

The Impacts Analysis of Pre And Post Merapi Mount Eruption on Residential Areas Using Sentinel 1, ALOS Palsar and Landsat Satellite Images Combination in 2009-2015

Yudo Prasetyo^{1*}, Riska Pratiwi¹ and Nurhadi Bashit¹

¹Remote Sensing and Photogrammetry Lab, Geodesy Engineering Dept, Faculty of Engineering, Diponegoro University, Jl. Prof. Soedharto SH, Tembalang-Semarang, Central Java, Indonesia, 50277

yudo.prasetyo@ft.undip.ac.id

Abstract. Indonesia is a country located in the presence of three large tectonic plates like the Indo-Australian, Eurasian and Pacific plates. The path of plate movement approaching or steering away each other leads to high volcanic and earthquakes activity. As a proof of the active path of this plate movement can be seen from the series of active volcanoes lies from the island of Sumatra, Java, Nusa Tenggara into Papua. The impact of active volcano activity will be felt in the densely populated area where the island of Java became one of the islands with the largest residential area in Indonesia. This impact needs to be anticipated with an integrated high-tech technology and volcanic disaster mitigation system. One of the most active volcanoes in the island of Java is Merapi mount which is experienced the last major eruption peak on October 26th, 2010. This volcanic eruption is effusive eruption type where magmatic gas pressure in the crater is not too strong and magma eruption is just flowing out past the slopes of the Merapi mount area. However, magmatic gas pressure and magma volume still result in deformation changes that have a direct impact on residential areas throughout the Merapi mount area. Therefore, this research performs deformation calculation using DInSAR (Differential Interferometry Synthetic Aperture Radar) method on Sentinel 1 SAR and ALOS PALSAR 1 satellite images between 2005-2015 acquisition year. Then the deformation patterns obtained from the DInSAR method will be spatially correlated with residential areas throughout the Merapi mount area. Residential areas were obtained through supervised classification process from Landsat 5 and 8-satellite imagery in the 2005-2015 acquisition year. The reason of observation year selection is based on pre and post eruption concept to get pattern of Merapi's mountain body change through deformation analysis. The result of the combination of deformation pattern and residential area changes was further analysed to obtain spatial correlation. The value of this spatial correlation will be an indicator of how's far the deformation changes due to volcanic activity will have an effect on the residential areas in the Merapi mount area. The output of this research is a map of Merapi mount deformation (due to volcanic activity) impacts on the residential area. The results are expected to contribute to the volcanic disaster mitigation system and the development of residential area plans in Merapi mount area.

Keyword: ALOS, DInSAR, Disaster, Sentinel, Volcanic



1. Introduction

Indonesia is a country located at the meeting of three large tectonic plates of the Indo-Australian, Eurasian and Pacific Plate [6]. The movement of the approaching plates will plunge into the bottom of the younger plate.

Behind the plate subduction path will form a series of magmatic and volcanic activities. This causes the Indonesian territory has many volcanoes scattered from the island of Sumatra, Java, Nusa Tenggara to Papua. Java Island has several volcanoes that are still active, one of which is Mount Merapi. Mount Merapi is located between several districts in the Central Java Province. The south side slopes are in the administration of Sleman Regency and the Special Province of Yogyakarta, Magelang Regency on the west side, Boyolali Regency on the north and east side and Klaten Regency on the southeast side. For geographical area of research lies in latitude position $110^{\circ}14'60''$ E- $110^{\circ}32'30''$ E and in longitude position $7^{\circ}29'47''$ S- $7^{\circ}47'53''$ S and can be seen clearly in **Figure 1**.

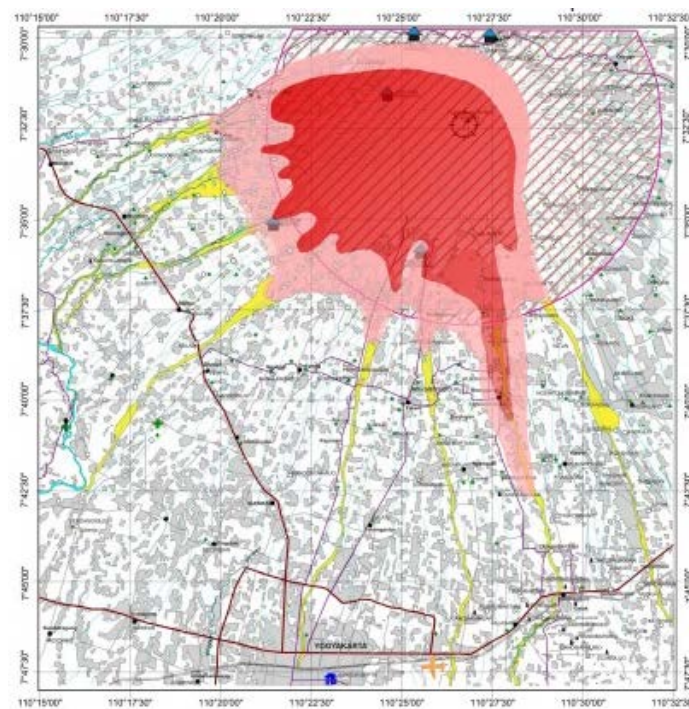


Figure 1. Research Area on Merapi Volcanic Mount (BNPB, 2016)

Mount Merapi has a topography height around 2,930 meters above mean sea level. Mount Merapi eruption occurred on October 26th, 2010. Merapi volcano eruption is a type effusive eruption in the form of lava melts where the pressure of magmatic gas is not so strong. For the flow of magma coming out of the cavity just flows through the slopes on the top of the mountain. Although only a type effusive eruption, this eruption causes many physical, environmental and economic losses. The flow of lava flow will affect the land cover around the area, so there will be changes in land cover before and after the eruption of Mount Merapi. This causes significant deforestation (deformation) before the eruption. Volcanic deformation occurs due to volcanic activity in the form of magma movements below the surface that affect the changes in pressure on the pocket of magma. The presence of submarine motion is an early indication of eruption and an increase in pressure that will result in ground deformation. This research uses remote sensing technology using active sensor data and passive sensor. Active sensor data used is ALOS PALSAR and Sentinel-1, which is used to analyse pre and post eruption using DInSAR (Differential Interferometry Synthetic Aperture Radar) method. This research will analyse the pattern of deformation that occurred at Mount Merapi in the time before and after the eruption. Includes an analysis of the impacts on changes in land cover in the research area.

2. Materials and Methods

2.1. Research Methodology

For research data used consist of spatial and attribute data where the data research details can be seen in **Table 1**.

Table 1. Research Data

No.	Description	Acquisition Time
1.	ALOS PALSAR Images	2009-2010
2.	Sentinel 1 1W Images	2015
3.	Landsat 5	2009
4.	Landsat 8	2015
5.	SRTM DEM image	2010
6.	TerraSAR DEM image	2011
7.	Administration Map of Yogyakarta Province and Central Java	2016
8.	Merapi Volcanic Hazard Map	2009-2016

In this research, there are several research stages that have been done; the outline of research methodology is described in **Figure 2** and DInSAR processing stage is described in **Figure 3**

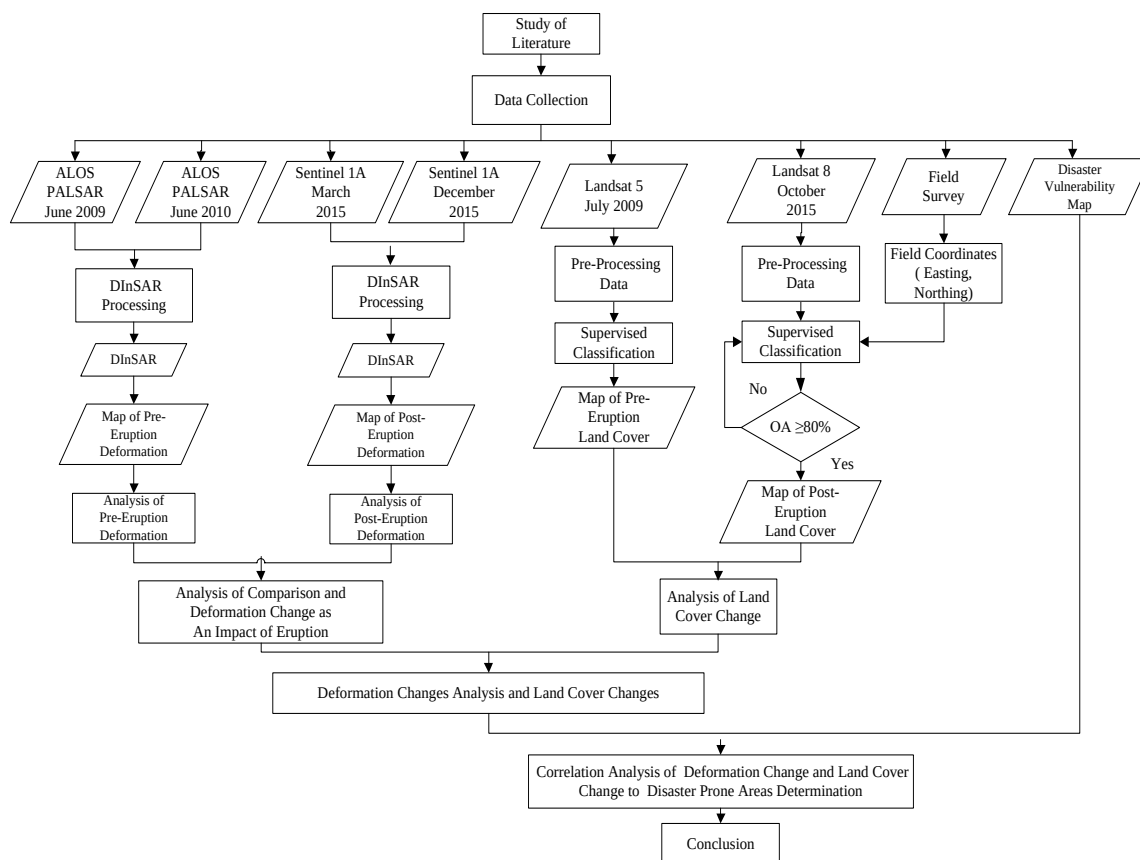


Figure 2. Research Methodology

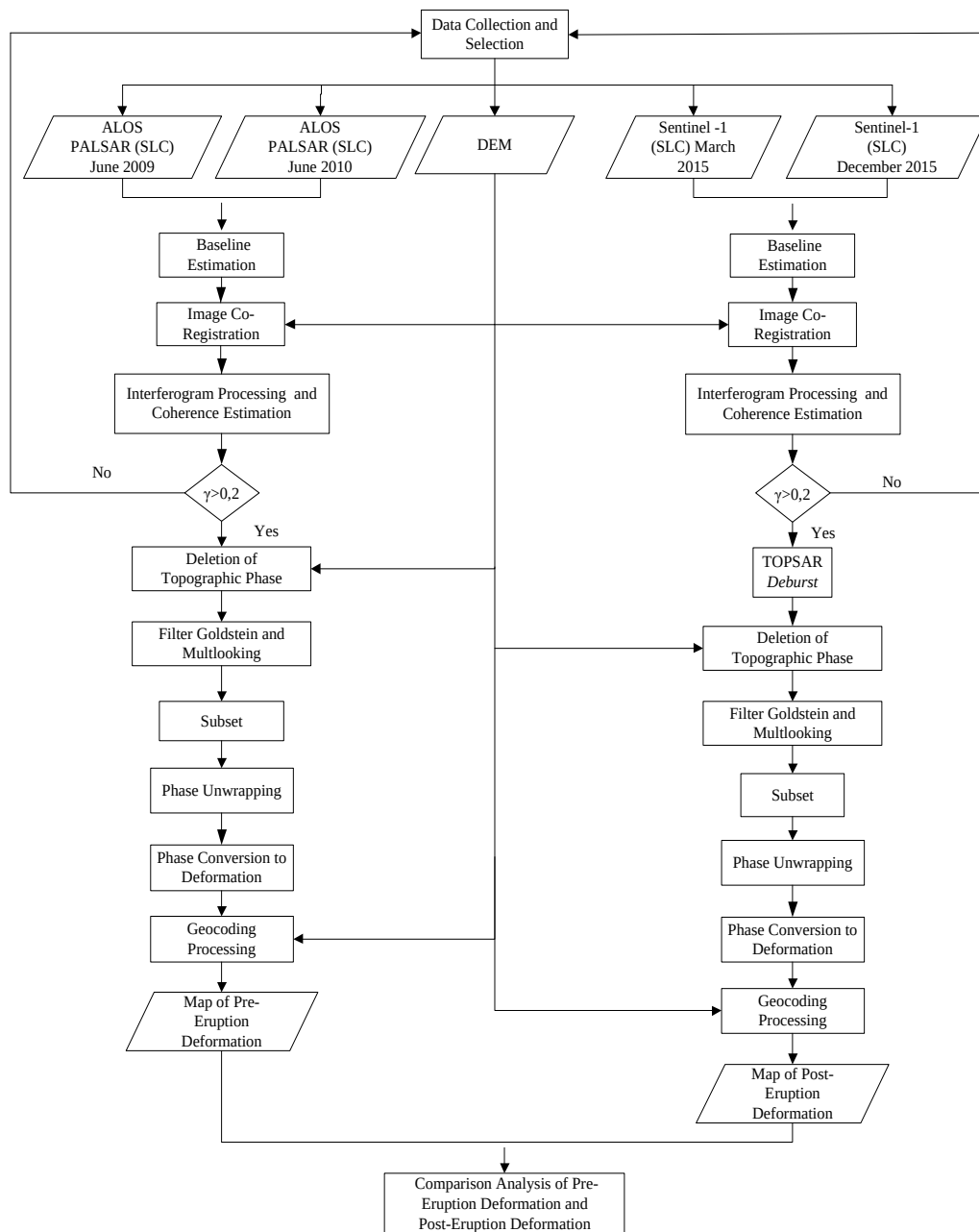


Figure 3. DInSAR Processing Stage

2.2. Deformation on Volcanic Mount

Land surface deformation occurs because of changes in magma pressure or magma intrusion [3]. Usually deformation is expressed by displacement of horizontal, vertical and tilting direction [8]. In volcanic areas there is often a change in topography caused by lava flows or eruptions. These changes may be additional materials. Another case, sometimes the magma activity in the magma bag does not produce additional material on the surface. The result of all of the magma activity in the volcanic mountain is deformation on land surface. In principle the deformation of the volcano body can be an increase in soil surface (uplift) or a decrease in soil surface (subsidence). Deformation in the form of inflation generally occurs because the process of magma movements to the surface that presses the surface of the soil above it. Maximum deformation is usually observed shortly before volcanic eruptions take place. Deformation

of deflation generally occurs during or after eruption. At that time the magma pressure inside the volcano's body has weakened, causing the surface to tend to return to its original position. Symptoms of volcanic deformation will cause a shift in the position of a point in the body of a volcano. This position shift can occur in both horizontal and vertical directions. According [7], the value of this shift can reach tens of meters on a silicone volcano that forms a lava dome.



Figure 4. (a) Explosive Type (b) Effusive Type (Explore Volcanoes, 2008)

2.3. DInSAR (Differential Interferometry Synthetic Aperture Radar)

Differential Interferometry Synthetic Aperture Radar (DInSAR) is an acquisition technique of two paired SAR images in combination of complex image data at the same spatial position (differential SAR) or slightly different position (terrain height InSAR) in the same area by multiplication of multiple conjugations. The final result is a digital elevation model (DEM) or a shift in a surface of the earth [2]. DInSAR is often used to monitor changes (deformation) of an area to the order of order cm. Such order of thoroughness, obtained from InSAR data processing methods in different way. In this method used several pairs of interferogram at once to detect the topographic surface changes with very high accuracy [5]. In the interferogram, the phase difference is described as the distance difference measured by the line of sight (LOS) radar and includes topography, orbit shifts, surface deformation and atmospheric effects [1]. The following **Equation 1** can show the phase difference equation in DInSAR method.

$$\Delta\phi = \Delta\phi_{topo} + \Delta\phi_{defo} + \Delta\phi_{atm} + \Delta\phi_{orb} \quad (1)$$

In:

$\Delta\phi$ = Phase Differential

$\Delta\phi_{topo}$ = Topography Phase

$\Delta\phi_{defo}$ = Deformation Phase

$\Delta\phi_{atm}$ = Atmospheric Phase

$\Delta\phi_{orb}$ = Orbital Phase

There are two ways to implement DInSAR method in this research. One is with an external elevation model (DEM) and by using extra radar imagery to form topography model. The method using an external DEM requires only two radar images, assuming the deformations that occurred during the acquisition and known by the two-pass method. The second method does not require data other than radar data. The topographic reference here is made with additional radar data obtained, three or four images (used) and sequentially called by the three-pass and four-pass method.

3. Results and Discussion

3.1. Deformation analysis for volcanic pre-eruption in Merapi Mountain

The internal RMSe value of pre-eruption deformation processing results is 0.0044 ± 0.1933 m/yr. The result of pre-eruption deformation can be seen in **Figure 5**.

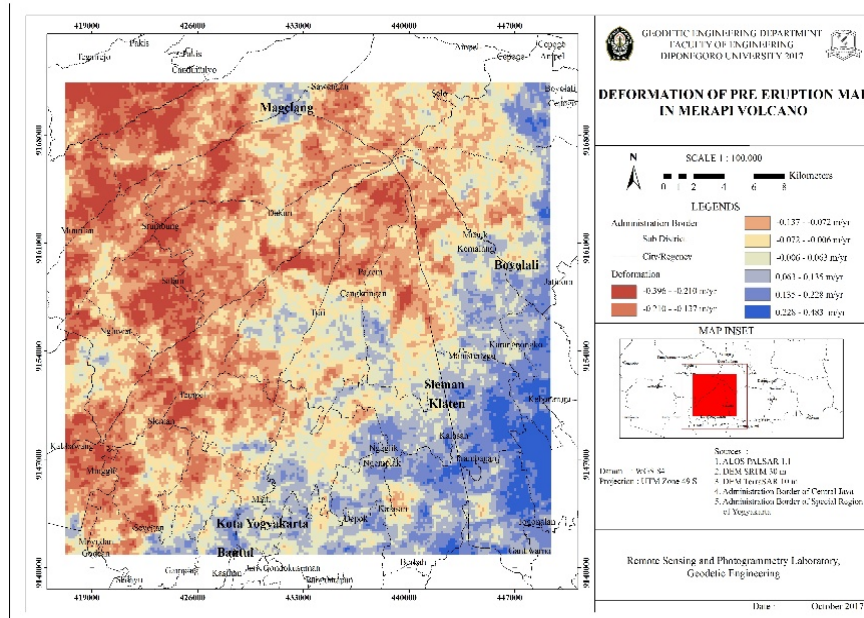


Figure 5. Deformation of Pre-Eruption in Merapi Volcanic Mount

In **Figure 6** it can be seen that the highest land subsidence in land surface occurred in Candimulyo District, Magelang Regency with decrease reach -0.2109 ± 0.067 m/yr. The land subsidence rate calculation is earned by searching for the highest value of land subsidence for each districts administration. For the land subsidence rate is obtained by finding the average value of land subsidence from the DInSAR processing data. This land subsidence phenomenon is common happened in Magelang and Sleman districts. This is because the two districts are directly adjacent to the peak of Mount Merapi, so it can cause a land subsidence in the ground surface when there is an unstable magma movement before the eruption. This land subsidence may also occur due to dense development activities in both districts.

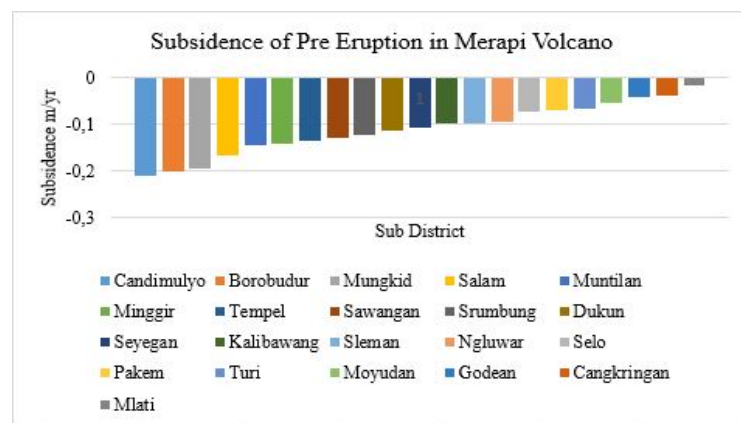


Figure 6. Land Subsidence in Pre-Eruption Phase in Merapi Volcanic Mount

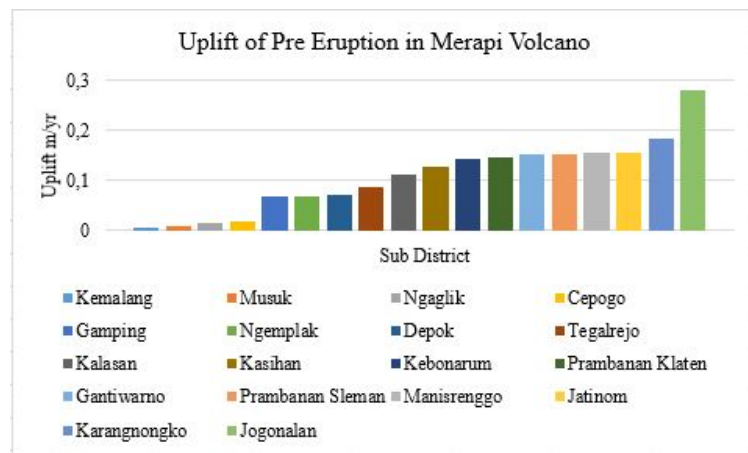


Figure 7. Uplift in Pre-Eruption Phase in Merapi Volcanic Mount

The highest rise of the land subsidence and uplift of land surface in **Figure 6** and **Figure 7** is located in Jogonalan Sub-district, Klaten Regency with uplift on land surface around 0.2788 ± 0.0803 m/yr. The cause of this land surface rise is the lack of perfect phase unwrapping process, so there are still many artefacts that have not disappeared and cause the final result to be less suitable, especially in the southern part of the study area located in Klaten regency.

3.2. Deformation analysis for volcanic post-eruption in Merapi Mountain

The internal RMSe value of post-eruption deformation processing is -0.0346 ± 0.0441 m/yr. The result of post-eruption deformation can be seen in **Figure 8**. In **Figure 9** the highest land subsidence in land surface reaches -0.0871 ± 0.0024 m/year in Tegalrejo Sub-district, Jogjakarta City. This land subsidence is common in Sleman and Magelang regencies. This is because the two districts are directly adjacent to the peak of Mount Merapi, so that it can be affected directly during the eruption. The immediate impact is the flow of lava that flows and can cause a decrease in the face of the soil. This land subsidence may also occur due to dense development activities in both districts.

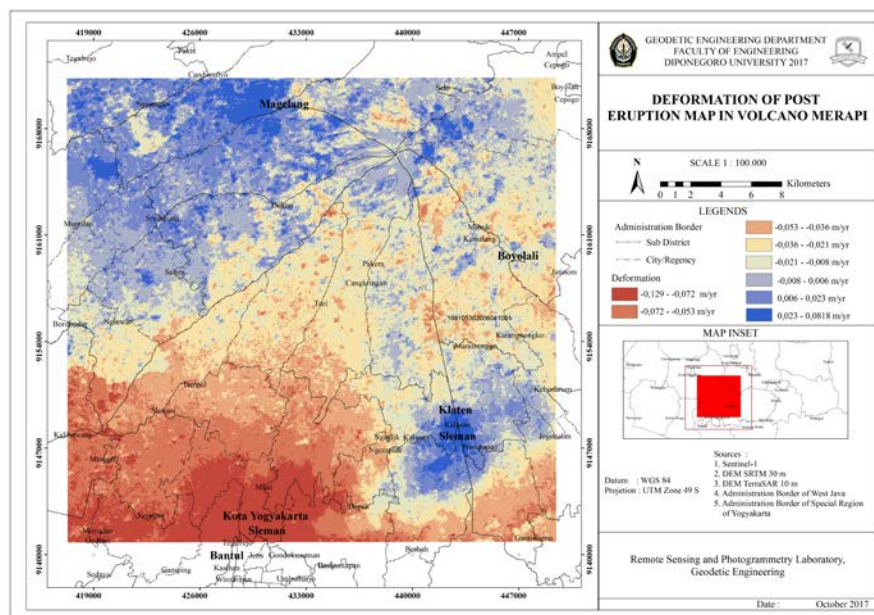


Figure 8. Deformation of Post Eruption in Merapi Volcanic Mount

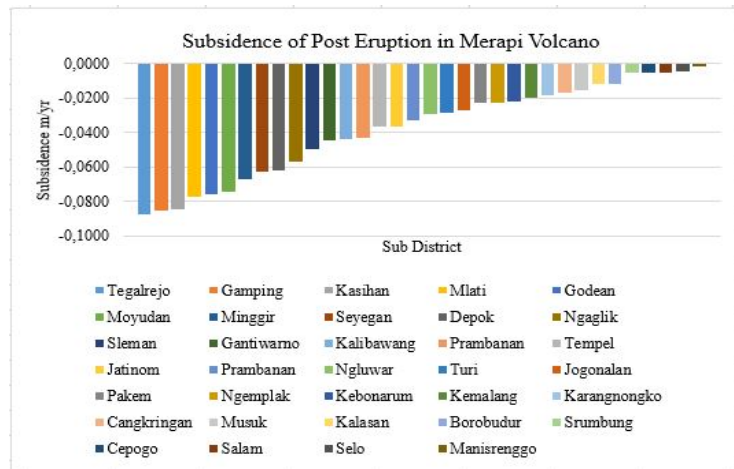


Figure 9. Land Subsidence in Post Eruption Phase in Merapi Volcanic Mount

The highest uplift is in Sawangan District, Magelang Regency with an increase of 0.0148 ± 0.0184 m/year can be seen in **Figure 10**. One of the causes of post-eruption soil eruption is the process of phase unwrapping is not perfect, so there are still many artefacts that have not been lost. The deformation change is obtained from the pre and post eruption volumetric values. The changes are classified into 3 classes, namely low, medium and high classes. This classification is based on the highest and lowest values then divided equally. The lowest deformation change value was 0.0187 m/year and the highest was 0.3056 m / yr. The lowest grade has a deformation change value of 0.0187 m/year up to 0.0749 m / yr. The moderate class has a deformation change value of 0.0749 m/year up to 0.1667 m / t and the highest grade has a deformation change value of 0.1667 m/year up to 0.3056 m/yr.

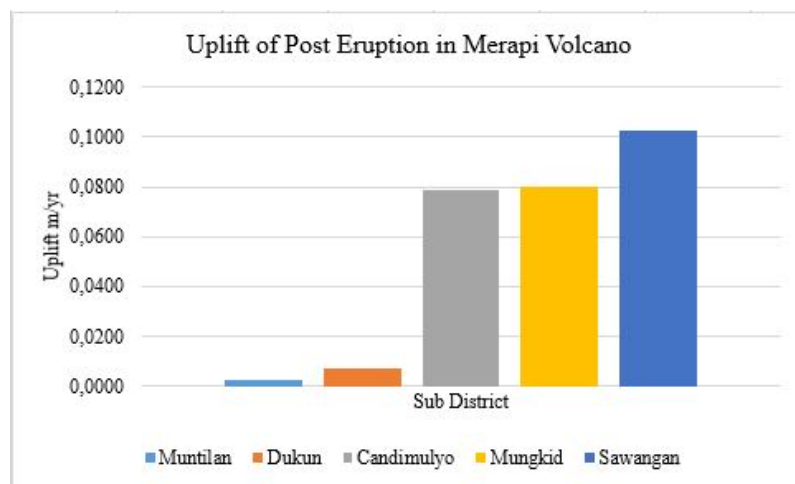


Figure 10. Uplift in Post Eruption Phase in Merapi Volcanic Mount

The results of the classification resulted in 16 sub-districts entering the lower classes, 12 sub-districts entering the middle class and 11 sub-districts entering the highest class. The highest rate of deformation change occurred in Jogonalan Sub-district, Klaten regency with a change value of 0.3056 m/year. The lowest rate of deformation change occurred in Moyudan sub-district, Sleman District with a change value of 0.0187 m/yr. One of the causes of high deformation changes in the southern areas of the study area is the process of unwrapping processing is less than the maximum, both on the result of pre-eruption

deformation. The comparison of pre and post eruption deformation values and the deformation change map is overlaid as shown in **Figure 11** and **Figure 12**

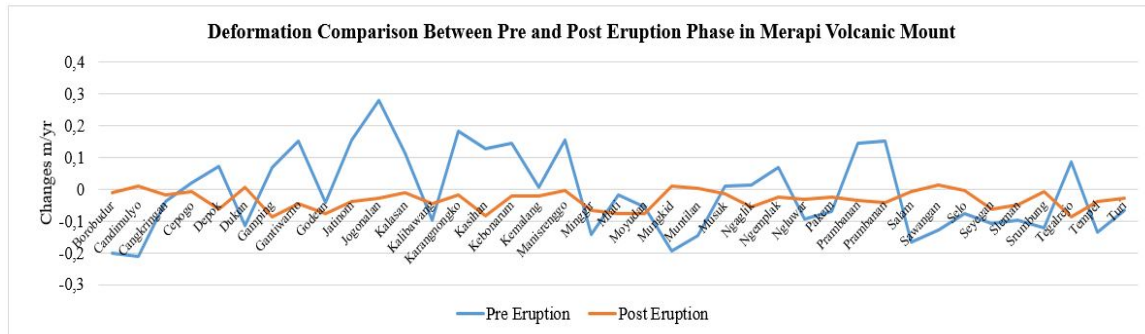


Figure 11. Deformation Comparison Between Pre and Post Phase in Merapi Volcanic Mount

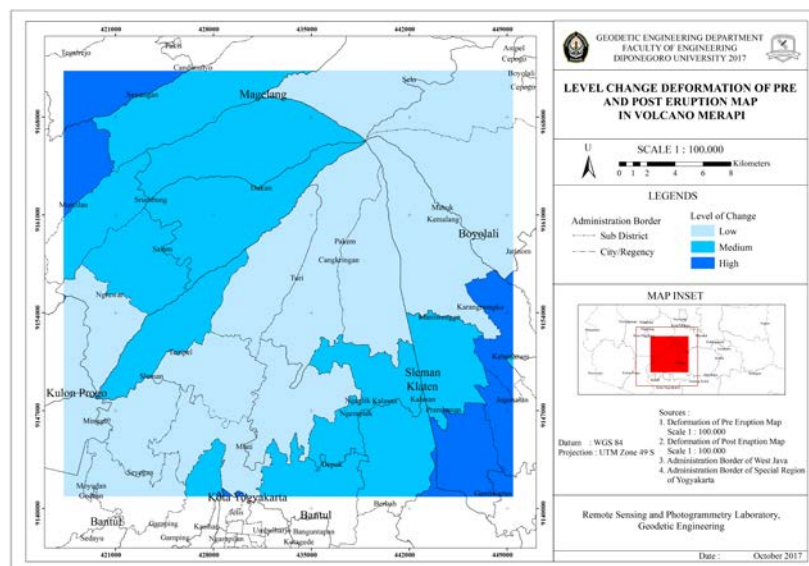


Figure 12. Deformation Changes Between Pre and Post Phase in Merapi Volcanic Mount

3.3. Volumetric analysis based on pre and post eruption in Merapi Mountain

Volumetric pre and post eruption can be obtained from the calculation of area and distance shift from the surface of the earth to the point of shifting. The distance of this shift is obtained from the speed of decline and the increase calculated per year. The objective of research to find the volumetric deformation value from radar image observation is to observe the pattern of land surface change in the period pre and post-eruption. The change pattern will be seen and observe to know the influence into land cover change pattern in the research area.

In **Table 2** and **Table 3** it can be seen that the pre-eruption volume is 117,803,878,288 m³ or 164,925,429.6 tons and the volume of post-eruption is 29,960,942,643 m³ or 41,945,319.7 tons. From these volumetric results can be seen that there is a volumetric decrease from pre-eruption to post eruption of 87,842,935.645 m³ or 122,980.109.9 tons.

Table 2. Volumetric Calculation for Pre-Eruption Phase

No	Width (m ²)	Velocity (m/year)	Time (Year)	Distance (m)	Volume (m ³)
1	74430266,6117	-0,3954 -0,2100	1	0,3024	22509886,545
2	16095160,2800	-0,210 - -0,1371	1	0,1733	27884875,365
3	20834611,8200	-0,1371- -0,0716	1	0,1044	21741857,243
4	17797532,4830	-0,0716 - -0,0062	1	0,0389	6923906,8846
5	137465200,1480	-0,0062 - 0,0627	1	0,0283	3886060,3099
6	123928131,9090	0,0627 - 0,1351	1	0,0989	12254923,997
7	74237052,7870	0,1351 - 0,2280	1	0,1816	13478627,815
8	25662850,5688	0,2280 - 0,4830	1	0,3555	9123740,1283
Total					117803878,288

Table 3. Volumetric Calculation for Pre-Eruption Phase

No	Width (m ²)	Velocity (m/year)	Time (Year)	Distance (m)	Volume (m ³)
1	70954856,5955	-0,1296 - -0,0716	1	0,1006	7139713,4536
2	98892397,8844	-0,0716 - -0,0525	1	0,0621	6137969,5900
3	119145335,8040	-0,0525 - -0,0359	1	0,0442	5271002,3449
4	172359218,0000	-0,0359 - -0,0210	1	0,0285	4909819,9441
5	178655849,6640	-0,0210 - -0,0078	1	0,0144	2570887,7802
6	180346915,2730	-0,0078 - 0,0063	1	0,0007	127856,4045
7	123503417,0110	0,0063 - 0,0229	1	0,0146	1806929,6487
8	38137024,9132	0,0229 - 0,0818	1	0,0524	1996763,4770
Total					29960942,643

This change can occur because of volcanic activity in the form of magma movements below the surface that affect the pressure changes in the pocket of magma. The land subsidence movements are an early indication of eruptions and increases in pressure that will result in ground deformation.

Deformation in the form of inflation generally occurs because the process of movement of magma to the surface that presses the surface of the soil above it. This causes the maximum deformation usually observed shortly before the volcano eruption that is at the time of pre-eruption, while deflation deformation generally occurs during or after the eruption. At that time the magma pressure inside the volcano body has weakened, so that the ground surface tends to return to its original position. This causes post-eruption deformation more stable than pre-eruption, so the volume due to deformation is reduced.

3.4. Impact analysis on residential area based on deformation results

The results of land cover classification pre and post eruption can be seen in **Figure 13** and **Figure 14**.

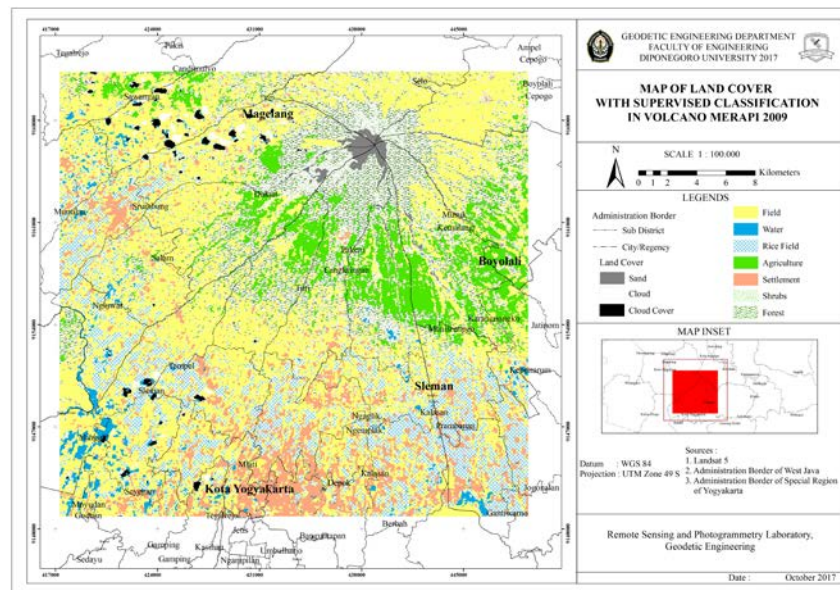


Figure 13. Land Cover Classification in Pre-Eruption Phase

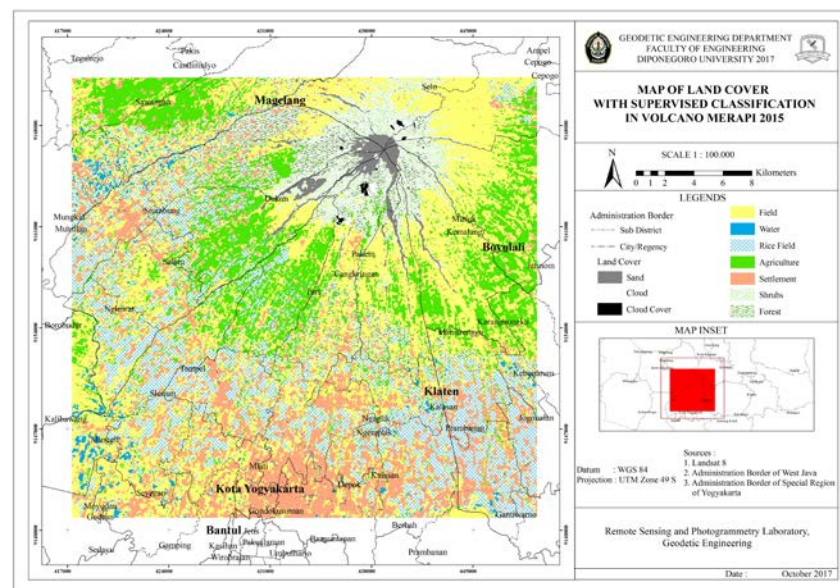


Figure 14. Land Cover Classification in Post Eruption Phase

Table 4. Land Cover Classification in Pre and Post Eruption

No	Description	Pre Eruption (Ha)	Post Eruption (Ha)
1.	Sand	902.982	1,846.726
2.	Bush	6,258.923	5,070.847
3.	Forest	14,880.213	5,967.533
5.	Field	43,111.097	35,284.768
7.	Water Body/River	1,987.325	1,253.26

No	Description	Pre Eruption (Ha)	Post Eruption (Ha)
8.	Rice Plant	12,215.235	16,186.164
9.	Farm	8,546.549	15,729.437
10.	Residential	9,014.236	16,160.846

In **Table 4** it can be seen that any land cover that undergoes changes, either increase or decrease values. This uplift land surface during post eruption can impact to the increasing number of people every year, thus affecting the increase of settlements, rice fields and plantations. Based on calculation result of land cover at condition of pre and post eruption got difference value equal to 7,146.610 Ha. The subsidence in land cover during pre-eruption can be impact to the forests, fields, bush and water bodies area. All this area is widely used for the development and establishment of more useful and durable land such as plantations. Forests and shrubs located around the peaks of Mount Merapi can be severely damaged as they become the path of the flow of magma that occurs during the eruption.

4. Conclusion

Based on land surface changes in pre and post-eruption phase, volcanic deformation is classified into 3 levels (low, medium and high). The highest rate of deformation change occurred in Jogonalan Sub-district, Klaten Regency with a change value of 30.56 cm/year. And the lowest deformation rate occurred in Moyudan Sub-district, Sleman Regency with a change value of 1.87 cm/yr. In addition to deformation changes, this research has found a land volumetric pre-eruption amounted to 164,925,429.6 tons and a land volumetric post-eruption amounted to 41,945,319.7 tons. The result of volumetric calculation can be seen that there is a volumetric decrease from pre-eruption to post eruption of 122,980,109.9 tons. A significant pre and post eruption deformation also seen in pre-eruption deformation ranged from -21.09 ± 6.7 cm/year to 27.88 ± 8.03 cm/year. Likewise, a post eruption ranged from -8.71 ± 0.24 cm/year to 1.48 ± 1.84 cm/year. This is due to the movement of the magma is less stable and can expand the volcanic dome during pre-eruption of Mount Merapi.

For the analysis of the level of land cover change during the pre and post eruption period, some areas were affected by the volcanic activity of the Merapi Mount. The highest rate of land cover change occurred in Turi Sub-district, Sleman Regency with 70.187% change value. And the lowest land cover change rate occurred in Prambanan Sub-district, Sleman Regency with change value 21.83%. Related to the impact of the pre-eruption activity in Merapi Mount to residential area gained a result around 9,014.236 Ha and in the post-eruption phase around 16,160.846 Ha. Thus, obtained significant value of the impact of deformation due to volcanic activity on Mount Merapi to residential areas amounted to 7,146.610 Ha.

References

- [1] Castaneda *et al* 2011 Dedicated SAR interferometric analysis to detect subtle deformation in evaporite areas around Zaragoya, NE Spain. *International Journal of remote sensing* **32**(7):1861-1884.
- [2] Cumming I G *et al* 2005 *Digital Processing of Synthetic Aperture Radar Data*. Artech House Remote Sensing Library.
- [3] Danoedoro P 1996 *Pengolahan Citra Digital*. Yogyakarta. Gadjah Mada University Publisher
- [4] Sharav A 2003 *Differential SAR Interferometry for Crustal Deformation study*. The Netherlands: International Institute For Geo-Information Science And Earth Observation Enschede : The Netherlands.
- [5] Prasetyo Y, Fahrudin and Islam L F J 2011 Integrated analysis of differential interferometric synthetic aperture radar (DInSAR) and geological data for measuring deformation movement of Kaligarang fault, *AIP Conference Proceedings* 1857: 090003. doi: 10.1063/1.4987102
- [6] Purwadhi F S H 2001 *Interpretasi Citra Digital* Jakarta. Grasindo Publisher

- [7] Van der Laat R 1996 *Ground-Deformation Methods and Results- In Monitoring and Mitigation of Volcano Hazards*. Springer Verlag, Berlin, pp. 147 - 168.
- [8] Vidyan Y *et al* 2013 Pemanfaatan Metode TLS untuk Pemantauan Deformasi Gunung Api, Studi Kasus : Kerucut Sinder Gunung Galunggung, Jawa Barat. *Environment and Geology Disaster Journal* **4** (1): 49-69.

Acknowledgment

The authors would like to thank the reviewers for their valuable comments. The authors would also like to thank at Badan Nasional Penanggulangan Bencana (BNPB) for provide ALOS PALSAR raw images and all research assistant in Remote Sensing and Photogrammetry Laboratory in Diponegoro University for the assist of radar satellite image data processing.