Identification of Surface Manifestation at Geothermal Field Using SAR Dual Orbit Data

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Abstract. The Wayang - Windu Geothermal Field located in West Java, Indonesia is a geothermal field under tropical zone which is identified by high precipitation, dense vegetation, and extensive weathering/alteration. The clouds due to high precipitation and vegetation conditions on the tropical zone inhibit the identification of surface manifestation using optical remote sensing techniques. In this paper, we reduced these inhibiting factors using microwave remote sensing techniques termed as Synthetic Aperture Radar (SAR). The SAR dual orbits were used to observe the targets on the surface by minimizing the effects from the clouds and dense vegetation cover. This study is aimed to identify surface manifestation based on Geomorphologic and Structural Features (GSF) of the SAR in Ascending and Descending orbits. The Linear Features Density of SAR (lifedSAR) method was applied to quantify the linear features of the ground surface and served as basis of surface manifestation identification. Based on the lifedSAR and field observations, the surface manifestations could be detected successfully at Wayang and Cibolang craters with density about 45%. The soil measurements were used validate the result and to interpret the correlation between LFD and surface manifestations.

1. Introduction
Wayang Windu Geothermal Field termed as WWGF is geographically located in West Java Province, Indonesia. The WWGF is located under tropical zone which has high precipitation and dense vegetation. This condition inhibit identification of surface manifestation using optical remote sensing techniques. Overcoming the problem, we used the Synthetic Aperture Radar (SAR) system to detect the targets by reducing the atmospheric and vegetation conditions [4]. The WWGF is interpreted as transition of geothermal system between water and vapor-dominated system [2]. The reservoir of the WWGF is characterized by the three steam dominated reservoirs with two steam dominated reservoirs in the south associated with Mt. Wayang - Windu and one steam dominated reservoir in the north associated with Mt. Gambung – Puncak Besar. The steam dominated reservoirs are located above the water dominated reservoir with elevation 0 - 400 m above sea mean level in the northern areas [2]. The steam dominated reservoirs are increasingly deep towards to the south associated with Mt. Gambung – Puncak Besar at the north to Mt. Wayang - Windu at the south [2]. The geomorphic of WWGF is composed by structural features of volcanic complex [7]. The Linear Feature Density of SAR (lifedSAR) method could quantify the linear features of the ground surface and served as basis of surface manifestation identification. The measurements data was used to validate the identification surface manifestation and linear features at ground surface, accurately.
2. Data and Methodology

2.1. Data
We used the Phased Array L-band type Synthetic Aperture Radar (PALSAR) onboard Advanced Land Observing Satellite (ALOS) in ascending and descending orbits data. Both data are orthorectified in level 1.5. The ascending orbit indicates that the satellite moves from South to North with looking direction to East. Meanwhile, the descending orbit indicates that the satellite moves from North to South with looking direction to the West. In addition, we also used ground measurement at surface manifestations to validate the SAR analyses. Figure 1 shows the ascending and descending orbits of ALOS PALSAR backscattering intensities images.

2.2. Methodology
Linear Feature density (LFD) is a map which illustrates the density of linear features in particular grid. More linear features detected in a grid cell will produce high density. On the contrary, less linear feature will produce low density. The LFD map was generated following lifedSAR processing [4]. The program required the input from ALOS PALSAR level 1.5 or orthorectified intensity images. The lifedSAR used edge detection process based on the Laplacian of Gaussian (LoG) filter to define the linear feature in two intensities images at different LOS. Density was then calculated based on grid size about 10 x 10 pixels [5]. The lifedSAR result could be confirmed by extracting circular and linear features related to the crater rim and geological structures [4]. In this paper, we focused on the correlation between SAR dual orbits and LFD, obtained from lifedSAR, and the ground measurements of the surface manifestation including magnetic susceptibility, pH and ground temperature. The visual interpretation was taken into account to assess the effectiveness of the SAR dual orbits and LifedSAR in predict of geothermal surface manifestation.

Figure 1. Backscattering intensity of ALOS PALSAR data in Ascending orbit (A) and Descending orbit (B) shows Mt. Wayang dan Windu at West and East Line of Sight (LOS).
3. Result and Discussion

3.1. Linear Features

Linear features are useful to interpret the information related to crater rim, ridge and valley, as well as to provide an overview of the volcanic structures in the study area. Figure 2 shows the detected linear features at study area based on SRTM, ALOS PALSAR dual orbit and geological maps [3]. The visual analyses were showed by red thin line that Mt. Malabar (Northern Area) has density of linear features originated from foothill, ridge, and valley. On the contrary, the linear features at Mt. Wayang - Windu smoother than the linear features at Mt. Malabar because linear features detected at Mt. Wayang less than Mt. Malabar.

According to the figure 2, the thick red lines are main faults of Mt. Wayang - Windu regions [3]. See figure 3, Bedil fault is located between the Northern of Mt Wayang and Southern of Mt. Bedil. The dominant strikes of the fault are Northeast – Southwest direction. Then, the Cibolang fault located at the Southern of Windu crater, and the dominant strikes of the fault are Northwest – Southeast direction. The dominant strikes of the youngest fault system (Windu fault) are Northwest - Southeast direction and located at North of Cibolang fault [8].

3.2. Ground Measurements at Surface Manifestation

The ground measurements of surface manifestation such as altered ground, mud pool, steaming ground, warm springs and hot springs were measured by thermometer, pH meter, and magnetic susceptibility meter. Wayang crater has only steaming and altered ground surfaces. The measured temperature and acidity at the ground surface of Wayang crater are about 60 ºC, and pH 3, respectively. It may indicate that the ground surface was affected by hydrothermal activity strongly.

The Cibolang crater presented by dotted-line is located at the North and East of surface manifestation points including steaming ground, altered ground, and hot springs with soil pH about 3.6 and temperature steaming ground at crater about 90ºC and hot spring exist far from crater about 40 ºC. They indicate hydrothermal activity at the surface of Cibolang crater.

Figure 2. The linear features overlaid on shaded map of SRTM data. Thick and thin red lines are faults based on geological map and interpretation from SRTM and ALOS PALSAR data, respectively. The dotted-lines are crater features based on SRTM data.

Figure 3. The distribution of field measurement points overlaid on shaded map of SRTM data. Wayang manifestation depicted by blue, Cibolang by green, Sukaratu by red and Citawa by yellow points.
The hot springs temperatures and acidity at Citawa and Sukaratu were measured about 40 – 50 °C and pH 6, respectively. The medium pH with warm temperature indicated a mixing with surface water at the hot springs. This mixing process decreases the temperature, but increase the pH. These conditions lead to interpretation that Citawa and Sukaratu are outflow zones of Wayang-Windu geothermal systems.

According to magnetic susceptibility measurements, the Wayang and Cibolang craters were less than $1.5 \times 10^{-3}$ SI with average about $0.5 \times 10^{-3}$ SI. Meanwhile, the areas outside from the crater showed magnetic susceptibility larger than 2 with average about $3.5 \times 10^{-3}$ SI. The low magnetic susceptibility might be associated with altered rock/soil. The hydrothermal activity caused alteration that the magnetic minerals decomposed into non-magnetic minerals such clays [1].

3.3. Correlation of Surface Manifestation with SAR Dual Orbit Data

Figure 4 shows the locations of surface manifestation in ascending and descending orbits. The surface manifestations are consistent for both images that bright and dark tones are identical with rough and smooth surfaces, respectively. Interestingly, different orbits or Line Of Sight (LOS) provide different brightness level for the same surface manifestation. For descending image, the surface manifestation of altered zones at Wayang crater with ground pH about 2 is detected by dark tone with medium to low (-20 – -10 dB) backscattering coefficient. Then, the altered zones were surrounded by medium (0 – 10 dB) backscatter coefficient. For ascending image, the altered zones are identified by medium to high (10 - 20 dB) backscattering coefficient. Therefore, the altered zones at Wayang crater are presented by medium to high (ascending image) and medium to low (descending image) backscattering coefficient. The slope toward the sensor and incidence angle are supposed to be responsible to the different backscattering coefficient values. Contrary, the hot springs are difficult to be identified because of no signature anomaly in ascending nor descending orbits. The limitation spatial resolution of the images and the spotted location of hot springs were predicted responsible to the problem.

Figure 5 shows the LFD based on lifedSAR method from ALOS PALSAR data in ascending and descending orbits. The grey color bar indicates the area containing minimum (black) and maximum (white) linear features about 60% for grid cell 30×30 pixels. For ascending image, the Wayang and Cibolang craters with steaming and altered grounds were identified by medium to high density about 35 – 45 % grid. Contrary, the craters were identified by a low density less than 20 % grid in descending image. Therefore, combining both LFD provided a complete LOS and surface structures such as roughness effects from surface manifestation. The surface roughness is one parameter to identify surface characteristics related to geological features [6].

3.4. Surface Manifestation on LFD

The total LFD in ascending and descending is depicted in figure 6. The minimum and maximum density values 0 to 80 % were marked by dark blue to red, respectively. The LFD map provided information about the spatial distribution of the density of linear features [4].

Interestingly, the steaming and altered grounds are located at the green portion or medium LFD (see figure 6). Therefore, we interpreted that the surface manifestation zones were located at the medium density about 40 - 45 % grid. These phenomenon agreed with bright tone in ascending image (see Figure 5A). The Western LOS in ascending image can provide better view of Wayang and Cibolang crater because the high topography was located at the Eastern side.
Figure 4. The backscattering intensity images of ALOS PALSAR data in Ascending (A) and Descending (B) at surface manifestation of Wayang – Windu Geothermal Field (WWGF).

Figure 5. The Linear Features Density (LFD) map based on lifedSAR method from ALOS PALSAR data in ascending (A) and descending (B) orbits.
3.5. Discussions
The LFD map and field observation data provided a good correlation between medium densities with the presence of surface manifestations of geothermal system at Mt. Wayang - Windu. The altered surfaces at the northern flank of Wayang crater are depicted by blue dots and the hot springs at the southern flank of Cibolang crater are depicted by dark green dots (see figure 6). We defined the low and high densities correspond to LFD value less than 30 and more than 50 % grid, respectively. The altered
surfaces at the Wayang and Cibolang craters are located at medium density. The Malabar, Wayang, and Windu craters in the North and South part were located at medium – high density. The altered surfaces at Wayang crater depicted by blue dots and at Cibolang crater depicted by dark green dots north part and hot springs were also located at medium density as depicted by yellow and dark green dots south part. But, hot springs also found with low density at Sukaratu depicted by red dot at western area. The surface manifestations could be detected at Wayang and Cibolang craters successully at the green portion with density about 45 %. The surface manifestation such as altered and steaming grounds located at medium density, this surface manifestation probably serves as upflow zone from geothermal system. The upflow zones at the crater were composed by medium linear features with smoother surface than ridges or valleys. The medium density at the surface manifestation corresponded with linear features obtained from geological map, SRTM, and ALOS PALSAR dual orbit (see Figure 2). The manual extraction of the linear features confirmed that the densities of linear features at ridges or valleys and foothills of Mt. Malabar are corresponded to the geological structures. The activity of hydrothermal at crater causes an alteration of the minerals smoother surfaces than ridge or valley. It may indicate that the medium density of LFD affected by complex factor, but the activity of hydrothermal is the most influence to the density.

4. Conclusions
The density of linear features at Mt. Wayang Windu are less than Mt. Malabar. The Wayang crater was composed by steaming and altered surface manifestations with ground temperature and acidity about 60 ºC and pH 3, the steaming ground at Cibolang crater was 90 ºC and pH 3 with hot springs temperature about 40 ºC at the foothill. The Sukaratu and Citawa are composed by hot springs with temperature about 40 – 50 ºC and pH 6. The magnetic susceptibilty measurement at the altered surfaces of the Wayang and Cibolang crater about 0.5×10^{-3} SI, but weathered surfaces outside the crater about 3.5×10^{-3} SI. The low magnetic susceptibility originated from decomposition of magnetic minerals due to hydrothermal activities. The ALOS PALSAR dual orbits provided variation of brightness levels for the same surfaces. The rough surface topographic was presented relatively by brighter tone than smooth surface in the backscattering images. The altered zone at the craters were presented by medium - high backscattering coefficient for ascending orbit image, but medium - low for descending orbit image. The difference originated not only from surface roughness, but also slope and incidence angle. According to the LFD for ascending image, the crater with steaming and altered grounds were identified by medium - high density about 35 – 45 % grid and descending image less than 20 % grid. The ascending and descending image were combined to reduce the difference of surface roughness, slope and incidence angle and get the better result of the LFD. Total LFD shows surface manifestation at Wayang Windu Geothermal Field (WWGF) were located at medium density in general. Therefore, the surface manifestations could be detected at Wayang and Cibolang craters successully at the green portion with density about 45 %.The field observations and soil measurements were used to interpret the correlation between LFD and surface manifestations. The value of magnetic susceptibility and pH are low, and temperature manifestation is high, this value have good correlation with medium to high density on LFD map. Hydrothermal activity at the crater (upflow zone) affected strongly to the transform value of magnetic susceptibility, pH and temperature and also appearence of surface manifestation.

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