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Application of Time-Series Sentinel-1A for Land Deformation in Central Aceh, Indonesia

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Abstract. Several decorrelation phenomena of Interferometric Synthetic Aperture Radar (InSAR) have led researchers to develop various multitemporal InSAR (MT-InSAR) techniques with the application of time series/stack of images. In this study, we present the land surface movement monitoring using MT-InSAR techniques in the Central of Aceh-Indonesia, and focus on the temporal and spatial pattern of uplift and subsidence by using multi InSAR methods such as Quasi-Persistent Scatterer (Q-PS) and Small Baseline Subset (SBAS). A total of 18 scenes of Sentinel-1A(S-1A) and 14 scenes of ALOS PALSAR-1(PALSAR-1) images were acquired between 2018 and 2019, as well as 2007 and 2010, where then the multitemporal methods and techniques were applied sequentially to a set of those data. The results showed that the either the S-1A and PALSAR-1 velocity subsidence at Nunang and Musara Alun villages were range from 2.4 to 5.7 and 0.6 to 2.3 mm/year, respectively which corresponded to the results obtained by other research publication. The deformation in Central Aceh needs continuous monitoring using InSAR as the place is a landslide prone area because of the nature of the terrain.

1. Introduction

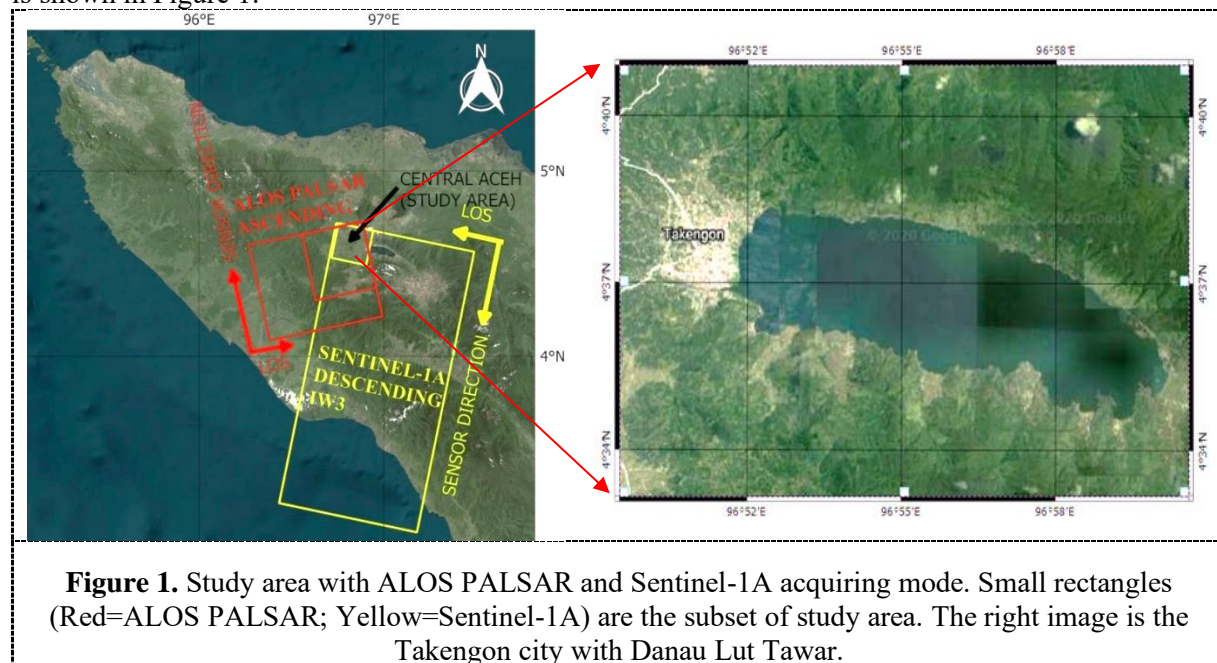
Interferometric synthetic aperture radar (InSAR) involves the interaction of electromagnetic waves known as interference, to measure precise distances between the target and the sensor to derive a landscape topography and its subtle changes in elevation. There are three main factors which can reduce the accuracy for deformation monitoring by using the SAR interferometric phase: (1) the signal distortion because the influence of the atmosphere; (2) temporal decorrelation due to changes in backscattering as a result of changes in the surface as the SAR images are recorded at different times; and (3) geometric decorrelation due to diverse imaging geometries such as a long spatial baseline or coregistration errors [1,2].



To overcome the above limitations, various MT-InSAR approaches and technique have been developed [3,4,5,6]. MT-InSAR exploits large datasets (usually more than 20 interferograms) of multi-temporal SAR data to generate multiple phase relationships, allowing the precise estimation of deformation components from other phase components for each SAR image [7]. The first Persistent Scatterer Interferometric (PS-InSAR) the method was introduced by Ferretti et al. [7,8]

2. Study Area

Central Aceh (Aceh Tengah) Regency is one of the districts in Aceh Province. Its capital city is Takengon, a small city with cool air is an area one a ridge of the Bukit Barisan mountain range that runs along the island of Sumatra with a population is less than 230,000. The topography of the city is hilly and mountainous, Landslides are one of the natural disasters that frequently occur in this city. Landslides over this area are generally triggered by natural disasters or extreme events, both geological and hydrometeorological hazards, such as earthquakes, extreme rainfall, and flooding disasters. On July 2, 2013, an earthquake with a moment magnitude (M_w)~6.2 struck a wide area in Gayo Highland (Aceh Tengah and Bener Meriah Regency) resulted in at least 39 fatalities. The source of the earthquake was on the northwest side of the Danau Laut Tawar or the southwest foot of the Burni Telong mountain. According to the report from the Regional Disaster Management Agency (BPBD) Aceh Tengah, this quake has destroyed thousands of homes including public facility buildings were also damaged. Mainly damaged and the victim was caused by significant landslides triggered by this earthquake in several places. The Takengon City by using SAR satellite image for the application of land surface movement is shown in Figure 1.



3. Data and Methodology

In this study, we utilize two different radar images, namely ALOS-PALSAR and Sentinel radar imagery. ALOS-PALSAR (2007 – 2010) was used to calculate the land surface movement history over the study area, whereas S-1A use for monitoring the current situation of the land surface movement. S1-A Single Look Complex (SLC) satellite images with vertical-vertical (VV) polarization Interferometric Wide (IW) mode were retrieved from the ESA (European Space Agency). Figure 1 also shows the footprint and the subset (based on the study area) of the ascending of ALOS-PALSAR and the descending Interferometric Wide 3 (IW3) Mode of Sentinel-1A. Each sensor (ALOS-PALSAR and Sentinel-1A) have its own sensor direction and right looking of LOS (Line of Sight) acquisition. A total of 18 scenes

of Sentinel-1A(S-1A) and 14 scenes of ALOS PALSAR-1(PALSAR-1) images were acquired between 2018 and 2019, as well as 2007 and 2010.

In order to overcome the limitation of classical DinSAR for landslide detection, thus, advanced InSAR methods such Quasi Permanent Scatterers (QPS) InSAR [9, 10] and Small baselines subset (SBAS) InSAR [11, 12] which mainly make use of point-like scatterers were then applied respectively to identify and monitor land surface movement in this study. The Sentinel-1A imageries were processed using SARPROZ software, while ALOS PALSAR-1 imageries were processed by using the Environment for Visualizing Images (ENVI) SARscape software. Table 1 and Table 2 show the Sentinel-1A and ALOS PALSAR data. The flowchart methodology of the processing is available in the Figure 2.

Table 1. List of Sentinel-1A 18 images in Descending SLC IW1 VV Polarization

No.	Date	Baseline Perp.(m)	Orbit No.	Temporal (days)	Track No.
1	2018-06-19	34.5473	22432	0	135
2	2018-07-01	42.8466	22607	12	135
3	2018-07-13	6.2557	22782	12	135
4	2018-07-25	10.2937	22957	12	135
5	2018-08-06	-13.1216	23132	12	135
6	2018-08-18	-20.7337	23307	12	135
7	2018-08-30	-49.3395	23482	12	135
8	2018-09-11	13.889	23657	12	135
9	2018-09-23	0 (Master scene)	23832	12	135
10	2018-10-05	18.6327	24007	12	135
11	2018-10-17	-86.3434	24182	12	135
12	2018-10-29	-73.2204	24357	12	135
13	2018-11-10	-55.3373	24532	12	135
14	2018-11-22	-6.5605	24707	12	135
15	2018-12-04	-58.02	24882	12	135
16	2018-12-16	43.1581	25057	12	135
17	2018-12-28	-72.2274	25232	12	135
18	2019-01-09	-14.518	25407	12	135

Table 2. Availability of Alos Palsar Ascending of 14 images

No.	Product date	Mode	Polarization	Temporal (days)	Orbit	B temporal (days)	Rainfall (mm)
1	10-01-2007	FBS	HH	0	5129	368	19
2	25-02-2007	FBS	HH	46	5800	322	0
3	13-07-2007	FBD	HH+HV	184	7813	184	0
4	28-08-2007	FBD	HH+HV	230	8484	138	3
5	13-10-2007	FBD	HH+HV	276	9155	92	1
6	13-01-2008*	FBS	HH	368	10497	0	0
7	14-04-2008	FBS	HH	460	11839	92	0
8	30-05-2008	FBD	HH+HV	506	12510	138	0

9	30-08-2008	FBD	HH+HV	598	13852	230	10
10	15-10-2008	FBD	HH+HV	644	14523	276	0
11	18-07-2009	FBD	HH+HV	920	18549	552	0
12	21-07-2010	FBD	HH+HV	1288	23917	920	0
13	21-10-2010	FBD	HH+HV	1380	25259	1012	0
14	12-06-2010	FBD	HH+HV	1426	25930	1058	6

*Master image

For Alos Palsar, there are only available daily rainfall in Lhokseumawe (North Aceh).

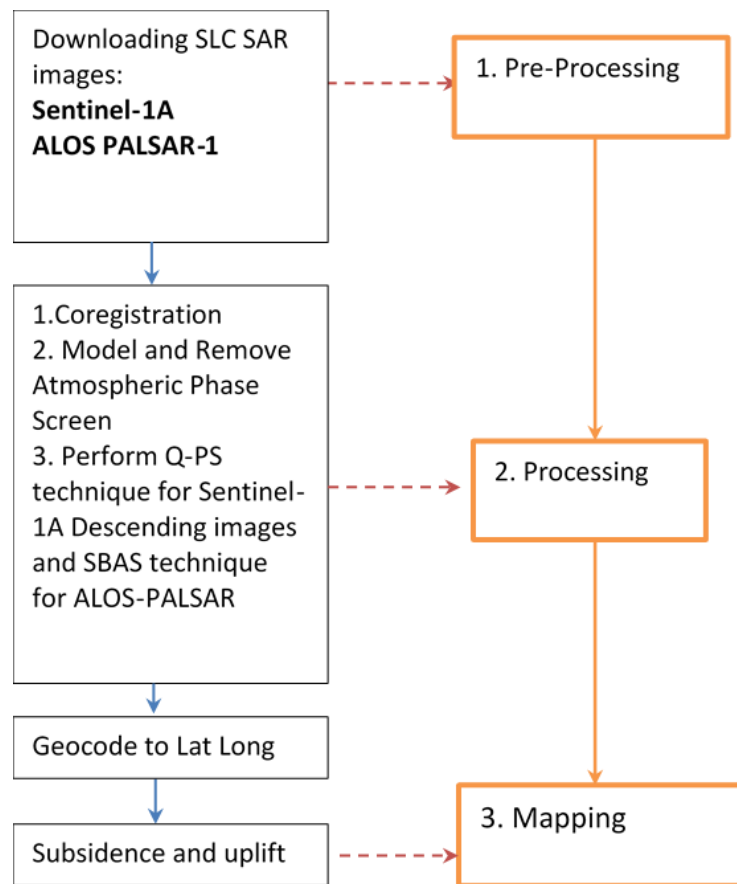
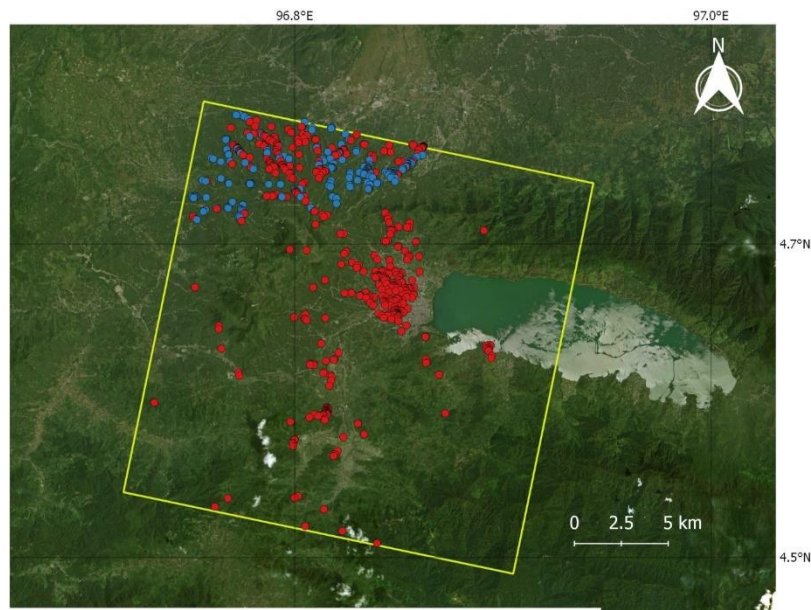


Figure 2. Study area with ALOS PALSAR and Sentinel-1A acquiring mode. Small rectangles (Red=ALOS PALSAR; Yellow=Sentinel-1A) are the subset of study area. The right image is the Takengon city with Danau Lut Tawar.

4. Results and Discussion

Figure 3 shows the velocity deformation of the Q-PS result with Sentinel-1A in LOS (Line of Sight) direction. The subsidence (red colors) appears clearly in the city or urban area, whereas many back scattered points such as building and other man made infrastructures. While in the Northern left corner also occur the subsidence and an uplift (blue colors) in the natural terrain.

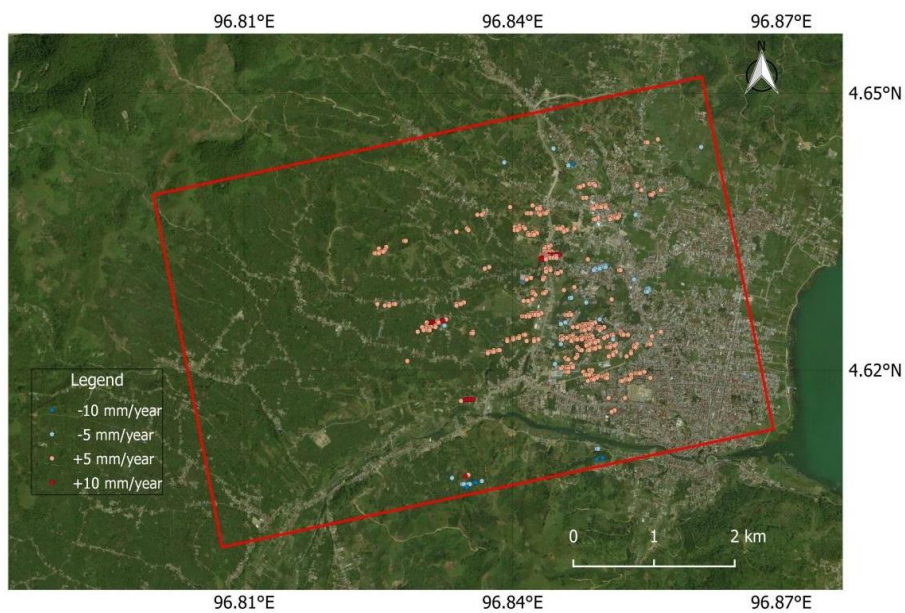


Legend

- Subsidence and uplift (mm) using Q-PS Sentinel-1 Descending 18 Images
- -10 to -20 (subsidence)
 - 10 to 16 (uplift)

Figure 3. Subsidence and an uplift of Sentinel-1A Descending 18 images in LOS (line of sight).

Figure 4 shows the velocity deformation per year in Takengon city derived using the Small Baseline Subset (SBAS) technique. About 1577 points were detected in 6.96 x 4.33 km area or 30.136 km square (red line). Red points (+) mean subsidence occur about 10 mm/year away from Light of Sight (LOS). Blue points (-) mean uplift ground phenomena about 10 mm/year approach the sensor. Overlay image is SPOT 6 which is provided by Bappeda Aceh.



- Legend**
- -10 mm/year
 - -5 mm/year
 - +5 mm/year
 - +10 mm/year

Figure 4. Velocity map of ALOS PALSAR 1 using SBAS technique

Small Baseline Subset (SBAS) approach represents one of the most powerful techniques for Earth's surface deformation processes monitoring, especially for long-term evolution phenomena. In this work, time series of ALOS PALSAR (2007 - 2010) has been processed by SBAS in order to study the evolution of a slow-moving landslide in Takengon (Aceh Tengah, Indonesia). The displacement rate sensitivity depends on the system wavelength. ALOS PALSAR (wavelength 23 cm) will have a sensitivity sparsely than the sensors one with shorter wavelength such Sentinel-1 (wavelength 5.6 cm). On the other hands, longer wavelengths will have higher temporal coherence and hence denser spatial coverage. The strong subsidence (dark violet-black) and the uplift (red) can be noted in the first velocity estimation.

4.1 Verification

From the results, landslide potential areas were identified. From the results calculated, deformation of velocity at Nunang and Musara Alun villages were found to range from 2.4 to 5.7 and 0.6 to 2.3 mm/year respectively which corresponded to the results obtained by Rusydy et al, 2017[13]. Figure 5 shows the contour map of Takengon city (black dot) and the three red stars are the location of the measurement test by (1). These points with numbers which are 2, 3 and 4 correspond to soft, stiff and stiff soil, respectively. These points also located in the same area which is Cekung Takengon or Takengon Basin based on (1).

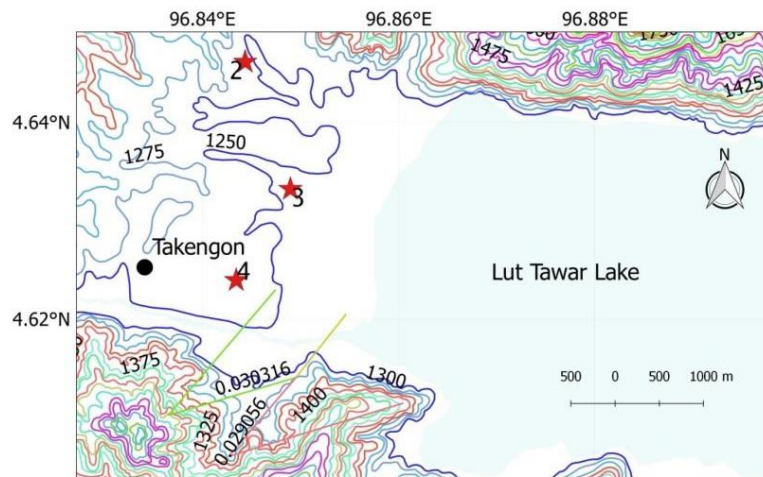
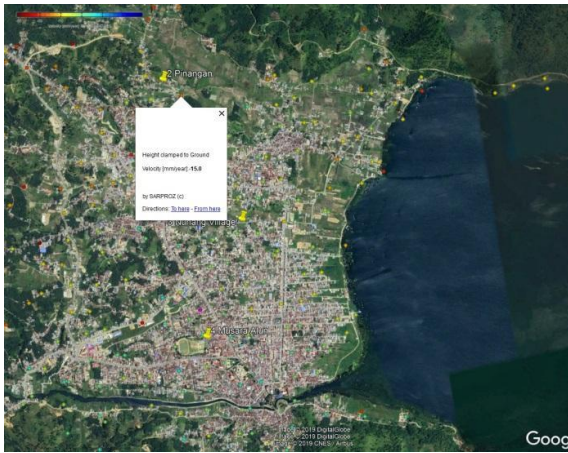
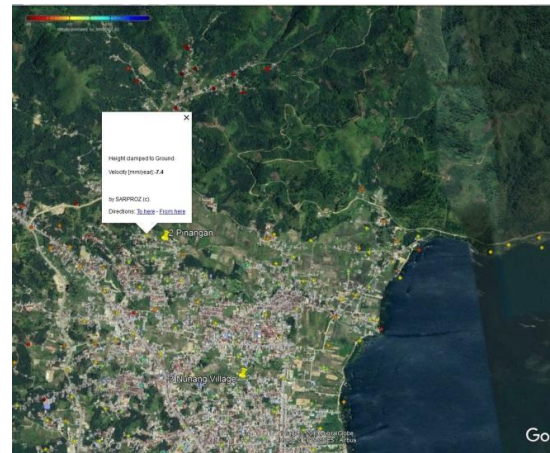


Figure 5. Point 2, 3 and 4 are in the same area which is Takengon Basin, according to (1).

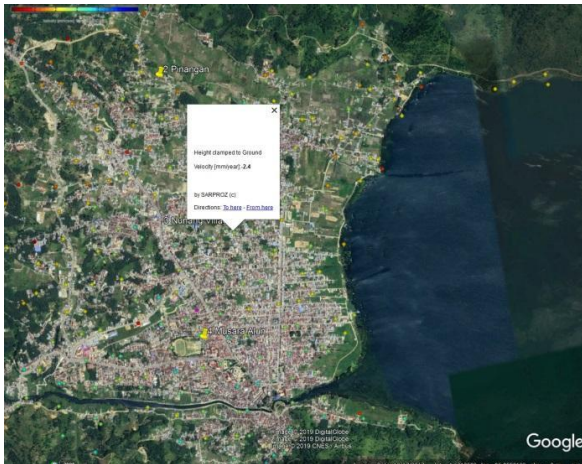
Rusydy et al., (2017) categorized the soil based on their experiment with MASW (Multi-Channel Analysis of Surface Waves) measurement on 3 locations (number 2, 3 and 4) in Takengon Basin and a part of Lut Tawar Lake. The MASW measurement showed the V_s value from the depth of 30 meters (the average shear wave velocity up to the depth of 30 meters). An assumption is made where the soft soil trend moves more rapidly than the stiff soil. Location number 2 is in Pinangan Village, which is categorized by soft soil has a deformation of velocity 7.4 to 15 mm/year. Whereas, areas with stiff soil, marked as locations 3 and 4 are found in Nunang village and Musara Alun village. The velocity of deformation is 2.4 to 5.7 mm/year and 0.6 to 2.3, respectively. The Musara Alun village also has two points showing uplift with a velocity of 1.8 mm/year. These results are agreed with a velocity of deformation from 18 ascending IW3 images from Sentinel-1A.



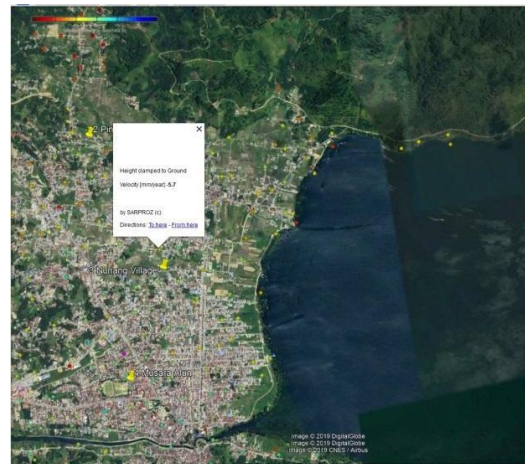
Subsidence 15 mm/year in Pinangan



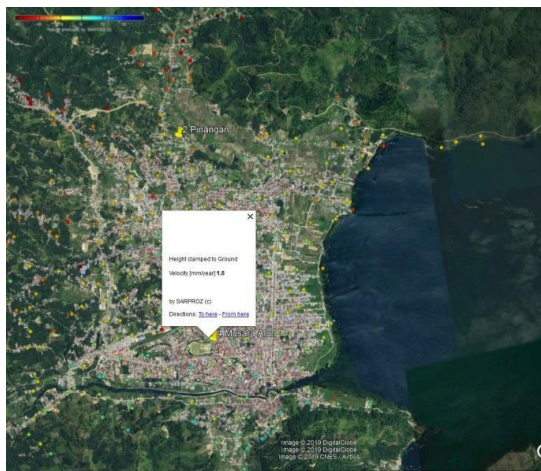
Subsidence 7.4 mm/year in Pinangan



Subsidence 2.4 mm/year in Nunang



Subsidence 5.7 mm/year in Nunang



An uplift 1.8 mm/year in Musara Alun



Subsidence 2.3mm/year in Musara Alun

Figure 6. Location of verification of velocity and field works based on Rusydy et al., (2017).

5. Conclusion

Based on the two examples of natural hazards, landslide deformation and flood detection using InSAR techniques, concluded that radar image could be the potential application for mapping such evidence. Nowadays, with all the capabilities of InSAR techniques, radar images show a positive trend to use and to interpret natural hazard in the smart city. For smart society, radar processing could be useful to map flooding in wide areas without overlay immediate government activity such as, for evacuation, medical threadment and blanket and tend and food distribution to the victims and refugees. In other word, the flood mapping with remote sensing is not disturbing any other agencies. For landslide monitoring using InSAR techniques could be also benefit to the society since the InSAR techniques can detect very small movement (e.g. 1-10 cm) as a pre-landslide movement. It gives a warning sign before real landslide occur. Landslide monitoring with InSAR shows a large scale (e.g. in district or sub-district) could be mapped continuously.

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