Deciphering Land Subsidence in Kediri, East Java through Integrated Geophysical Investigation

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Abstract

On April 2017, a natural phenomenon has occurred in a village located in Puncu District, Kediri, East Java. Area in the proximity of hundreds water wells in the village has collapsed. A team of researcher was dispatched in order to investigate what caused the phenomenon and prevent further social unrest. This paper is meant to elaborate the workflow that has been done to investigate the root cause of the land subsidence.

Puncu District is located at the base of Mount Kelud, an active volcano. The area lies above volcanic sediments instead of carbonates therefore the subsidence is unlikely to be caused by sinkhole. The phenomenon also occurred regionally which means the cause has to be substantial enough to affect the region. Other possible cause which fits the criteria is an increment of water influx that in turn influence the pore pressure beneath the surface and trigger mechanical failure on the rock.

Several hypothesis was formulated at the beginning of the investigation that might increase the groundwater influx into the area including:

1) Increase of volcanic activity that increased the conductive process and send more water above,
2) Rainy season that increases the precipitation processor,
3) Deforestation or decrease of evapotranspiration capability of the catchment area,
4) Active geological structure which become conduit for subsurface connate water to be discharged unto the surface.

In order to comprehensive geophysical investigation was systematically conducted. Geomagnetic survey was done to gain a sense of the underlying sediment and geological structure. Geoelectrical and weather data was utilized in combination to evaluate the groundwater level. And thermal imaging was used to find out whether there is an increase of volcanic activity in the area.

Introduction

Puncu Sub-district is located in the northwest of Mount Kelud which is a quaternary volcanic environment and surrounded by several other volcanoes as Mount Kawi-Butak in the east, Mount Anjasmoro and Mount Arjuno-Welirang in the northeast, and Mount Wilis in the west (Figure 1). Puncu area is located at northwest part of Kelud Mountain which is part of the Kelud Muda Volcano Formation (Qvk) consisting of volcanic breccia, tuff breccia, agglomerate, tuff and lava, and is estimated to have a thickness of about 400-500 m based on regional geology sheets Kediri (Santosa & Atmawinata, 1992). Mount Kelud's body is dominantly composed of deposits of falling and pyroclastic flows. The sediments are loose materials that are very easily eroded and transported by rainwater to form lava deposits in the lower regions. In general, the characteristics of the eruption of Mount Kelud eruption is very porous, not compact, loose, and widespread (Zaennudin, Primulyana, & Siregar, 2013).

The phenomenon of collapsed water wells 2016 in Puncu, Kediri, was originally suspected as a sinkhole phenomenon because the character of the occurrence of collapsed wells occurred suddenly due to the collapse of the ground surface (Figure 2). But the location of the incident is in the quaternary volcano environment, and from regional geological data which do not reveal karst or limestone lithology make the phenomenon of collapsed well give rise to the advanced hypothesis, the role of active or activated geological structure which can cause liquefaction.

To find out the cause of the Kediri collapsed well, the LAPI ITB team conducted a direct investigation into a location consisting of geological and geophysical surveys using Vertical Electrical Sounding (Geoelectric 1D), Geoelectric 2D, Geomagnetic, Aerial photography (by using drone), and well water temperature investigations. Secondary data analysis was also conducted which consisted of rainfall data, regional geology data, and previous investigations related to Kelud mountain area.

Aerial Photography

The results of the aerial photography investigation show that the location of Puncu area is a volcanic foot plain dominated by tropical rain forest vegetation that has been combined with agricultural and plantation (Figure 3), shows no sign of significant geological manifestation of structures leading to sinkhole phenomenon.

Geoelectrical Survey

Geoelectrical investigation was conducted of VES 15 point and 2 lanes of 2D geoelectric. The results of the 2D geoelectric investigations of Dorok village and Jambean village concluded that the characteristics of subsurface layers in general have low resistivity values (ρ <150 ohm.m) (Figure 5). Low resistivity layer is interpreted as a subsurface layer of rock that has a high porosity level and saturated water, with the reality form of plantation and agricultural land. The existence of a high resistivity anomaly (ρ> 150 ohm) is located at the surface of the soil to a depth of 3m (west of the Dorok lane, and all parts of the Jambean lane) in the form of settlement / anthropological activities. This anomaly (ρ> 150 ohm) is interpreted in association with land use in the form of settlements to make the soil layer in the residential areas more compact that decreases the porosity (rather hard to absorb water).

The results of the VES investigation show that the resistivity distribution is divided into two values: high resistivity (ρ> 150 ohm.m) on the top of the layer and low resistivity (ρ <150 ohm.m) below it (Figure 6). The thickness of high resistivity layer in the northern part (Dorok village) is 3m, in the central area (Nanas village, Jambean village, and Manggis village) are 3m-5m, and in the southern area (Ringin Bagus village) is 11m-13m. In general, the results of the 1D geoelectric investigation showed that high resistivity layer is thickened to the south of the Ringin Bagus village. Based on the results of the resistivity model of 1D and 2D geoelectrical investigations show that the Puncu region has a subsurface water-saturated layer at depths of 3 to 5 meters from the surface, so it can be concluded that at the time of the investigation the groundwater level was 3 to 5 meter's depth.

Geomagnetic Survey

Variations in magnitude and direction of Earth's main field influence both the magnitudes and shapes of local anomalies (Milsom, 2003). Geomagnetic survey measures the superimposed of the Earth's main field and local geological bodies anomaly. The survey was done in three separate N-S trajectories that has length of one kilometer with distance between observation points as far as 50 m. Total magnetic intensity data that gain from the survey are transformed into reduce to the equator data (Figure 7). This procedure was done to simplify the interpretation of dipole characteristic magnetic data into monopole characteristic magnetic data. Low magnetic anomaly (red to purple color) from RTE data generally caused by magnetized body on the area. The magnetized body is a geological body which can induced by earth's magnetic field more strongly than the demagnetized body. Based on regional geology, it could be inferred that the underlying rocks is originated from volcanic eruption of Mount Kelud. The result of the eruption is pyroclastic material that is rich with iron (Fe) and magnesium (Mg) which in turn makes the rock highly magnetic compared to its surrounding (Lowes, et al., 1988). Other area surrounding the top of Mount Kelud also has a relatively high anomaly which is low magnetic value is inferred as fresh rock that has lower Fe and Mg concentration unlike the northern deposit. The measurement also does not indicate the presence of an anomalously significant lineament that is produced by regional geological structure.

Precipitation Rate Analysis

Precipitation rate analysis from three meteorological observation stations around Puncu area (i.e. Karang Kates, Karang Ploso and Tretes), rainfall data from January 2005 to May 2017 in millimeters, shows average value per year indicates a value that is always close to the characteristics of wet months (Figure 8). This explains that the characteristics of Puncu area have a relatively high rainfall during the year. Rainfall data from January 2005 to May 2017 showed that the study sites had a monsoonal climatic type based on climatic classification by Schmidt and Ferguson rainfall (Tjasjono, 1999). The area has wet months for 5 to 6 months or called half-year rain which means high rainfall during the year. In 2016 to early 2017 there is an average increase in rainfall with peak rainy season at the end of the year and the beginning of the year compared to 2014 and 2015. The phenomenon of increasing the average rainfall has also occurred in the year 2010 - 2011.

Physical Condition and Thermal Imaging

The 174 water wells' physical condition is thoroughly checked, photographed and measured for its temperature, indicates no heat temperature anomaly (Figure 2 and Figure 3). Investigation result shows that the wellbore sidewall is consisted of loose and porous sediments that is in agreement with the regional geology of the area where the underlying geologic formation, Young Kelud Volcanic Rock (Qvk) is consisted of unconsolidated sediments from pyroclastic, tuff breccia, agglomerate, tuff to lahar deposit (Santosa & Atmawinata, 1992). Outcrop verification of the area is shown in Figure 9. Temperature measurement falls within acceptable range of surface ground temperature that is influenced by the sun (Oppenheimer & Yirgu, 2002).

Discussion

The recorded video data from underwater cameras in a non-collapsed well shows from the top to the bottom of the well. A brick wall wells up to a depth of about 8 meters come in contact with volcanic rocks in the form of compact pyroclastic breccia (with agglomerate fragments as in depths 8 to 14 m) (Figure 9).

Most of the sank wells are characterized with 3-5 m depth case that stand on alluvial sand and unconsolidated pyroclastic (Figure 11). The condition of wells case is very vulnerable to collapse due to rapid rise of water level as the influence of increasing precipitation (rain). Rapid fluctuation of water level makes the wells case, which consists of alluvial sand and pyroclastic, are fell apart and become unconsolidated.

Field observation result gathered from aerial photography, magnetic method, resistivity method, and outcrop scanning does not show the occurrence of geological structure that suspected as the trigger of sank wells phenomena. The sank wells phenomena then concluded as the impact of fluctuation of groundwater level that erodes well case. The fluctuation of groundwater level comes about with the increasing precipitation.

The interesting thing of this phenomena is the wells were collapsed in 2017. Based on precipitation data collected from three meteorological station, high precipitation occurred in 2010 and 2011 as happened in 2016 and 2017. Surprisingly, these high precipitation (2010 and 2011) did not make the wells collapsed. A new question then asked due to this situation considering that the factor of these wells sank is the fluctuation of groundwater level has been stated but in other way it did not happened in 2010 and 2011. What is going on actually?

Result collected from discussions and interviews to the native resident has gave some more information that in the end of year 2016 and in early 2017 water surface level on their water wells was rising from 10 – 12 m depth going to 3 – 5 m from the surface. The result strengthens the conclusion of factor that makes the wells are sank.

Water surface level is closely related to the water table and groundwater level. Water table defines as a plane between saturated and unsaturated ground water. Infiltration process of water to the underground body will fill in the porosity of soil or rocks till it becomes saturated. Saturated situation occurs when the water has fulfilled the porosity of soil or rocks. The water infiltration process will eventually reach the water table and saturated zone. Water will move horizontally through soil or rock layers furthermore called groundwater. The groundwater in saturated zone flows from the high ground to the low ground. Drastic rising of groundwater level in some wells at Puncu was indicated the overflow of ground water compared with normal situation, both in terms of quantity and/or flow velocity. Main factors that influenced the quantity and/or flow velocity are precipitation/rainfall, soil or rock porosity, vegetation, the amount of open area on surface, permeability and soil or pores effectiveness, and groundwater surface slope that tends to follow the topography

Puncu area have river radial centrifugal pattern that will leads water from higher part area top of Mount Kelud flowing and spreads radially to the mountain-foot. It describes that source of groundwater in Puncu area comes from high part of Kelud, furthermore it shows that the collapsed wells phenomena are correlated with the condition and process of groundwater in Mount Kelud (Figure 11). Based on topographic situation, Mount Kelud high part is a recharge area and Puncu is a discharge area. The occurrence of sank wells in Puncu shows a sort of phenomena that caused by fluctuation of groundwater level which beyond normality, so then it can be concluded that the character of infiltration system in recharge area has changed.

Based on Pusat Vulkanologi dan Mitigasi Bencana Geologi (PVMBG) information, last time the Mount Kelud erupted was on February 13th 2014 with a relatively brief time of eruption (Wasono, 2014). The eruption was generating 20 km – 30 km of elevation of volcanic ash so that created lots of new volcanic material. The process of last Mount Kelud eruption has made the vegetation around top Mount Kelud has burned or buried by the volcanic material, furthermore it became an arid or barren area, deforestation Mount Kelud (Figure 12). The benefits of forest in Kelud Mountain becoming groundwater regulators in the hydrogeological cycle are disrupted, because forests behave like giant sponges that can absorb rainwater during the rainy season and slowly release it during the dry season. In normal conditions, Mount Kelud Forests provide infiltration and water storage systems based on the presence of tree roots and leaf litter so as to create conditions that drive rainwater infiltration into the soil and then into ground water, store it during the rainy season and provide water supply during dry period.

Conclusions / Concluding Remarks

The deforestation around top Mount Kelud as the impact of eruption has caused the rise of groundwater. This could be happened as the rain water that entered the ground, fulfil the soil or rocks pores to become a groundwater, did not well processed by vegetation in forest. Subsequently the groundwater in the aquifer became saturated so then flowed to the lower potential ground, include Puncu district. Groundwater which entered Puncu area then became the factor of wells case erosion, furthermore make those wells sank which dominantly stand on unconsolidated lithology.

Acknowledgement

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Appendix

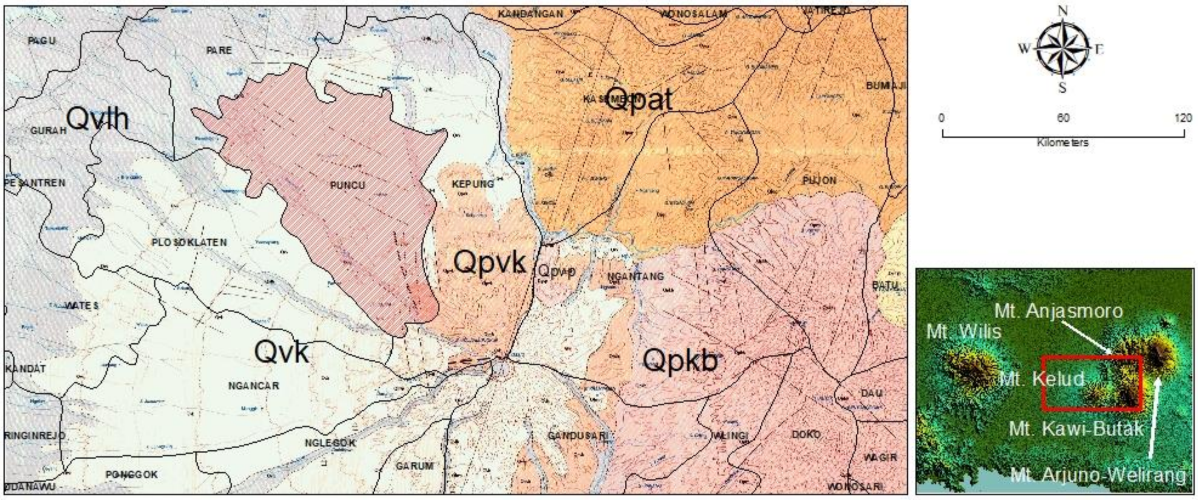


Figure 1 Location of Puncu District in northwest of Mount Kelud where stand in volcanic rock formation of Kelud Muda (Qvk) which composed from volcanic breccia, tuff breccia, agglomerate, tuff and lahar, and also the Mount Kelud is locates in quarter mountainous.

Figure 2 Physical condition of the sank water wells.

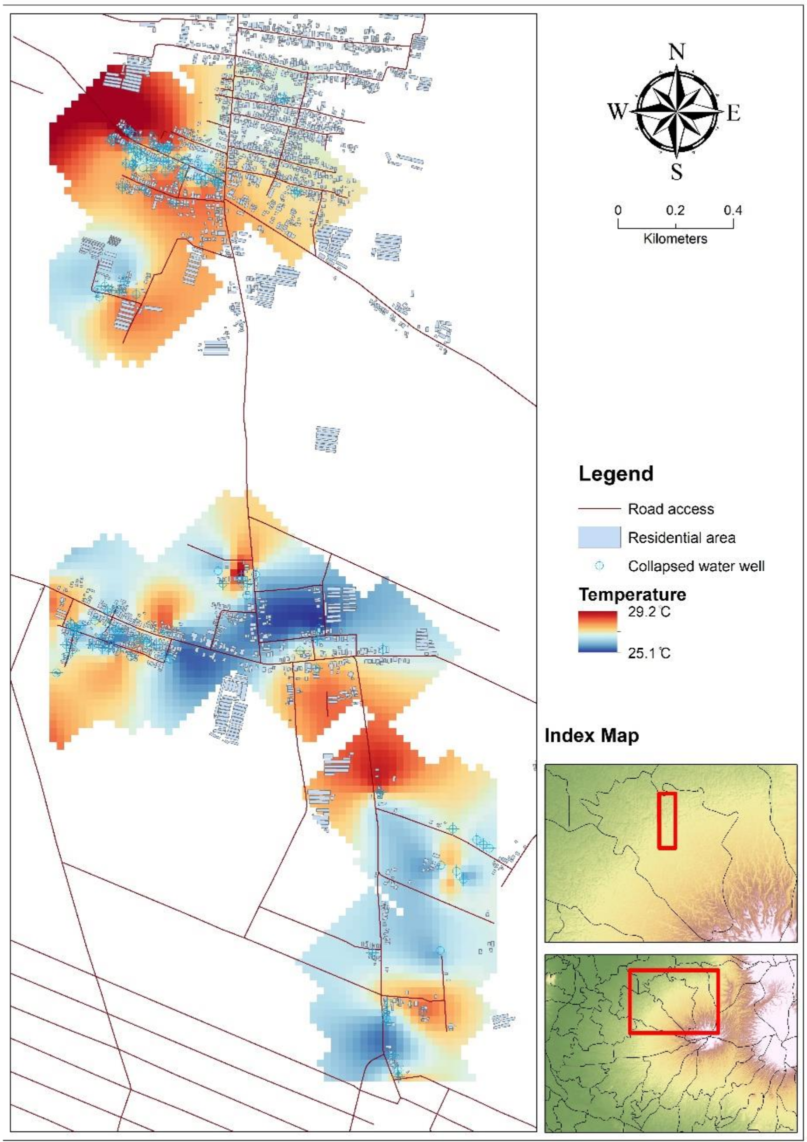


Figure 3 Map of temperature measurement result of the sank water wells.

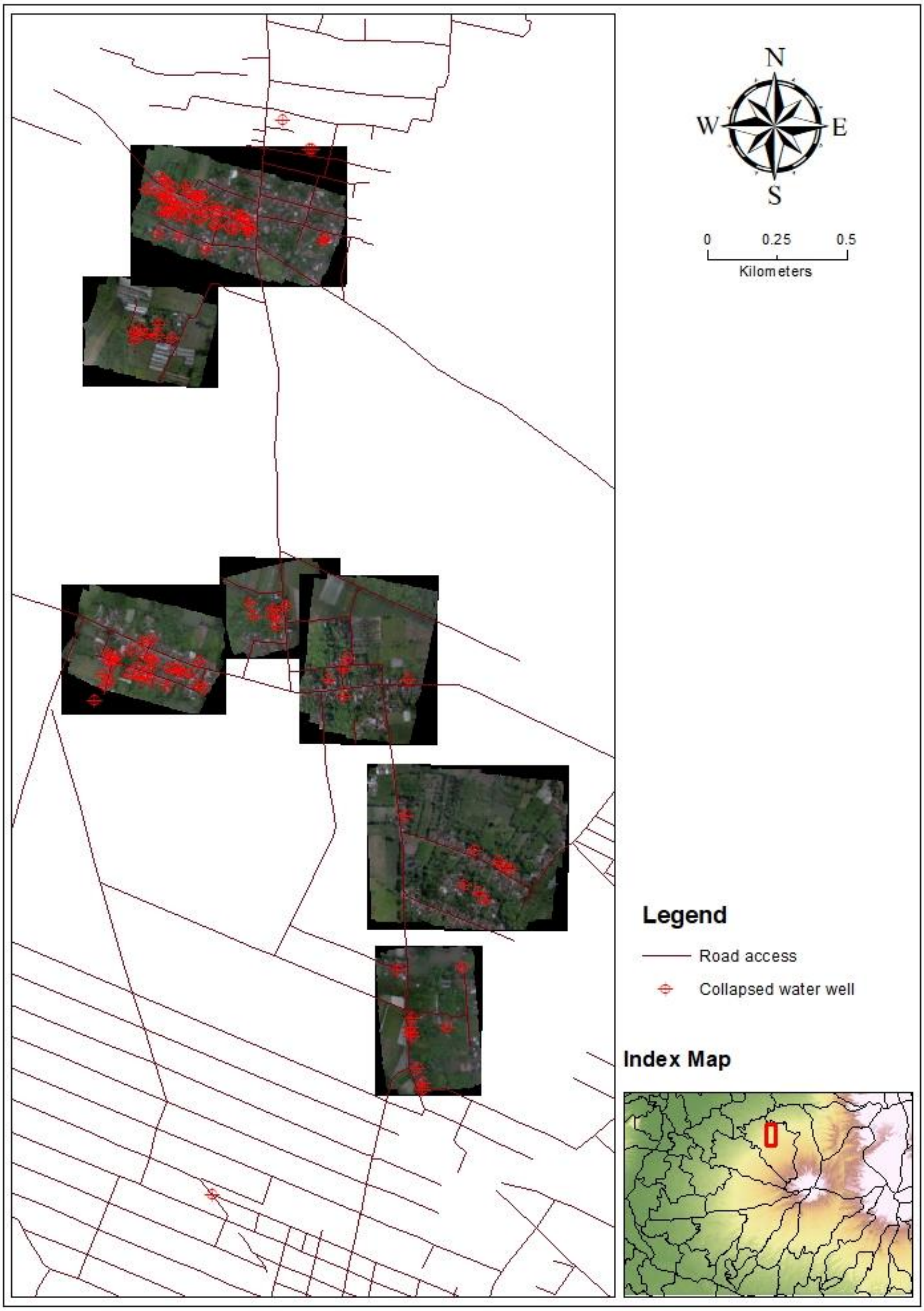


Figure 4 Topography of Puncu which composed of agricultural vegetation/plantation and housing area shown by aerial photography.

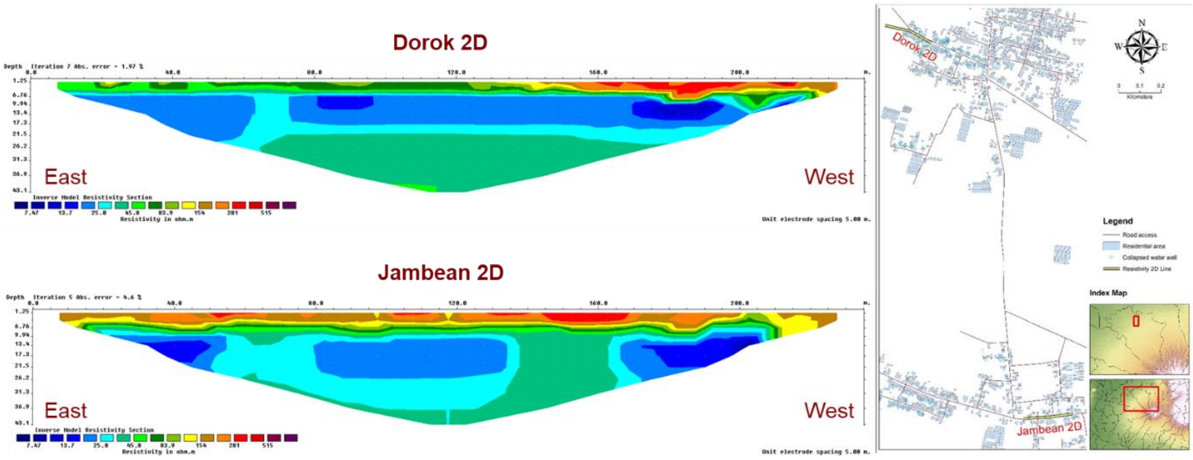


Figure 5 Image of 2D resistivity cross section.

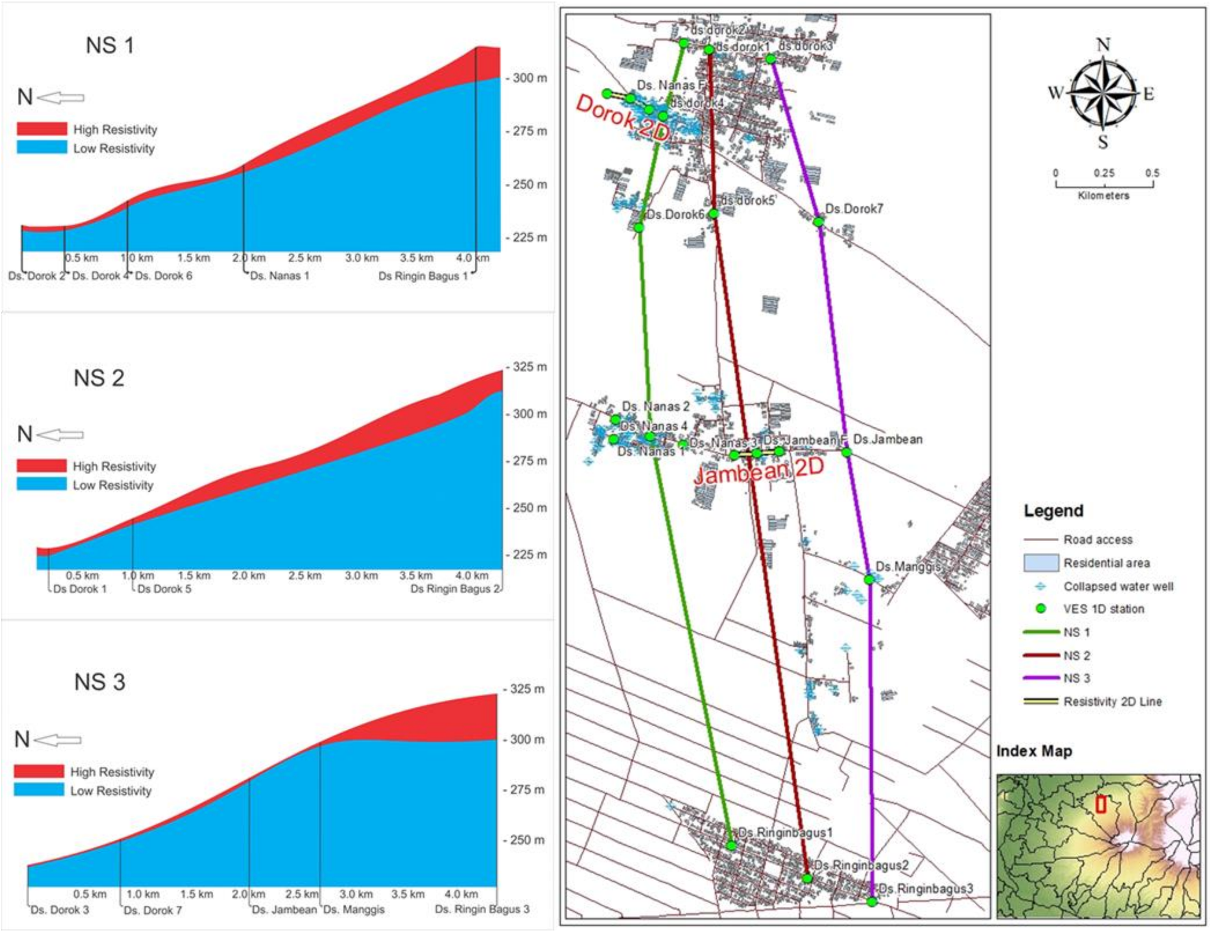


Figure 6 Resistivity model cross section shows a thicker high resistivity layer that lies on a higher elevation topography in Puncu rather than on a lower elevation topography.

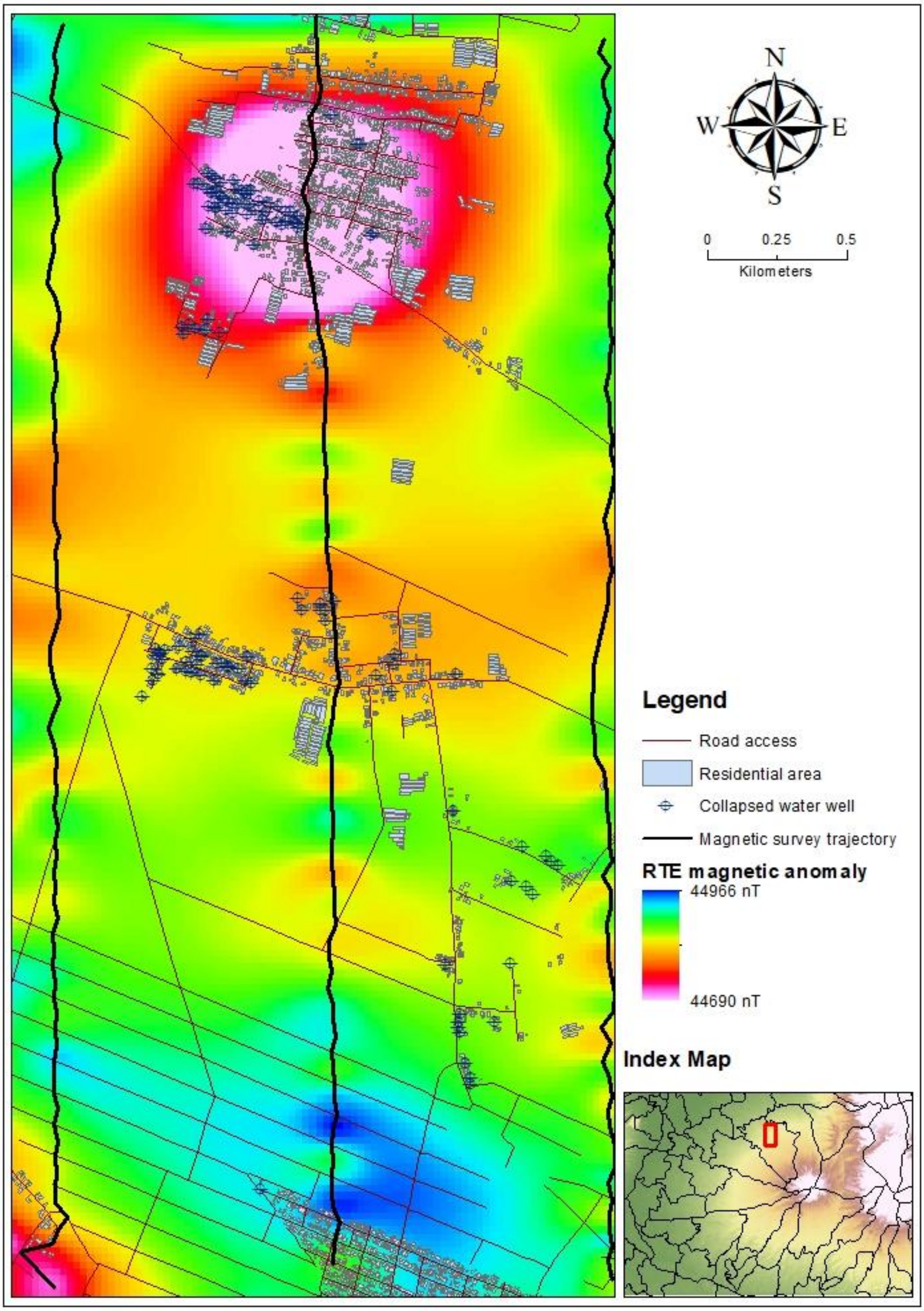
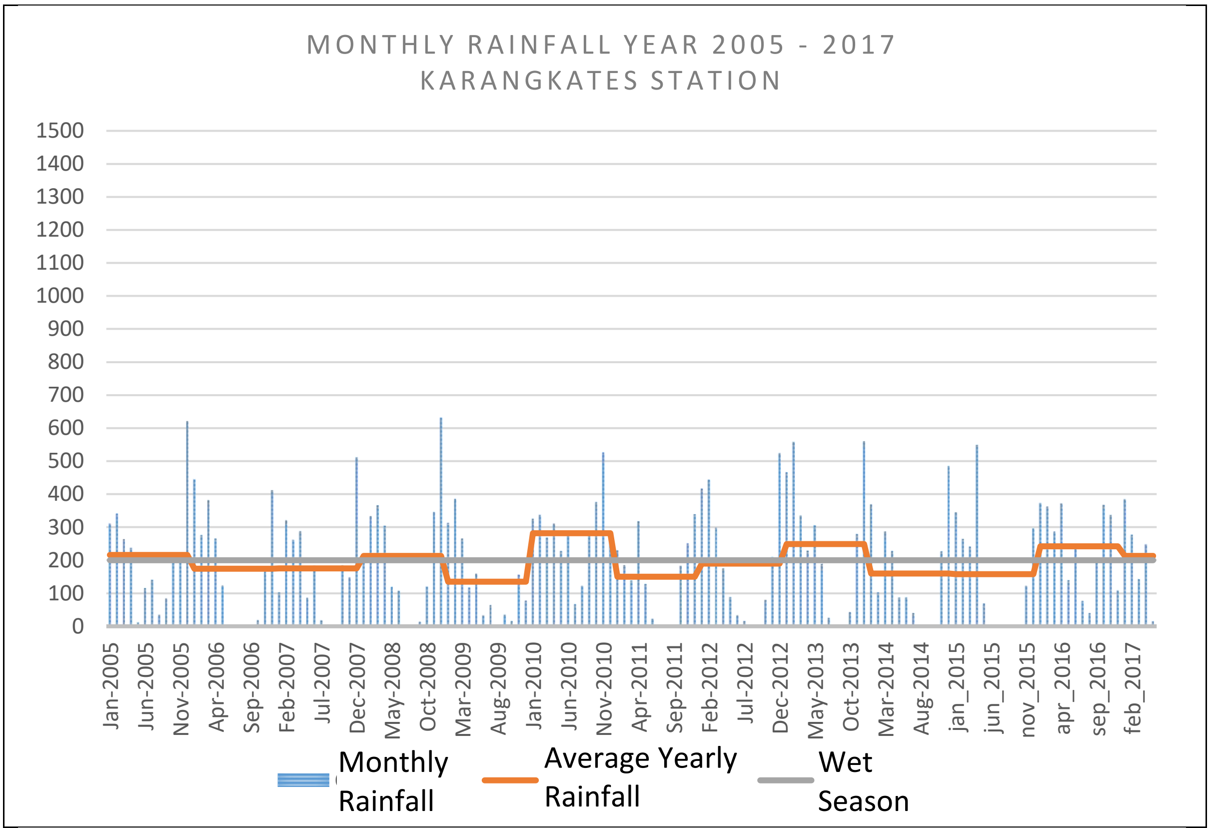


Figure 7 Magnetic anomaly image in Puncu which not shows the occurrence of geological structure pattern significantly that suspected as the factor of sank of the wells.


MONTHLY RAINFALL YEAR 2005 - 2017
KARANGKATES STATION
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Jan-2005
Jun-2005
Nov-2005
Apr-2006
Sep-2006
Feb-2007
Jul-2007
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May-2008
Oct-2008
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May-2013
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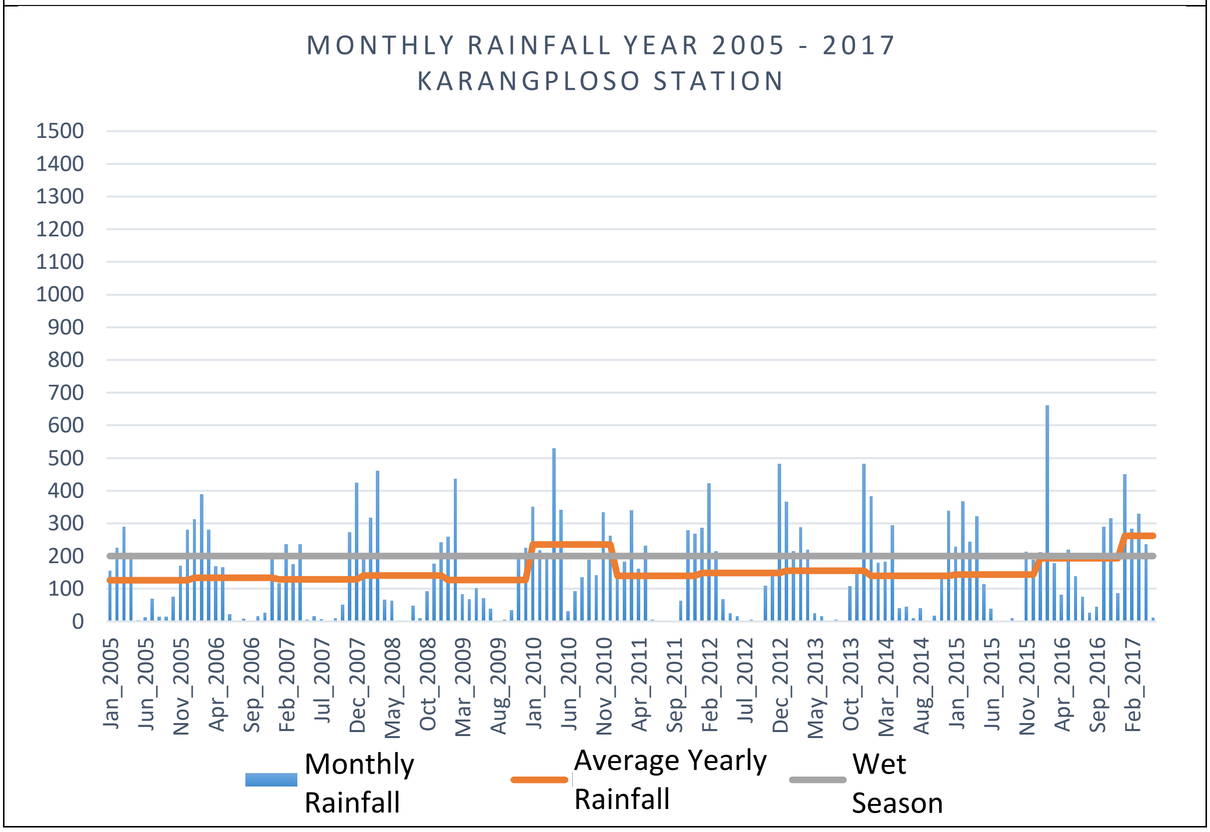
sep_2016
feb_2017
Monthly Rainfall
Average Yearly Rainfall
Wet Season


MONTHLY RAINFALL YEAR 2005 - 2017
KARANGPLOSO STATION
1500
1400
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Monthly Rainfall
Average Yearly Rainfall
Wet Season

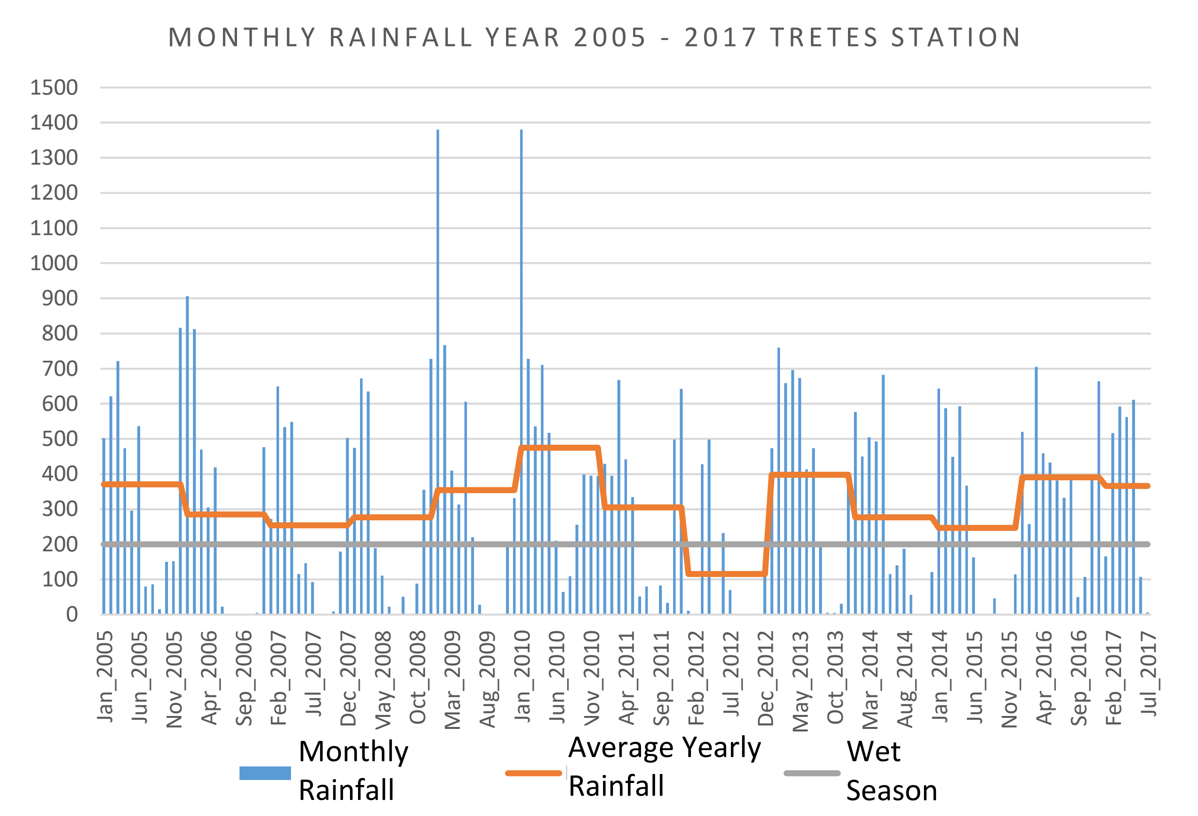

Figure 8 High precipitation in 2016 and early 2017 shown from precipitation data of three station which locate near Puncu District.

Figure 9 Volcanic sediment outcrop of Kelud Muda (Qvk) is locates in the southeast slope of Mount Kelud. This agglomerate-composed volcanic sand layer was found in resident well at 5-13 m depth.

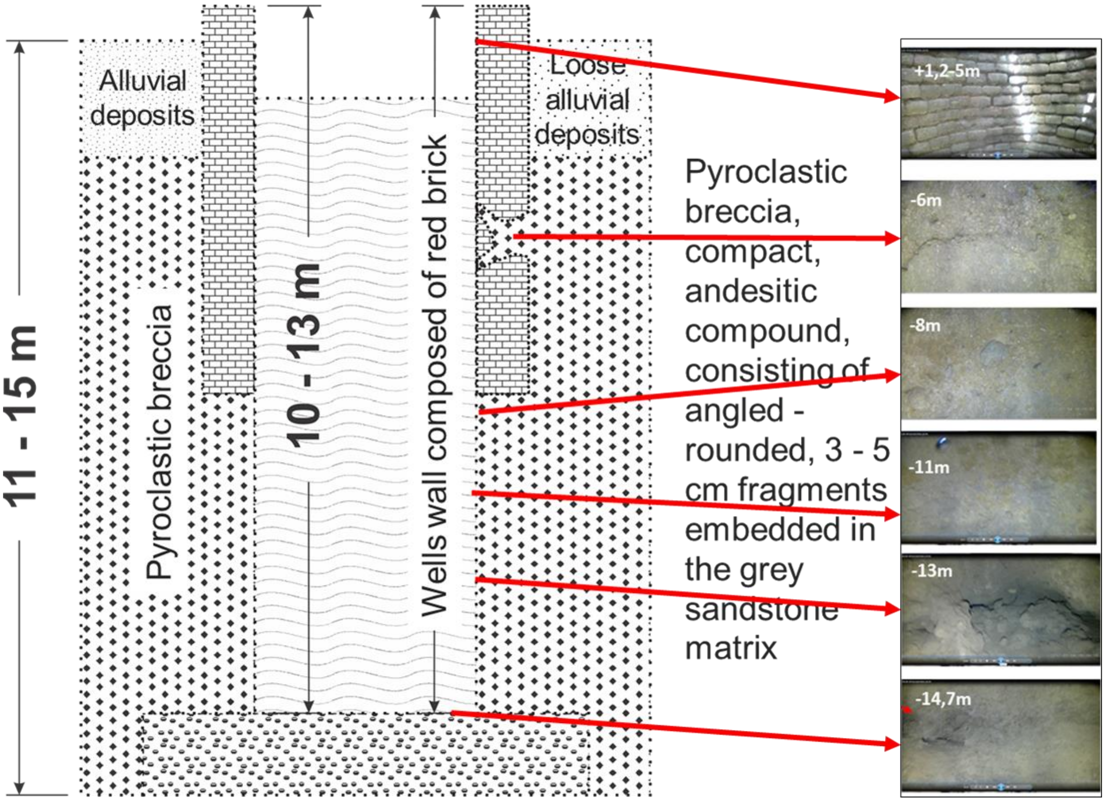

Figure 9. Cross section image of good condition well in Dorok area.

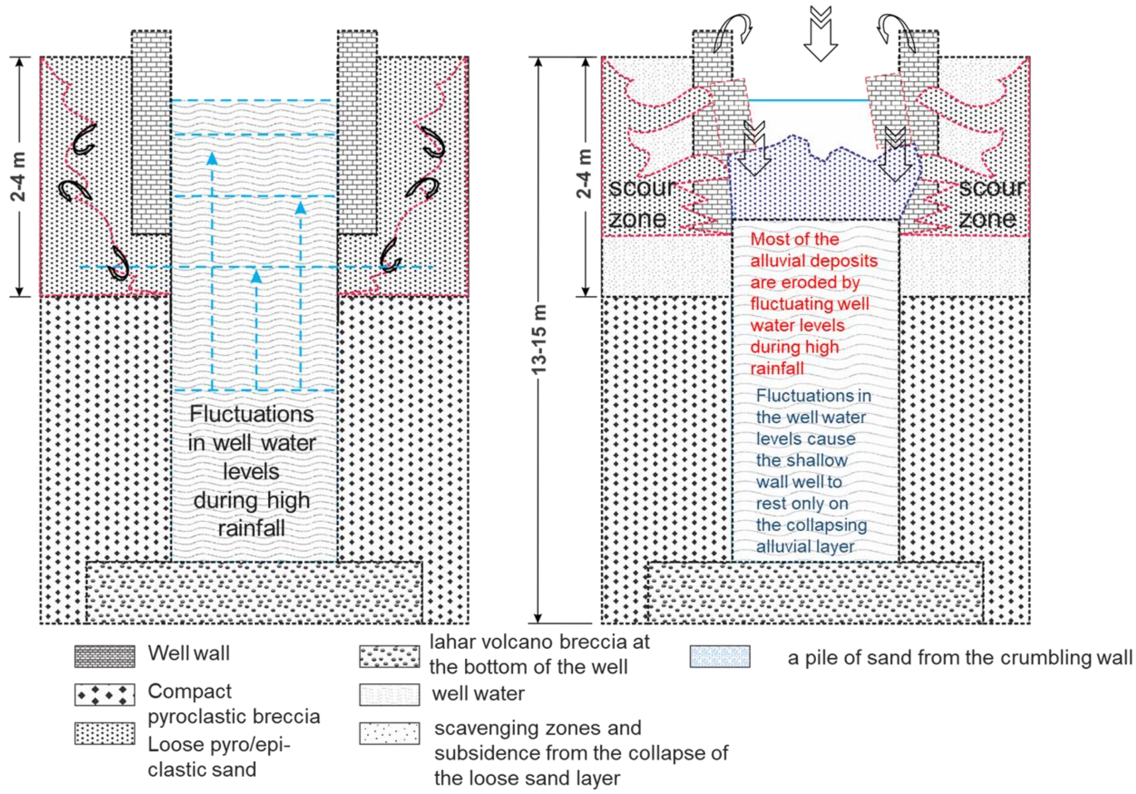

Figure 10 Image of sank well condition and the mechanism of occurrence.

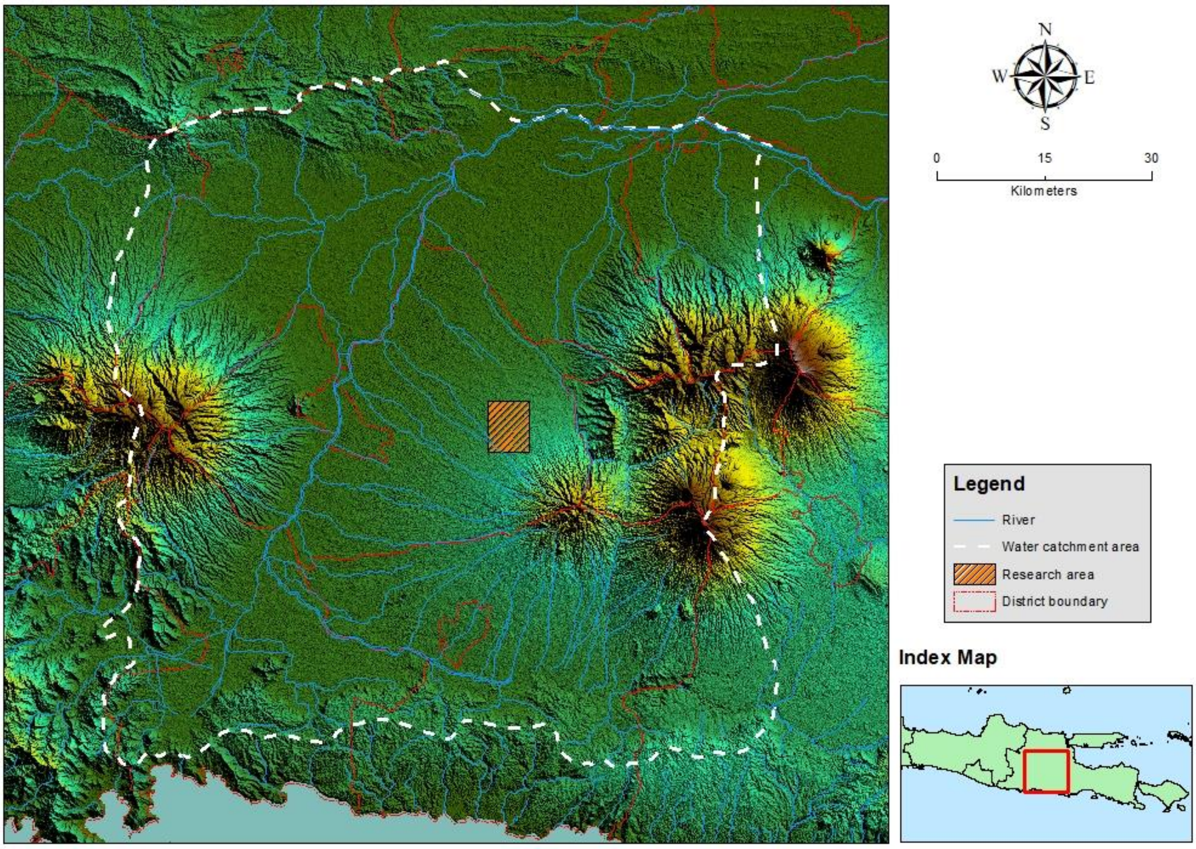

Figure 11 Location of Study, Puncu District, mountain-feet area which locates in northwest of Mount Kelud. The topographic configuration shows a radial centrifugal pattern where originated from high-ground of Mount Kelud, radially spread into mountain-feet.

Figure 12 Satellite image (source: google earth) sequences from December 2010 to December 2016 of Mount Kelud. The condition of Mount Kelud was enclosed by vegetation till 2013, however in 2014 there was an opened area without any vegetation (stressed vegetation).