International Journal of Remote Sensing and Earth Sciences Vol. 8: 32-40 (2011) © IReSES

DEVELOPING TROPICAL LANDSLIDE SUSCEPTIBILITY MAP USING DINSAR TECHNIQUE OF JERS-1 SAR DATA

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Abstract. Comprehensive information in natural disaster area is essential to prevent and mitigate people from further damage that might occur before and after such event. Mapping this area is one way to comprehend the situation when disaster strikes. Remote sensing data have been widely used along with GIS to create a susceptibility map. The objective of this study was to develop existing landslides susceptibility map by integrating optical satellite images of Landsat ETM and ASTER with Japanese Earth Resource Satellites (JERS-1) Synthetic Aperture Radar (SAR) data complemented by ground GPS and feature measurement into a Geographical Information Systems (GIS) platform. The study area was focused on a landslide event occurred on 26 March 2004 in Jeneberang Watershed of South Sulawesi, Indonesia. Change detection analysis was used to extract thematic information and the technique of Differential SAR Interferometry (DInSAR) was employed to detect slight surface displacement before the landslide event. The DInSAR processed images would be used to add as one weighted analysis factor in creating landslide susceptibility map. The result indicated that there was a slight movement of the slope prior to the event of landslide during the JERS-1 SAR data acquisition period of 1993-1998.

***Keywords**: Optical Images, JERS-1 SAR, DInSAR, Tropical Landslide, GIS, Susceptibility Map*

1. Introduction

Recently, natural disasters increased in terms of frequency, complexity, scope, and destructive capacity. They have been particularly severe during the last few years when the world has experienced several large-scale natural disasters such as the Indian Ocean earthquake and tsunami; floods and forest fires in Europe, India and China, and drought in Africa (Sassa, 2005). Mapping such natural disaster areas is essential to prevent and mitigate people from further damage that might occur before and after such event.

In Indonesia in particular, in these recent years natural disasters occurred more frequently compared to the last decade (BNPB, 2008). Once within a month in 2011, in three different islands, Indonesia was stricken by earthquake, tsunami, flash floods, and volcanic eruptions with severe fatalities to the people and environment. It was obvious that Indonesia was prone to natural disaster due to its position of being squeezed geologically by three major world plates and this fact makes Indonesia one of the most dangerous countries regarding natural disasters.

Mountainous areas are specifically vulnerable to sediment related disaster. High slopes with loose material support and high frequency of rainfall are areas fond of landslides incidence. Many landslides incidences occurred in Indonesia due to this cause. International Landslides Committee, ILC, filed a report that Indonesia had the second highest fatalities according in 2009 report where it mounted to 441 fatalities (Figure 1).

Local governments and responsible bodies are not able to fully monitor the area because of the lack of spatial information to support the decision makers regarding the disaster area`s condition. Therefore, the lack of detail and accurate susceptibility maps produce some difficulties to evaluate the extent of area affected. Thus, the establishment of a comprehensive database of disaster inventory is urgently needed.

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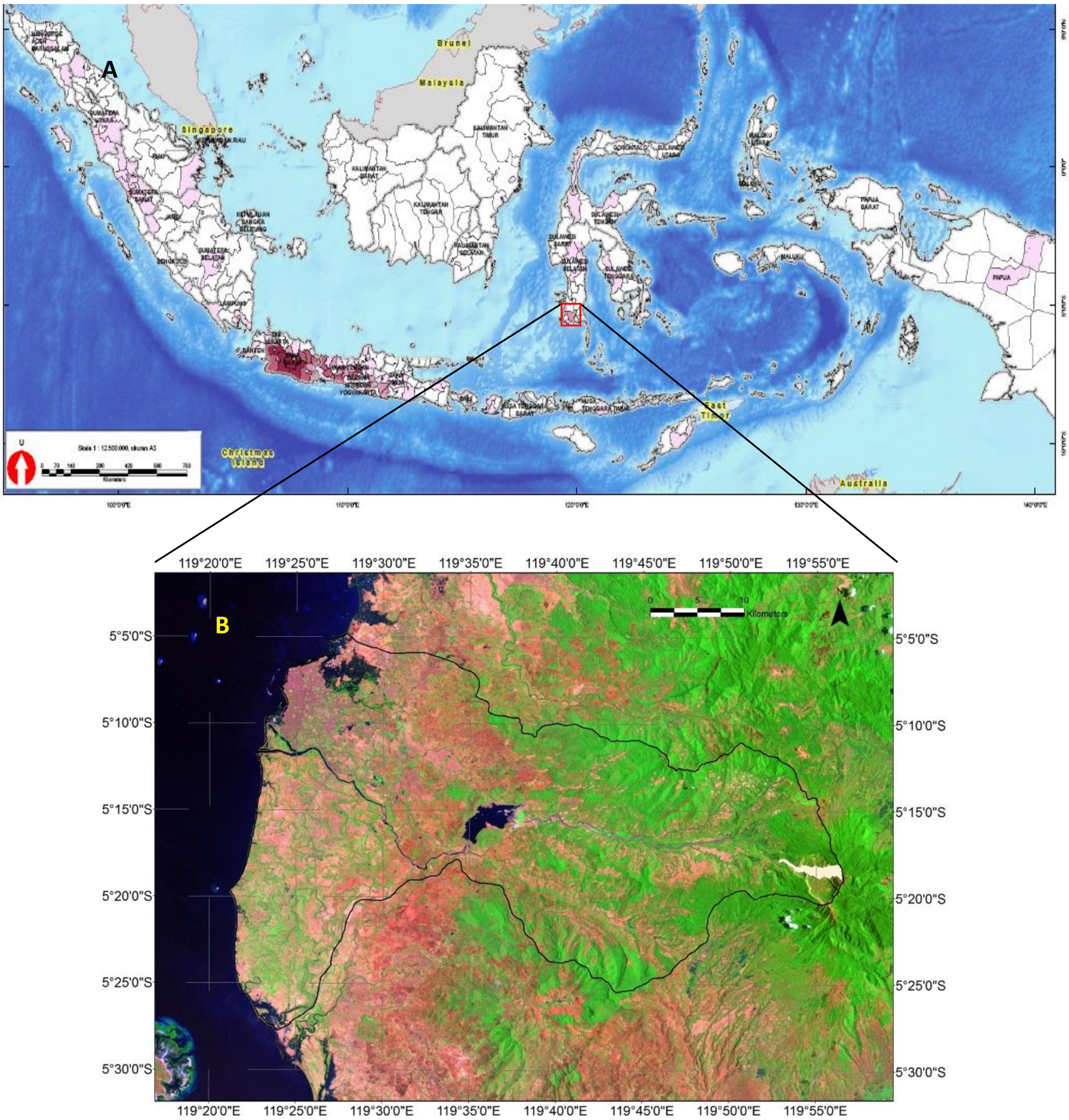

Figure 1. Study site. **A,** showing the whole area of Indonesia in regard to landslide incidences gradually from less incidence (white) to high (darker red) (BNPB, 2009). **B**. Specifically delineate the Jeneberang Watershed by the black outline with yellow line showing the material of the 2004 landslide incidence.

The availability of remote sensing data is now promising but it has not been effectively and efficiently utilized by end users. The use of remote sensing data can contribute to map disaster attributes on a variety of scales ranging from local, regional, and to global scale (Westen, 2000; Westen *et al*., 2008). Various techniques and models have been developed to specifically map landslides. The use of remote sensing data, whether air-, satellite- or ground-based varies according to three main stages of a landslide related study, namely a) detection and identification; b) monitoring; c) spatial analysis and hazard prediction (Singhroy *et al*., 2004; Matternicht *et al*., 2005). Rain induced landslides is one of the most common types of natural disasters and they frequently happen in Indonesia as well as in the Asia Pacific Region. During the period of 1990-2007 landslides occurred in Indonesia, these landslides caused of 2,886 people died, 1,215 people injured, and 14,849 lost their homes. Normally, a landslide occurs during a rainy season, bringing a sudden flow of debris and causes many destruction along its path.

Synthetic Aperture Radar Interferometry (InSAR) is an established method for the detection and monitoring of earth surface processes. This approach has been most successful where the observed area fulfills specific requirements, such as sufficient backscattering and flat slope gradients or very slow changes of vegetation. The emerging Differential SAR Interferometry technique is able map slight surface deformation for a specific type of landslide. This technique can be utilized to create an inventory database.

In this report we focus on a large scale mass movement occurred on 26 March 2004 in Jeneberang Watershed, Indonesia. A research on this landslide event was conducted by Hasnawir *et al*. (2006), and JICA Sabo Urgent Investigation Group led by Tsuchiya *et al*. (2009). The landslides area was also revisited for ground data collection in August 2009. Cracks existing along the steep slope of the landslide crown have been measured since 2006 and data has been retrieved for validation data.

The purpose of this study was to develop map of landslide susceptibility utilizing DinSAR technique on JERS-1 SAR data in Jenebrang Watershed South Sulawesi, Indonesia.

2. Method

2.1. Study Location and Data Used

The study area covers the whole Jeneberang watershed in South Sulawesi Province (Figure 1). The northeast monsoon produces rainy season between November and March (with the maximum rainfall in December and January), and the southwest monsoon causes the dry season between June and October. The monthly rainfall was more than 700 mm/month from December to February, and reached 900 mm in January. The average annual rainfall was 4,424 mm. Under these conditions, the outlet valley from the caldera can maintain its dominant down-cutting position by capturing the runoff from the primary depression to enlarge its drainage basin (Tsuchiya *et al*, 2009). The March 2004 landslide impacted significant damage with special concern on Bili-bili Dam located downstream, which supplies water to the city of Makassar (capital city, population of 1.2 million). Approximately 2×10^8 m^3 volume of volcanic fragmental rocks and debris (Bawakaraeng formation) slid to the upper part of River Jeneberang, covering one village, one primary school with 32 casualties (Tsuchiya *et al*. 2009). Some of the mechanical factors that enhanced this landslide were the tremendous height of the side wall of the caldera, fragility of the bedrock of the side wall, and susceptibility to erosion of the accumulated sediment inside the caldera (Hasnawir *et al*, 2006). This landslide was categorized as rock avalanche and the movement type was rotational and triggered by heavy rainfall.

In order to visually identify the affected area of the landslides, we utilized optical satellite images. Landsat 7 ETM visible/infrared image acquired on 28 September 2002 and an ASTER image of 2005 acquired after the landslide on 7 September were used to compare the pre and post event of the Jeneberang landslide. Synthetic Aperture Radar (SAR) images of JERS-1 acquired in 1993-1998 were used in this study. All the SAR images were on the descending mode. Figure 2 shows the Landsat 7 ETM image with false composite band of 742 (a) before the incidence (2002) and (b) ASTER composite image band 742 after (2005) the Jeneberang landslide, indicating the extent of the unvegetated area (yellow circle).

2.2. Data Analyses

There has been considerable amount of research implementing Differential Interferometry SAR (DInSAR) in the application of landslide mapping; Strozzi *et al*, 2005; Westen *et al*., 2008; Cascini *et al*, 2009.

Synthetic Aperture Radar Interferometry (InSAR) was an established method for the detection and monitoring of earth surface processes. This approach has been most successful where the observed area fulfills specific requirements, such as sufficient backscattering, flat slope gradients or very slow changes of vegetation. Generally two SAR data acquisitions, called scenes or images, of the same area are required to generate interference fringes resulting from phase differences that can be interpreted as heights or displacements (Riedel and Walther, 2008; Colesanti and Wasowski, 2006).

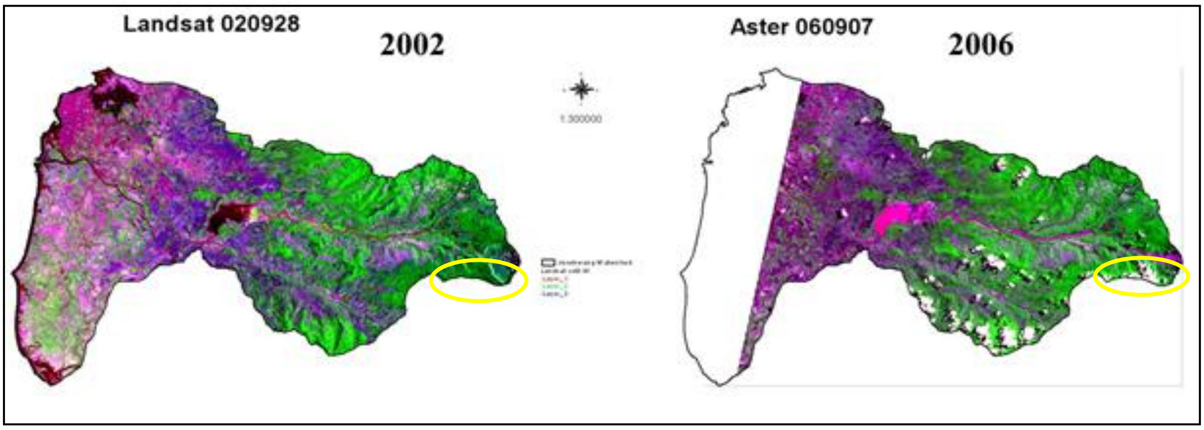

Figure 2. Optical Image of Landsat 2002 and ASTER 2006 with False Color Composite (FCC) of band 742 showing before and after the landslide occurred.

In SAR interferometry (InSAR), the phase data of SAR images are analyzed to derive the local topography (original InSAR) or detect and quantify the ground displacement that has occurred in the slant-range direction between the two acquisitions data called Differential-InSAR, (Agustan et.al, 2010). This technique has been used since 1995 to monitor surface displacement related to volcanic activity (Tralli *et al.*, 2003). The phase difference between an InSAR data pair can be ($f_{Int,P1\text{-}P2}$) expressed as follows:

$$f_{Int,P1\text{-}P2} = f_{Disp,P1\text{-}P2} + f_{atm,\,P1\text{-}P2} + f_{noise,\,P1\text{-}P2} + f_{topo,\,P1\text{-}P2} + f_{flat,P1\text{-}P2} \quad (1)$$

where $f_{Disp,P1\text{-}P2}$ + $f_{atm,\,P1\text{-}P2}$ + $f_{noise,P1\text{-}P2}$ + $f_{topo,\,P1\text{-}P2}$ and + $f_{flat,P1\text{-}P2}$ refer assumption of ideally flat earth terrain, respectively. In the process of extracting the ground displacement, the topographic condition (f topo,P1-P2) and flat earth (f flat,P1-P2) phase differences should be removed using digital elevation model (DEM) data and precise satellite orbital data, respectively (Bayuaji *et al*, 2010). The result of this process is generally called D-InSAR, which estimates the ground displacement in the slant-range direction.

DInSAR processing has been applied to 6 different level 0 data of JERS-1 SAR from different acquisition years of 1993-1998 with the JAXA/SIGMA SAR processing software (Shimada, 1999). Each pair of data went through the same procedure from image coregistrations, interferogram generation until phase unwrapping. Before phase unwrapping the DInSAR image was filtered using Goldstein and Werner filter with preconditioned conjugate gradient (PCG) (Singhroy and Molch, 2004). At the end all images were geocoded using cubic convolution with UTM transformation by resampling the DInSAR data to 12.5 resolution (Figure 3).

e processed 6 scenes of path 84 row 309 where all scenes were on the descending mode with single HH polarization. Change detection analysis and thematic classification were implemented to both the visible and SAR images over the study area to generate landslide susceptibility map. Under one GIS platform all data were integrated in ArcMap GIS 9.3 software with one UTM projections. All spatial data layers such as geology, structure, landcover, aspect and slope data as well as Digital Elevation Model (DEM) including field observation data were used to create a GIS-based landslide inventory database. This study required us to locate the exact location of the landslides coverage. On the ASTER image, we delineated the landslide coverage and made as a vector file to overlay in the SAR processed images.

Field surveys were conducted twice in 2009 and 2010 by visiting the affected areas specially for the GPS measurement of the crack incidences along the weak zone of prone areas that considered to be triggering slides in the future.

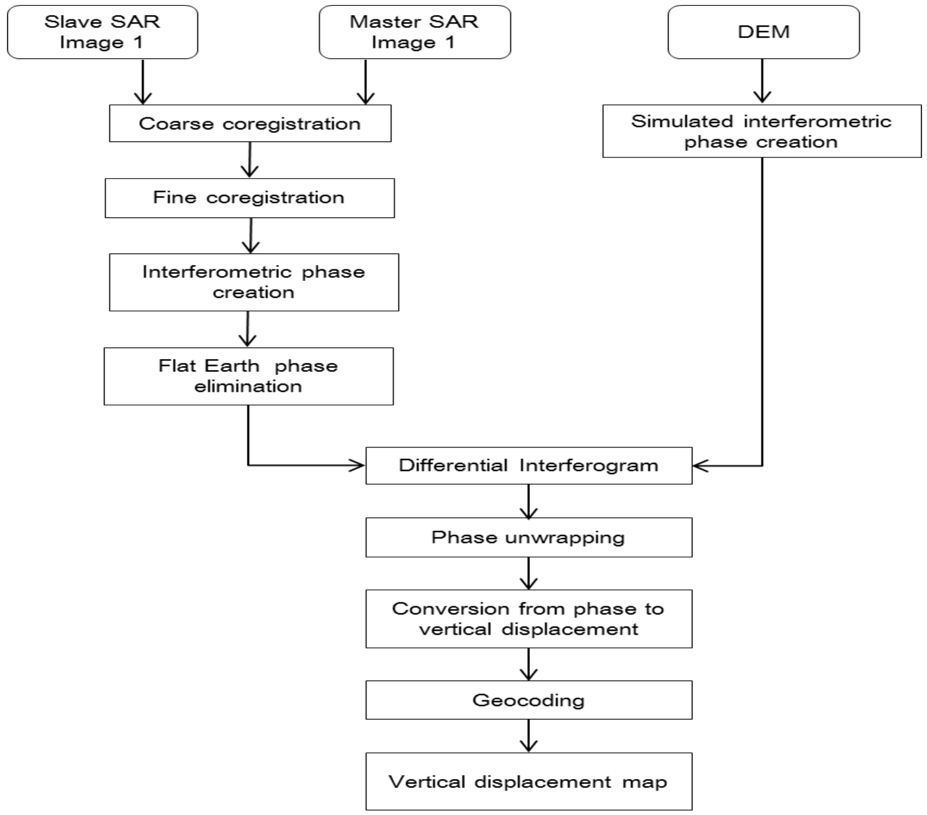

Figure 3. DInSAR Flow chart.

The field survey conducted in August 2009 performed GPS measurements and analysed sample material. The second visit was to obtain the crack locations and dimensions. The discussions with the staffs of the Jeneberang River Sediment Control Project under the coordination of public works office in South Sulawesi gave us significant overview of the post landslide monitoring. The project started monitoring the cracks along the weak zone of the upper head of the landslide since 2006 and continued until 2011. The crack location was measured regularly on monthly basis by staffs assigned to do the task. The measurement was done by measuring the distance of the crack. Table 1 below describes the geographic location, taken by geodetic GPS and dimension of the openings.

In the past, prior to the landslide, the crack was not monitored on a regular basis. Local people used to notice the gap and had to jump over to the other side of the crack. Based on the report from mountain climbers, several sites of the crack initially just showed small gap and gradually became larger and larger. Unfortunately the scientific records for these cracks were not found. After the landslide occurred people began to realize that the cracks happened in the past were no longer to be found. This is also happening to the new cracks that are now being recorded. Sometimes the displacement was nowhere to be found because they already collapsed. The displacement is important to be measured as it is the indication of the movement.

Table 1. List of crack dimensions

Location	L (cm)	D(cm)
Crack1-1	78.5	11.8
Crack1-2	87.0	5.0
Crack1-3	87.5	20.9
Crack1-4	280.0	26.0
Crack1-5	0.0	0.0
Crack1-7	0.0	0.0
Crack1-8	0.0	0.0
Crack1-9	189.5	24.0
Crack2-1	0.0	0.0
Crack2-2	0.0	0.0
Crack2-3	0.0	0.0
Crack2-4	0.0	0.0
Crack3-1	137.0	9.3
Crack3-2	0.0	0.0
Crack3-3	107.0	0.0
Crack4-3	328.0	244.3

L= length D= displacement

Ideally, the acquired SAR images should be with the same time as the measurement years. Overlying with the DInSAR processed images, we expect to improve the exact location and rate of changes in that area. Overlying these two data will give improvement on the landslide potential locations.

3. Results and Discussion

Based on the Geographic Information Systems (GIS) data processing using ArcGIS 9.3 and ENVI 4.5 software, visual delineation of Landsat image overlaid with vector data showed that an area of approximately 647 was affected at the upper part of River Jeneberang, with indications of significant mass movement prior to the landslide. On the other hand, the SAR processing using SIGMASAR yielded coherence images for each level 0 JERS-1 SAR data (Figure 4:1a, 2a, and 3a for each pair). Generating DInSAR images required a pair of different acquisition images. Among the 6 pairs being processed, only 2 pairs showed reasonable good coherence namely the pair images of 1995 March/1996 May and 1996/1997 (Figure 4:3b and 4:4b). Based on the theory, coherence in DInSAR images were partly caused by the baseline of the two different acquisition time of the satellites. In Table 2 showing the parameters of the processed data pair both 1995/1996 and 1996/1997 pairs had less than 500 m baseline. Other than this baseline factor, the coherence was also influenced by the atmospheric condition when the image acquired such as heavy rainfall.

The DInSAR image pair of 1995/1996 showed a linear movement of 5 cm around the landslide area, suggesting the occurrence of cracks/gaps related to subsidence before the landslide event (Figure 5). Ground validation using high resolution differential GPS from the field also supports this interpretation of the DInSAR image. From the project report of Jeneberang Sabo Dam, we obtained the GPS location of the cracks that occurred before and after the landslides. Overlaying this points allowed us to confirm the throne and the head of the landslides (Figure 5). The image analysis showed that there was a slight deformation along the slope of the potential landslide.

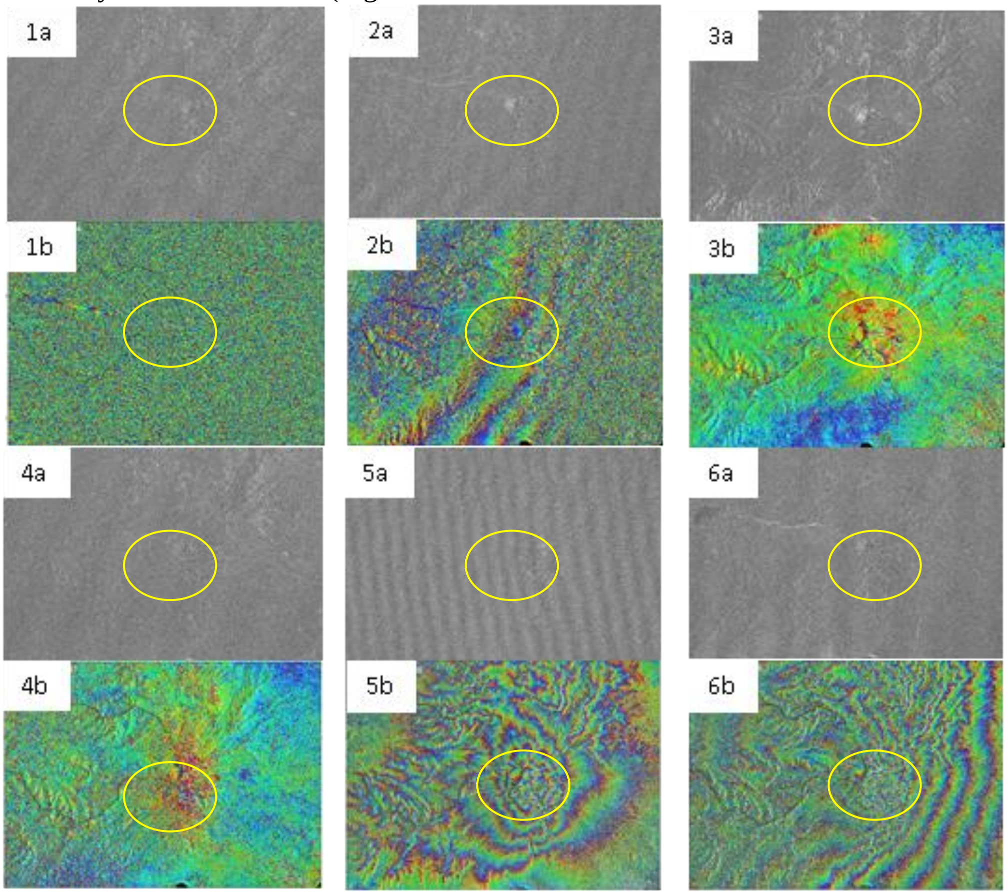

Figure 4. JERS-1 DInSAR Images: (a) coherence images of the six pairs of processed DInSAR. Yellow circle indicate the affected area. (b) DInSAR Images from 6 different pairs. 1-6 with pairs of 93/94, 94/95, 95/96, 96/97, 97/98, and 98/98.

Table 2. Baseline information for each pair of DInSAR Processing of Jeneberang Site

Pair (RSP 77/309)	Week Difference	Baseline (m)	Bp (m)	Bh (m)
19930317/19940417	56	1159.56	538.37	-1027
19940417/19950518	56	1384.25	1243.9	-607.4
19950518/19960321	44	424.74	250.22	-343.2
19960321/19970803	54	502.48	397.01	308
19970803/19981001	44	3382.77	2284.6	2495
19981001/19980818	36	1256.95	1130.6	-549.3

We also tried to process other area of landslide occurrence in Tenjolaya, West Java for comparison. Howeever, lacking good coherence images, it made difficult to analyze the image. DInSAR image showed a good coherence, hence, the subsidence in Bandung city area can be obviously identified and the phenomena was consistent in other pairs of the processed images. The matching process didn`t give good coherence, hence, we couldn`t identify any surface displacement in that particular area.

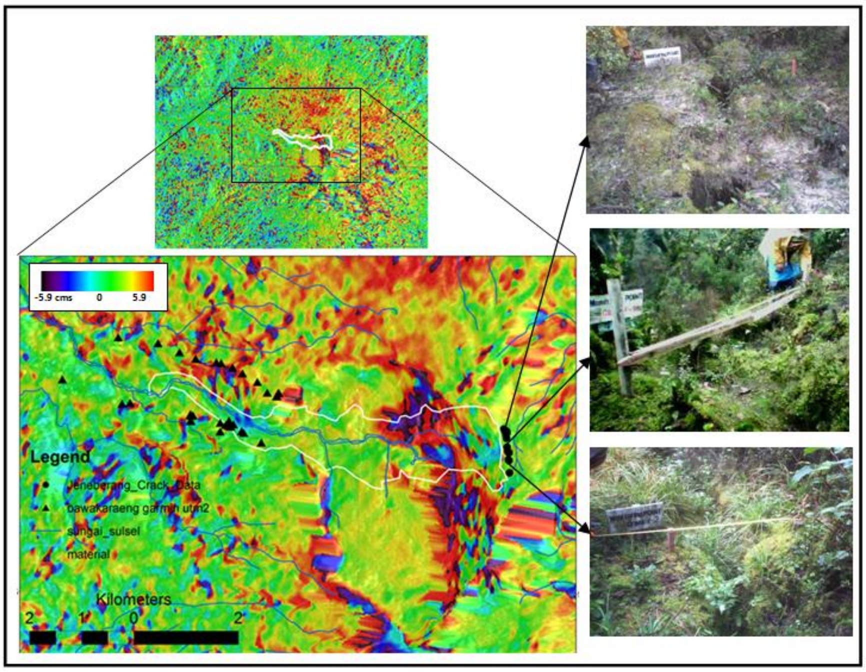

Figure 5. DInSAR image with crack locations and GPS positions from the field survey.

4. Conclusion and Further Work

DInSAR processing image obviously provided variety of results on surface displacement mapping. This study showed that not all JERS-1 SAR pairs of the designated areas gave good coherence image.Integrating optical satellite image (Landsat and ASTER) with SAR image processing can complement the change detection analysis and Differential Interferometric SAR (DInSAR) was proven to be one of the effective methods in mapping surface displacement especially for landslides. Integration of remote sensing and GIS can provide information on prior and post-landslide situations.

From the DInSAR image processing it was observed that there was a slight deformation measured up to 15 cm along the line of sight (LOS) and this confirmed that the cracks had been widening.

Further works must be carried out to validate the accuracy of the DInSAR image. Validation with ground checked must also be carried out. Applying DInSAR method with ALOS PALSAR images will produce a better result considering ALOS PALSAR has better accuracy for the device specifications compared to JERS-1. The next step is to input DInSAR image to the GIS map to create landslides susceptibility map.

5. Acknowledgement

The writers would like to thank Japan Aerospace Agency (JAXA) through Dr. Shimada for the cooperation of using SIGMASAR software.

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