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Contents

Multi-temporal Land Deformation Monitoring in V Shape Area Using Quasi-Persistent Scatterer (Q-PS) Interferometry Technique

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Abstract— Kelok Sembilan area, West Sumatra, Indonesia located in 'V' contour shape is playing an important role to support the transportation connection in the center of Sumatra. However, in the rainy season, landslide event was high along this way, then monitoring and mapping a necessity to for minimizing its impact. Quasi-Persistent Scatterer Interferometry (Q-PSI) technique was applied for extracting information of land deformation on the area from time to time. Beside have high performance for detecting land deformation, Q-PSI technique was selected to improve the number of PS point. It's required because the method applied to vegetation area with short wavelength SAR (C-Band). This research was supported by 90 scenes of Sentinel-1A taken from October 2014 to November 2017 for ascending and descending orbit. Both satellite orbits detected two critical location of land deformation namely as zone A and Zone B located in steep slope that more than 500 mm movement in the line of sight (LOS).

1. INTRODUCTION

Located in steep slope and high rainfall intensity area [1], the Kelok Sembilan flyover (Fig. 3) with the latitude of 0° 4' 13.30" S and longitude of 100° 41' 53.56" E West Sumatra, Indonesia is necessary to monitor. This crucial because the Indonesia government has categorized the area into middle and high land movement [2]. Furthermore, almost every year landslide occurs along this way. On March 3, 2017, was large-scale landslide incident in West Sumatra-Riau connection, which was 64 locations of landslide occurrence, two of them on Kelok Sembilan flyover [3]. Monitoring requires obtaining the scientific information about land movement and its critical places from time to time.

Persistent Scatterer Interferometric (PSI) Synthetic Aperture Radar (SAR) have proven effective and reliable technique for measuring multitemporal land deformation on earth surface by investigating point-like radar target during acquisition time. Also, the method can observe wide range deformation area in both subsidence and uplift. Some application applied PSI technique to earth observation such as seismic fault [4], coastal sedimentation monitoring [5], volcanos [6], landslide [7] with accuracy 1 m for height and 1 mm in displacement. However, when classical PSI-SAR technique applied in the non-urban area, the number of permanent scatterer target is low [7, 8]. To overcome the problem distributed scatterer target considered to be extracted then the number of PS point distribution on spatial can be improved. The technique is Quasi-Permanent Scatterer Interferometry (Q-PSI) SAR. Processing using PSI and Q-PSI SAR technique relatively equal. However, there are three points has adjusted namely [8]. 1). The images of the dataset are not correlating with one master images 2). Displacement and height of target exploiting from partial coherent target subset of the interferogram. 3). Spatial filtering applied to extend the signal-to-noise ratio.

In last research, observation on the area used the ALOS PALSAR (L-band) for ascending orbit with HH polarization only [7]. However, in this experiment are continuing the inspection with applying short wavelength (C-band) that observed in both ascending and descending orbit.

The objectives of the research are to map and monitor land deformation in "V" shape area using Q-PSI SAR technique observed by Sentinel-1A. The result projected on the ground using google earth with KML format.

2. STUDY AREA AND SATELLITE DATASET

Kelok Sembilan area located in Lima Puluh Kota district, West Sumatra, Indonesia. It has been the primary road which is playing an essential role in supporting economic and transportation in center of Sumatera island. The area recorded as a high land movement [3] due to topography and geology. The ranges of topographical slope in both positive and negative are between 50°–75° and 34°–70° respectively [7]. Based on geology survey at least two shapes of fault around Kelok Sembilan area namely normal fault and strike-slip fault. Also, the rock structure is shared-joint constructed of metamorphic rock and sedimentary rock. The complexity of geology condition in the area leads to the high probability of landslide occur. In three recent years from 2015–2017, 110 locations of a landslide along the area connection between West Sumatra and Riau Province [9]. Studying and monitoring a characteristic of land deformation in the area is a necessity as scientific information for preventing and early warning for government and resident.

For monitoring land deformation at the Kelok Sembilan area, 36 and 54 scenes ascending and descending orbit of Sentinel 1A C-band SAR satellite was extracted respectively. The acquisition time of data was taken from October 2014 to 7 December 2017. Both orbits of the satellite were selected to achieve the information in different view of line-of-sign (LOS). Also, to identify the consistency of land deformation zone detection. The track orbit of satellite Sentinel-1A is shown in Fig. 1.

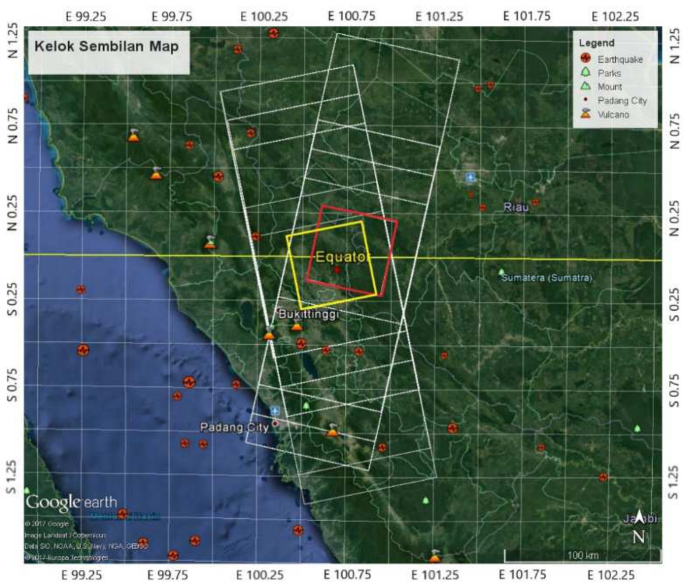


Figure 1: Sentinel-1A satellite with ascending and descending orbit. The yellow square is ascending and red square observation. Kelok Sembilan located near the equator line (yellow line) at a latitude of 0° 4' 13.30 " S and longitude of 100° 41' 53.56" E.

The polarization of SAR data is VV (vertical transmit and vertical receive) with wavelength is 5.44 cm (C-band) and Interferometric Wide (IW) swath mode. The data is provided by European Space Agency (ESA) in single look complex (SLC) product containing phase and amplitude information. Incidence angle radar to target for ascending and descending orbit is 43.39 degree and 43.89 degrees respectively. In an IW SLC product include one image per sub-swath and one per polarization with 5 m × 20 m spatial resolution. The critical baseline for satellite Sentinel-1A is 15,882 m. The orbit height is 693 km with inclination angle 98.18° and repeats cycle orbit 12 days [10]. The dataset of Sentinel-1A is shown in Table 1.

Sentinel-1A satellite in both ascending and descending orbit have small the normal baseline. The maximum baseline of the scenes is 200 m. The lower normal baseline will reduce the geometrical decorrelation [11]. Furthermore, the short repeat cycle orbit decreases the temporal decorrelation. Sentinel-1A has both criteria which are small normal baseline and short repeat cycle orbit within 12 days [12].

3. METHODOLOGY

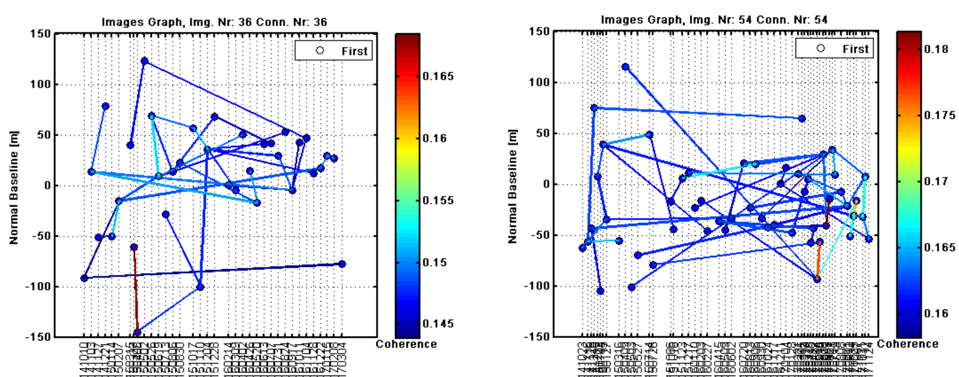
3.1. Quasi-Persistent Scatterer (Q-PS) Interferometry Technique

Quasi-Persistent Scatterer Interferometry (Q-PSI) technique is advanced of classical PSI technique that allows extracting the information from partially coherence targets γ. The basic idea of the technique is to improve the spatial distribution of measure points [13]. Q-PSI technique is not only qualified in an urban area but also in the vegetated area, that can improve the spatial density

Table 1: Sentinel-1A with ascending and descending orbit dataset: part 91 frame 592 and path 69 frames 1181 respectively.

No	Orbit	The number of Scenes	Beam swath mode	Acquisition time	Polarization	Off-nadir angle
1	Ascending	36	IW	October 2014–March 2017	VV	35.35°–40.40°
2	Descending	54	IW	October 2014–November 2017	VV	35.35°–40.40°

of Persistent Sacatterer Candidate (PSC) [14]. Kelok Sembilan is a vegetated area that has high topography, then the number of PS target is low while observed by C-band than L-band. This is because the number of PSC is correlate with the radar wavelength λ. To do so, Minimum Spanning Tree (MST) image graph configuration with coherence as weight was applied to maximize the coherence target γ. Three components of the image graph considered to improve the coherence target namely: first, the connectivity of image, this needed to unwrap the phase time series. Second, the number of the link. Third, the weight to each link in order to quantify its goodness [8]. The minimum number of image links for N image available is $N/2$ and maximum is $N(N-1)/2$ [13]. Q-PSI technique with MST image graph configuration shown in Fig. 2.



(a) (b)

Figure 2: MST image graph configuration for Sentinel 1A SAR satellite in Q-PS technique. (a) Ascending orbit with 36 total number of SAR images. (b) Descending orbit supported by 54 SAR images.

Estimating the atmospheric phase at the pixel position in all interferogram is carried out by selecting the Persistent Scatterer Candidate (PSC) based on amplitude stability index (ASI), $(ASI = 1 - D_a)$. The amplitude depression D_a [15].

$$D_a = \frac{\sigma_a}{m_a} \tag{1}$$

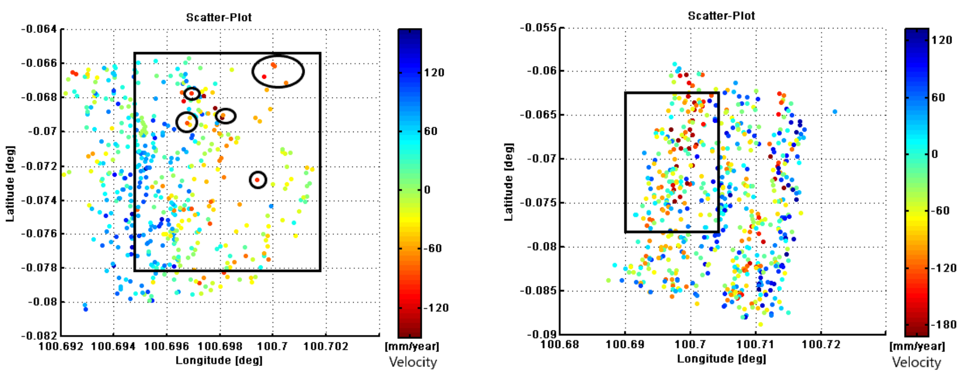
where σ_a the temporal standard deviation of the amplitude value and m_a the temporal mean of the amplitude value. The point are selected as PSC if the amplitude depression $D_a < 0.4$ [15, 16]. With minimum PSC density $3\,\text{PCS/km}^2$ [17].

For analyzing full target area, the close point of PSC selection connected each other which refer to the single reference point. The network followed the Delaunay triangulation algorithm [18]. This approach creates more redundancy network to improve the ability to detect the phase ambiguity errors and the robustness of the network.

4. RESULT AND DISCUSSION

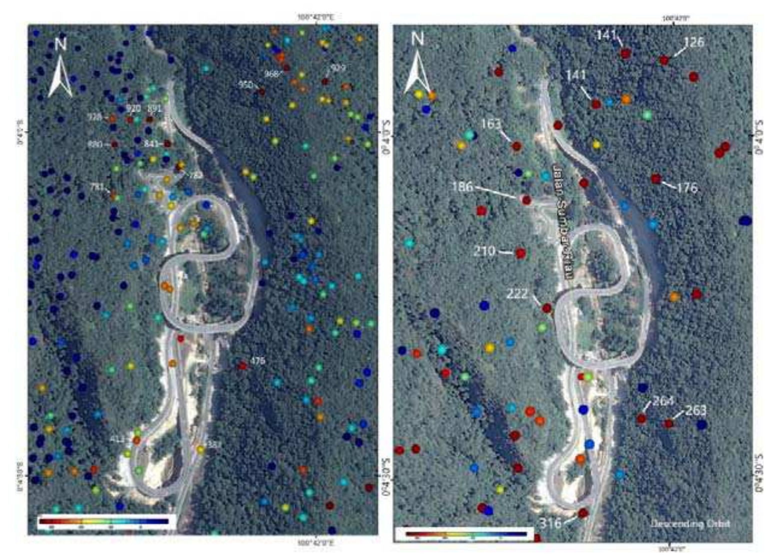
Investigation of land deformation in this research is based on the Quasi-Persistent Scatterer Interferometry SAR technique. The data processing was provided by ESA Sentinel 1A satellite in ascending and descending orbit. The time acquisition was taken from October 2014 to March 2017 to October 2014 to November 2017, respectively. For preliminary geocoding and removing the topographic phase component, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model with one arcsec resolution was applied. Furthermore, Amplitude Stability Index (ASI) was used to estimate the preliminary parameter and Atmospheric Phase Scene (APS) through Permanent Scatterer Candidate (PSC) network with threshold 0.6. In both ascending and descending orbit with area range and azimuth 220×600 pixel and 220×900 pixel, 2136 PSC and 3320 PSC was selected, respectively.

The main component result of Q-PS processing is velocity and height of PS point which represented the condition of the land surface. For Ascending and descending orbit, land deformation velocity around Kelok Sembilan area shown in Fig. 3(a) and Fig. 3(b). In both track orbit, most PS points analyzed locating on a high steep slope and high elevation (Fig. 3(b)) also its PS density. However, in the valley area, the density of PS point is low because the platform is moving parallelly with the terrain. The topography slope more than the off-nadir angle (θ35.35°–40.40°) blocked (shadow) the satellite signal then cannot penetrate the valley. Meanwhile, for descending orbit PS density higher than ascending orbit because the satellite slightly crosses topography then some



(a) (b)

Figure 3: Land deformation velocity for (a) ascending and (b) descending orbit which indicates by color in mm units per year. Persistent scatterer point plotted in geographic coordinate Latitude and longitude with the maximum velocity is more than 120 mm/year (red color). The data observed by Sentinel 1A with 36 and 54 number of scenes from October 2014 to March 2017, respectively.



(a) (b)

Figure 4: Land deformation area in Kelok Sembilan observed by Sentinel 1A for both ascending and descending orbit. (a) Cumulative displacement of land deformation geocodes into Google Earth for ascending orbit co-polarization (VV). (b) Observed with descending orbit co-polarization. The acquisition time is taken from October 2014 to March 2017 with 90 total number of scenes.

signal reach some area in the valley. For the area, $1.5 \times 0.97\,\text{km}^2$ which covered by vegetation, 474 PS, and 684 PS detected with temporal coherence $\gamma > 0.8$ in ascending and descending orbit, respectively. This is high quality value for estimate the height and velocity. The maximum velocity in this observation is more than 120 mm/year and 180 mm/year (red color) during time acquisition for both orbit respectively.

For real visualization land deformation, the PS point geocoded into an optical layer of Google Earth shown in Fig. 4(a) and Fig. 4(b).

For both ascending and descending orbit there are five areas was detected as land deformation consistently. Two of them is crucial because it has higher velocity and larger covered area. The first area represented by ID (476, 264, 263) and the second area by ID (960, 968, 929, 141, 126, 132) where is both zones located on a steep slope. The land deformation maximum for both first and second zones is more than 250 mm and 500 mm in LOS respectively.

5. CONCLUSION

In this paper, we show how Q-PS technique can successfully extract the SAR data of Sentinel-1A (C-band) for detection land deformation in V counter shape area. Also, we compared and overlapped the result from ascending and descending orbit observation. There is two location has detected land deformation with a cumulative displacement more than 250 mm and 500 mm with a velocity more than 120 mm/year.

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