2017. We found that the ground deformation occurred between -118 to +20 millimeters during the year of 2015 and 2017 acquisition or about -59 to +10 millimeters per year and its direction from north to south of the road body. The movement of ground deformation is dominated downward movement which it is estimated strength affected by the presence of faults near the location.

1. Introduction
Road infrastructure and transportation play an essential role in regional development. Road network opens accessibility in a region and remote area. Road networks will also increase regional economy, competitiveness between regions and social welfare. However, in the long term, the use of roads is highly dependent on the condition of the area where the road network is located.

One of the biggest challenges in road infrastructure management is early detection of its damages and taking actions to reduce repair costs. Many studies show that early detection of damages increases road quality life and reduces the total maintenance cost. Long term road quality life particularly in the developing region will ensure development sustainability and community welfare.

In the unstable soil due to geological and geophysical factors, road damage monitoring must be conducted continuously. Those various phenomena and processes include earthquakes, changes of groundwater flow by aquifer overexploitation and hydrocarbon extraction have as a consequence the deformation of the Earth's surface, which modifies its physical parameters. Therefore, there is a need for road monitoring methods that facilitate the detection of the road damage. Visual observation of road damages is quite difficult and impossible. This is due to the limitations of visual humans to detect small changes, especially for large areas. Remote sensing can overcome these limitations.

Remote sensing data has been extensively used in the last decades for change detection because of the repetitive data acquisition and wide coverage. One powerful technique is Synthetic Aperture Radar.
(SAR) Interferometry (InSAR) that enables the measurement of small-scale surface deformation since it can measure the overall phase center of a signal in a pixel [1]. Different from the Global Positioning System (GPS) method which is an only cover point per point analysis, InSAR can cover a wide area so that makes comprehensive analysis [2]. This method uses two or more Synthetic Aperture Radar (SAR) images to generate differential interferograms that allow measuring the rate of ground deformation in millimeter/year and that can be successfully used for monitoring natural hazards, such as volcanoes, earthquakes, landslides and subsidence and even tectonic deformation [3]. This research was conducted to analyze ground deformation on road infrastructure in North Buton, South East Sulawesi, Indonesia.

2. Method

2.1. Location
The study location is in North Buton Regency South East Sulawesi Province, Indonesia (Figure 1). It is about 150 km at the south east of Kendari, the capital city of South East Sulawesi Province. Geographically it is located on 4°37’42”S and 123°01’13”E in north Kulisusu sub district. The road is a part of the regency road network which becoming a connection road from Ereke (the city of north Buton) and the Muna Regency. It becomes the most important road since it is the main and only road in this road connection.

![Figure 1. Location of the study.](image)

The type of climate in the North Buton is according to Schmidt and Ferguson with an average annual rainfall of 2,286 mm, the humidity of 80% and temperatures ranging from 22 °C to 34 °C. The rainy season usually falls in January to June, while the dry season is in July to December. There are several landslides that occur particularly at an elevation of about 50 meters above sea level, with a slope of around 40%.

2.2. Data
We used two Sentinel-1 images acquisition in 2015 and 2017. The characteristics of the image are shown in table 1.
Table 1. Sentinel-1 image characterization.

| Mission                                     | Sentinel-1A                              |
|---------------------------------------------|------------------------------------------|
| Acquisition Mode                           | Interferometric Wide (IW)                |
| Frequency                                   | 5.4 GHz                                  |
| Product Type                                | Single Look Complex (SLC)                |
| Range Resolution                            | 2 m                                      |
| Azimuth Resolution                          | 14 m                                     |
| Polarization                                | VV                                       |
| Date of Acquisition (Master)                | 30 April 2015                            |
| Date of Acquisition (Slave)                 | 25 May 2017                              |

2.3. Data processing

InSAR measures the phase difference between two acquisitions. The equations regarding the phase difference explained in equation (1) to (4). Every single pixel from each SAR image will have a phase as displayed in equation 1 and 2 respectively:

\[
\varphi_1 = \frac{4\pi}{\lambda} R_1 + \varphi_{\text{scatterings}1} \tag{1}
\]

\[
\varphi_2 = \frac{4\pi}{\lambda} R_2 + \varphi_{\text{scatterings}2} \tag{2}
\]

If there is nothing change in terrain condition, then the question becomes (3):

\[
\varphi_{\text{scatterings}1} \approx \varphi_{\text{scatterings}2} \tag{3}
\]

So that we obtain the interferometric phase as follow:

\[
\varphi = -\frac{4\pi}{\lambda} (R_1 - R_2) \tag{4}
\]

3. Result and discussion

The InSAR imaging method can be applied to aircraft and satellite platforms. The aircraft used two antennas at the same time and used a single pass imaging, while on a satellite platform one antenna is used by imaging more than once at different times (multi pass). In the use of two antennas, based on the position of the antenna can be divided into two types, namely the transverse position of the aircraft (across the track) and the length of the plane (along track) [3].

InSAR uses two or more Synthetic Aperture Radar (SAR) images of an area to identify surface movements through time. ALOS PALSAR captures the same area every 46 days while Sentinel-1 every 12 days. Remote Sensing systems that collect SAR imagery transmit pulses of microwave energy to the Earth's surface and record the amount of backscattered energy. The use of microwave energy provides an all-weather capability because of its low sensitivity to clouds and rain. The use of certain frequencies, such as ALOS PALSAR L-band or Sentinel-1 C-band will affect the ability to detect changes that occur at the ground level [4].

SAR images contain information on the Earth's surface in the form of the amplitude and phase components of the backscattered radar signal. The signal transmitted and received in single, dual or quad polarizations. The amplitude image records information on the terrain slope and surface roughness, while the phase image records the information on the distance between the satellite and the Earth's surface. The phase shift will occur when the distance between the ground and the satellite changes between the two acquisitions due to surface movement.

By combining a network of multiple interferograms over a region, a velocity map and time-series products can be generated. A velocity map gives the surface movement for each image pixel averaged over the total observation period whereas the time-series product shows the history of surface positions.
for a pixel at each acquisition time (Figure 2). The road network which is above a subduction zone or fault will be impacted by the movement of the mass of the ground beneath it.

Figure 2. A schematic diagram illustrating the application of InSAR uses two SAR images acquired from two different times and its phase shift.

The road in north Buton consists of several road networks namely national, province and regency road. Due to geological and topographical conditions, those road networks are located above unstable soil. For instance, in this location there is an avalanche along the cliff caused by unstable loose soil. It should be noted that around the location there is a fault from north to south as indicated by the fault map of North Buton Regency as displayed in Figure 1. The location is approximately a half kilometers east of the nearest fault.

Figure 3 shows the existing condition of the road body where ground deformation occurs. The main factor of road damage in this area is active the fault near the road network as mention above. Since the existing road is the main road in the area connecting the city of Ereke to Muna Regency in Maligano,
then vehicles with excess weight cannot be prohibited crossing the road. This makes the road conditions more damaged especially during the rainy season.

On the left and right side of the road body, small landslide also occurred. The movement of the soil in this location is creep type, which is evidenced by the movement of electric poles or slope (Figure 3). Ground movement in this location is also affected by the type of soil, alluvial, where the soil texture has a very small cohesion. The length of soil movement at this location is around 50 m, but from regional observations, the ground movement at this location is longer with the same type of soil movement at several other locations.

Figure 4 shows ground deformation on the road body. Ground deformation occurred between -118 to +20 millimeters during the year of 2015 and 2017 acquisition or about -59 to +10 millimeters per year which its direction from north to south of the road body. The negative sign indicates that the ground movement is downward and vice versa.

![Figure 4. Ground deformation along the road body resulted from InSAR.](image)

From the InSAR map we obtain that there are also several points in which the ground deformation occurred along the road. However, there are several limitations to this research. First, temporal decorrelation affected by two different positions and acquisition dates must be considered as one of the error sources. Vegetation effect during SAR acquisition using C-band frequency may increase the temporal decorrelation. Second, the result of this research needs to be examined with another method such as GPS measurement or leveling. Even though GPS and leveling only cover point measurement, they can provide information on millimeter movement of ground deformation thus more accurate [5], [6].

4. Conclusions

We have investigated the ground deformation on road infrastructure in North Buton Indonesia. InSAR becomes one of the fast solutions to obtain spatial information about ground deformation. This research was conducted to increase awareness of the people regarding road damage and transportation safety. From the research we found that the ground deformation occurred between -118 to +20 millimeters during 2015 and 2017 acquisition or about -59 to +10 millimeters per year and its direction from north to south of road body. The movement of ground deformation is dominated by the downward movement. However, this result must be examined with another measurement such as GPS and Leveling to obtain more accurate results.

References

[1] Zebker H A and Goldstein R M 1986 Topographic mapping from interferometer synthetic aperture radar observations Journal of Geophysical Research 91 doi 10.1029/JB091iB05p04993 ISSN 0148-0227
[2] Zhou C, Gong H, Chen B, Li J, Gao M, Zhu F, Chen W and Liang Y 2017 InSAR Time-Series Analysis of Land Subsidence under Different Land Use Types in the Eastern Beijing Plain, China, Remote Sens 9 380

[3] Richards J A 2009 Remote Sensing with Imaging Radar Signals and Communication Technology Springer ISBN 978-3-642-02019-3

[4] Ferretti A, Prati C, and Rocca F 2001 Permanent scatterers in SAR interferometry IEEE Trans Geosci Remote Sens 1 8–20

[5] Gourmelen N F, Amelung and Lanari R 2010 Interferometric synthetic aperture radar–GPS integration Interseismic strain accumulation across the Hunter Mountain fault in the eastern California shear zone J Geophys Res 115 B09408 doi 10 1029/2009JB007064

[6] Fattahi H 2015 Geodetic imaging of tectonic deformation with InSAR PhD dissertation Univ of Miami Miami Fla